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Llenroc Plastics
Teaching Notes
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DRAFT

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CHAPTER 1. THE LLENROC EXPERIENCE

EDUCATIONAL OBJECTIVES

The purpose of the Llenroc Plastics series of cases is to (a) involve the student in the challenges of re-engineering a manufacturing company, (b) give the student experience in applying the techniques of operations research and the principles of operations management to a business problem, and (c) to encourage growth in the student’s professional maturity. By professional maturity, we refer to the student’s oral and written communication skills, and to their teamwork and leadership skills.

THE SEQUENCE OF CASES

The Llenroc Plastics text contains eight chapters. All but two of these can be used as cases, in isolation from the rest. As instructor, you can choose to employ only some of the cases and to arrange the cases in an order different from that presented here. The students, too, will form an opinion of the best order in which to tackle a re-engineering project such as this.

The cases have been written with this in mind; each case has been written as a stand-alone exercise linked by common themes. There is, however, a progression to the cases which makes us recommend the current order. In the first place, the order of the cases follows roughly the order in which the re-engineering project upon which the text is based actually played out. The project did begin with a study of a regional warehouse and grew along the lines indicated.

Secondly, the order of priorities seems to us to be about right. We start by trying to understand that portion of the overall system that is most closely connected with the custom. We try to understand the operations of a regional warehouse before attempting to redesign the national distribution system. Inside the factory, we identify the bottleneck operations and work there immediately to increase capacity. Our next concern is flow time through the non-bottleneck operations. Finally, we look to see how the information system might be simplified and improved.

The third argument in favor of the current order of chapters is that they have been written anticipating a progression in the student’s skill and capability in conducting analyses. The students will notice that in the first case (Chapter 2), the students are given very detailed assignments. These are designed to prepare the students to present an in-depth recommendation.
for one aspect of the company. In the later chapters, you will notice less and less such detailed guidance. In the sixth case (Chapter 8), for example, the students are expected to develop their own analytical model and implement it in a spreadsheet. The requirements also become increasingly open-ended in the later cases. The students become responsible for defining the scope of analysis. It is a valuable progression but not essential. In whatever order they approach the Llenroc Plastics series of cases, our main objective will be satisfied if they develop a system's view of operational and business analysis.

**ROLE OF TEAMWORK**

By design, there is more work outlined in the assignments of *Llenroc Plastics* than one student working alone could hope to accomplish within one semester. Therefore, the student must work as part of a team. Team organization is the predominant way in which work is accomplished in the industrial world. The students are not prepared for that workplace unless they have acquired good leadership and teamwork skills. The *Llenroc Plastics* experience is an opportunity for the students to exercise those skills in an academic environment. With such an experience and in spite of their best efforts, there is the risk that some team will fail to measure up to the standard expected of them. However, without that risk it would not be possible for them to experience the thrill and camaraderie that comes from successful teamwork. Our best advice to the students is to work hard and to keep a sense of humor.

**ORGANIZATION OF TEXT**

Each chapter of the text describes a different but critical aspect of the current manufacturing and distribution system employed by the Llenroc Plastics Corporation. All available relevant data have been organized into tables. For ease of reference, since many chapters refer to the same data, all tables have been collected and placed into Appendix A. In addition, each table is distributed in machine-readable form as a Microsoft Excel 4.0 (DOS format) spreadsheet file. The file name matches the table name. For example, Table 1 is found in file "TABLE01.XLS."

For several assignments the students will be expected to manipulate the data of these tables using spreadsheet software. We recommend Microsoft Excel version 4.0 or greater. In some cases, tables have been split into multiple parts (labeled a, b, c, ...) to facilitate printing and page layout. The students should use spreadsheet software to merge these tables before conducting an analyses.

**ORGANIZATION OF THE TEACHING NOTES**

Each chapter of these teaching notes corresponds to a chapter in the text. The beginning of the chapter contains an overview of the case, a statement of learning objectives, a discussion of the software provided on the accompanying compact disk, and some notes on class management.

Next, we discuss some questions and assignments suggested for this case. (To save space, only abbreviated versions of the questions are given.) The primary assignment, which is given first, is the capstone experience for the case. Many of the other assignments and discussion questions, which are detailed in subsequent sections, are in support of this task.

The final section of each chapter is a list of the assignments, often with additional information, which can be copied and distributed to students without obtaining "permission to copy" from the authors. In a full semester course devoted to Llenroc, the students might be expected to respond in oral or written form to all of the discussions and assignments. As instructor, you
can tailor the requirements to your own educational objectives.

Students can also tour the factory and get a rough overview of the problems Llenroc faces in many areas.

**ON CHAPTER 1 FROM THE TEXT**

**Overview.** Chapter 1 of the text, "The Llenroc Plastics Corporation," gives an overview of the company, its markets and competitors, and the different segments of the supply chain controlled by Llenroc.

**Software.** The Llenroc CD has much of this information available, in voice and text.

**Learning Objectives.** Students develop an understanding of the industry and the competitive position of the Llenroc Plastics Corporation. They must also understand the basics of the distribution system. They begin to see grasp the overall project, and propose the main features of a competitive strategy.

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**THE LLNROC PLASTICS CORPORATION**

**Discussion Questions**

1. What consequences do you predict if Llenroc Plastics pursues a "business-as-usual" strategy?

2. How could Llenroc Plastics achieve a growth rate greater than the growth rate of the HPDL market?

3. Is a new domestic manufacturer likely to enter the market?

4. What should be the strategic response of a domestic manufacturer if a foreign manufacturer enters the market through an importer?

5. Do Llenroc Plastics' competitors possess any inherent advantages or disadvantages? If so, how can Llenroc Plastics compensate for competitors' advantages or exploit their own advantage?

6. What are the principal characteristics of competition in the HPDL industry? That is, on what aspects of competition must Llenroc Plastics focus? What specific performance measures would you use to assess performance and what target values for these measures would you recommend?

*This assignment list may be distributed to students without obtaining further permission to copy.*
2. The Atlanta Transportation System

Overview

Introduction to the Case

Many factors affect customer service at Llenroc Plastics. This case considers cost and customerservice issues in the Atlanta region. The primary issue is how to ship goods from the regional warehouse to the customers so as to achieve good customer service at a reasonable cost—just the opposite of what Llenroc is now achieving. The Atlanta region is considered representative, and hence, this study should suggest improvements applicable to the entire system.

The current policy is to ship all orders once they become available. In other words, orders are not consolidated over time to improve truck utilization. This is one aspect of the policy that students are encouraged to question.

This case is an excellent introduction, though the lessons are not particularly deep. Furthermore, there are many opportunities to expand the coverage with additional readings and assignments.

Learning Objectives

This case uses a variety of methods to explore the inter-related problems of managing a regional warehouse and transportation system. Through game play, students experience routing and scheduling problems. They compare alternative policies using simulation and analyze demand data for patterns. Students are then asked to pull all of the material together and propose a detailed plan for a new transportation system.

Software and its Use

Software (the Transportation Game) is available that allows students to “play” the role of the dispatcher. Students must define routes and schedule specific trucks to meet the shipping requirements over one week.

Using the software, students can approximate the cost of running the system under the current policies. This means that students must experiment with different scheduling strategies.

Next, the students can use the software to approximate the effects of violating the current policy
against consolidation of orders. Here students will have to think carefully about what this consolidation really means with respect to customer service and inventory availability.

The appendix contains additional information on the Transportation Game software.

Main Issues

The following presents the most likely sequence students would follow in tackling this case. This also corresponds to the sequence in which the assignments are discussed later in this chapter.

Probing the Data

Students are anxious to play the game, but it important to begin by probing the data for information and idea generation. In this first phase, students need to recognize that very large customers tend to order close to full truckload quantities. That they account for 80% of the business, and they place orders of a regular basis. Students must recognize the difference between large customers and regions with high demands; high-demand regions will have large and small customers, and low-demand regions might have a large customer. It is true?

Evaluating Alternative Scheduling Strategies

In the next phase, students prepare a cost model and use it with the software to evaluate costs under the current policy. (The game costs must be scaled, since the simulated shipping requirements for one week represent about two-thirds of the actual average weekly demand.)

The students should begin to understand the tradeoff between full trucks (which reduce costs) and customer service (which is hurt by full truckloads since they must travel to many regions). At this point, they are ready to consider demand consolidation. With demand consolidation, full or nearly-full truckloads can be sent often. Students should consider shipping to some regions less often than others and may explore cyclic scheduling patterns.

However, students must think carefully about what this consolidation really means with respect to customer service and inventory availability. We cannot ship ahead of schedule unless the inventory is available. This restriction places an even greater emphasis on solid inventory management.

Students might also use operations research techniques to formalize and optimize their approach.

The Common Carrier Alternative

So far, the students have been consumed with improvements in dispatching at Llenroc. As a result, they have considerable "ownership" of this approach and are reluctant to consider using an outside vendor to provide these services. This aversion to external solutions is positive as it helps them to see how personality can interfere with the development of creative alternatives.

It takes little time to discover that the common carrier alternative is much less costly. A full evaluation requires students to consider how the lessons learned thus far can be used to support an arrangement with a common carrier that is cost effective while providing good service.

Wrapping it Up

Bringing closure to this case can be done in many ways. Deriving some generalizable relationships can be an effective vehicle. If this case is being used in conjunction with some of the other Llenroc cases, it is important to have the students detail (in oral and/or written presentations) their plan to handle transportation needs at Atlanta. In the following section where suggested assignments are given, this "Primary Assignment" is given first, as the students should be encouraged to keep their ultimate goal in mind as they progress through the
Class Management

This case provides an excellent opportunity to examine truck scheduling, and can easily stand on its own. When used in the sequence, it is the student’s first experiential learning experience, and the first case. Thus, most teams put an extraordinary effort into this case. Moreover, it is important to establish a good working relationship with the students from the beginning, since this will set the tone for the remainder of the experience. Because the pedagogy is different, and because students are asked (often for the first time) to think creatively to solve a business problem and to present their ideas to the whole class, they often need praise for their efforts.

It is possible to cover this case in one week, but it is also easy to spend two or three weeks on it. In the latter case, more time might be spent on useful operations research techniques.

PRIMARY ASSIGNMENT

For students with little or no experience with case studies, this primary assignment can be addressed in the last class dedicated to this case, with students submitting written solutions to the other assignments prior to the final discussion.

The assignment is to propose a detailed plan to handle transportation needs in the Atlanta region. There are a variety of strategies that students might consider. It is interesting to note that a common mistake is the failure to focus on transportation-related issues in this assignment. (Some teams start focusing on warehouse location and inventory-related issues and have little to say about transportation.)

The common carrier alternative is so much cheaper than running a trucking system. The economics drives one to the solution of selling all the trucks and using common carrier for all shipments. The concern then becomes customer service. The case mentions that common carrier consolidation time is 2-4 days. But, if we provide the common carrier with a full truckload for a particular destination, then the common carrier could be expected to ship it immediately.

When one notes that the very large customers tend to order close to full truckload quantities, that they account for 80% of the business, and they place orders of a regular basis, the common carrier strategy would likely result in a very good customer service for most of Llenroc’s business. For the remaining customers, a consolidation time of 5 days plus a 4 day transportation time would still place our delivery performance superior to Wilson’s 10 days, assuming the fill rate problem is solved.

The small customers are not ordering in economic quantities. We could allow them to suffer the common carrier delays or pay a premium for small order rapid service. It is an un-revealed fact of the case that a single sheet of laminate can be rolled up, placed in a large cardboard tube, and shipped using UPS.

When considering the issue of customer service, it is useful to identify the customers. The large customers are the OEMs who use MRP systems and place orders on a regular basis. One day delivers service is not likely to be important to them in their current environment. As long as we have the material in stock and can get it to them within the week, they are likely to be satisfied with our service. Strategies to improve fill rate will drive our market share with these types of customer. Assuming the fill rate performance becomes competitive, a common carrier should be able to provide more than adequate delivery service for these customers. Students often fail to exploit these observations.

If students strongly favor keeping trucks (and most do), note that the fixed routes they arrive at in one of the assignments 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.
Epilog. It is often useful to look at what the company actually did, though this does not mean that their solution was the best available. Llenroc 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 is the client.) Llenroc was able to negotiate the kind of customer service it desired 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.

Comments
From the case, the dispatcher is held accountable for total transportation costs. However, there is no mention of customer service. So, we might expect schedules that maximize truck utilization at the expense of customer service. (The warehouse manager is very aware of customer service problems, and the dispatcher presumably answers to him.)

Question
It is possible to focus on the transportation time as the primary component of customer wait time. What else must be included?

Comments
If orders are being consolidated, then we should include the review cycle time. Customer wait time will increase.

Customer Analysis

Assignment
Perform an ABC analysis of customers according to size.

Comments
A sample plot is given on the following page. Observe that 21% of the total number of customers, that is, 25 customers, account for 81% percent of the Atlanta region's total demand for Llenroc Plastics products. These 25 customers are classified arbitrarily as "large customers," the next 30% of customers are classified as "medium," and the remaining 49% as "small." The small customers in total account for only 5% of Llenroc Plastics' sales, as measured in square feet.

One might also observe, for example, that the 10 large customers in Atlanta, Charlotte and Raleigh together account for 33% of all demand in the region. (Keep in mind that the data in Table 9 are scaled, and therefore do not match the unscaled data of Tables 11 and 12.)
**Question**
The dispatcher claims that there is no pattern to the deliveries that need to be made. What do you think? Do large customers typically place a large number of small orders or do they order infrequently but in large quantities? How regular is the timing of orders?

**Comments**
This is truly difficult for most students. Although they think they understand it, but asking them to articulate it they discover how uncertain their grasp is. This question can lead to a lively, if frustrating, discussion.

**Question**
From Table 13, we see that very large customers tend to order close to full truckload quantities, they account for 80% of the business, and they place orders of a regular basis. For example, it looks as if Herman Miller orders about once per week, generally on Wednesday.

The small customers are not ordering in economic quantities.

**Question**
Explain how it might be possible for the customer ordering behavior to be predictable but the delivery pattern to be chaotic. That is, what features of Llenroc Plastics' distribution system create instability?

**Comments**
How many sheets does Jackson Supplies order per order? What does one of these sheets sell for? Approximately how much money do we make on these orders?

**Comments**
A typical order is one sheet: $3' \times 8' = 24 \text{ ft}^2$.

A sheet sells for about $12.48 = 0.52/\text{ft}^2 \times 24 \text{ ft}^2$. See chapter 1 for parameters. We lose money; cost of driver time, fuel and truck costs, and paperwork costs would outweigh the gross margin.
EVALUATING ALTERNATIVE STRATEGIES

Cost Model

Assignment
Build an economic model of transportation costs.

Possible Solution

Per Truck Cost

<table>
<thead>
<tr>
<th>Cost / Truck In the Fleet</th>
<th>Before Tax Cash Flow (end-of-year)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Year</td>
</tr>
<tr>
<td></td>
<td>Purchase</td>
</tr>
<tr>
<td></td>
<td>Salvage Value</td>
</tr>
<tr>
<td></td>
<td>Insurance</td>
</tr>
<tr>
<td></td>
<td>Registration</td>
</tr>
<tr>
<td></td>
<td>Total</td>
</tr>
</tbody>
</table>

Tax Deductions

|                           | Ins/Reg | (2,300) | (2,300) | (2,300) | (2,300) | (2,300) |
|                           | Depreciation (1) | (6,240) | (6,240) | (6,240) | (6,240) | (6,240) |
|                           | Gain on Sale of truck (2) |    |    |    |    | (800) |
|                           | Total    | (2,300) | (8,540) | (8,540) | (8,540) | (8,540) | (7,040) |

Cash Flow from Taxes

| Tax Effects (3) | 1,035 | 3,843 | 3,843 | 3,843 | 3,843 | 3,168 |

Summery

| After Tax CF | (40,265) | 1,543 | 1,543 | 1,543 | 1,543 | 10,168 |
| NPV         | (40,265) | 1,342 | 1,167 | 1,015 | 882  | 5,055  |
| Total       | (30,804) |    |    |    |    |    |

| Num Weeks | 250 |
| Cost / Week | 123 |

(1) Straightline depreciation, taken only on $32,000, which cost net of salvage value
(2) This is a loss taken on the book value minus salvage (7,800 - 7,000).
(3) For every deductible expense, there is an additional cash flow of the tax rate times that expense.
**Driver Costs**

<table>
<thead>
<tr>
<th></th>
<th>Before Tax</th>
<th>After Tax</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fuel</td>
<td>$0.13</td>
<td>$0.07</td>
</tr>
<tr>
<td>Maint and Tire</td>
<td>$0.12</td>
<td>$0.07</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td>$0.25</td>
<td>$0.13</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th></th>
<th>Before Tax</th>
<th>After Tax</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pay</td>
<td>$13</td>
<td>$7.15</td>
</tr>
<tr>
<td>Benefits</td>
<td>1.95</td>
<td>$1.07</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td>$15</td>
<td>$8</td>
</tr>
</tbody>
</table>

If we assume 10 hrs / day, the after-tax cost per day for the driver is $82.225

Summarizing, we have the following costs.

**Summary**

<table>
<thead>
<tr>
<th>Criteria</th>
<th>Unit Cost</th>
</tr>
</thead>
<tbody>
<tr>
<td>Number of trucks</td>
<td>128.48</td>
</tr>
<tr>
<td>Miles</td>
<td>$0.13</td>
</tr>
<tr>
<td>Driver days</td>
<td>$82.23</td>
</tr>
</tbody>
</table>

**Base Case Analysis**

**Assignment**

Use the Transportation Game software to estimate the cost of the current system.

**Possible Solution**

One possible solution from the game, using all 10 trucks, has the following costs.

<p>| | | |</p>
<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Driver Days</td>
<td>44.8</td>
<td>$82.23</td>
</tr>
<tr>
<td>Miles</td>
<td>17000</td>
<td>$0.13</td>
</tr>
<tr>
<td>#Trucks</td>
<td>10</td>
<td>$123</td>
</tr>
<tr>
<td><strong>Cost / week</strong></td>
<td></td>
<td>7,207</td>
</tr>
</tbody>
</table>

Scaling this, we get $10.8 m / year.

**XX?? Peter:** this concerns me. We are still half of the number given in Table 3. Do we have the scaling wrong? Or, could we have removed HALF the costs already?

**Demand Consolidation**

Suppose the policy of shipping product as soon as it becomes available were modified to permit the dispatcher to make better use of the truck capacity. For example, consider allowing the dispatcher to consolidate orders by holding an order up to a maximum number of days with the goal of accumulating enough orders to send a full truckload.

**Question**

Will customers change their order patterns if we practice demand management?

**Comments**

If we always ship to a certain city on the same day, some customers will synchronize their order cycle with our shipping cycle.

**Assignment**

Develop a strategy for dispatching that allows consolidation of orders for up to 5 days. Describe your rational, and use the distribution game to estimate costs.

**Comments**

The rules of the game still require that all orders be shipped by their due date. So, we will get a schedule for the trucks that does not correspond to the actual schedule. We will be operating in more of a steady state. We would stagger these shipments through the week. So, how many trucks do we need? You can cut and paste the schedules from some trucks onto others. This will not be feasible, since shipping requirements due dates will be violated. But, so long as the resulting schedule is shorter than one week, we...
have a good estimate of the number of truckes required.

How do we evaluate the actual customer wait time? If we really are shipping 5 days ahead, the measurement given are good approximates. But, what if we are holding some orders until there are subsequent orders available to consolidate (like we imagine a common carrier works). Then, we might assume that some orders in that truck are as much as five days "over-due" already. All of this raises questions about how to interpret the shipping requirements. Is the order due to ship on that day because it is available on that day? If so, then we cannot ship ahead. What is the relationship between the customer due date and the ship date? The software must be used cautiously and creatively.

Possible Solution
Note that a common mistake is the failure to reduce number of trucks used—one of the chief advantages of demand consolidation.

We might consider establishing patterns where high-volume area receive shipments more frequently than low-volume area. One possible solution is given here. With a simple spread sheet, a the five-day load can be allocated roughly to routes where we try to make more frequent shipments to the locations with the higher volumes. One possible 10-route allocation is shown below, where the fraction shipped is given in the first row of the route, and the quantity shipped is given in the second.

### Possible Allocation

<table>
<thead>
<tr>
<th>Rt</th>
<th>Bltm</th>
<th>Alexn</th>
<th>Richm</th>
<th>Raleigh</th>
<th>Charl</th>
<th>Clmb</th>
<th>Mcon</th>
<th>Jcksn</th>
<th>Orlan</th>
<th>Tampa</th>
<th>Atlanta</th>
<th>Brmn</th>
<th>Nashvl</th>
<th>Mmph</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>1.00</td>
<td></td>
<td>0.33</td>
<td></td>
<td>7,090</td>
<td>13,704</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>20,794</td>
</tr>
<tr>
<td>2</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>1.00</td>
<td>1.00</td>
<td></td>
<td>0.33</td>
<td></td>
<td></td>
<td>4,100</td>
<td>4,012</td>
<td>13,704</td>
<td>21,816</td>
<td></td>
</tr>
<tr>
<td>3</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>1.00</td>
<td></td>
<td></td>
<td>0.33</td>
<td></td>
<td></td>
<td>5,554</td>
<td></td>
<td>13,704</td>
<td></td>
<td>19,258</td>
</tr>
<tr>
<td>4</td>
<td>0.30</td>
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<td></td>
<td></td>
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<td></td>
<td></td>
<td></td>
<td>13,573</td>
<td>6,676</td>
<td></td>
<td></td>
<td>20,249</td>
</tr>
<tr>
<td>5</td>
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<td>0.50</td>
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<td></td>
<td>20,249</td>
</tr>
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<td>0.20</td>
<td></td>
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<td></td>
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<td>6,095</td>
<td>5,790</td>
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<td>20,934</td>
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<tr>
<td>7</td>
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<td>0.50</td>
<td>0.20</td>
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<td></td>
<td></td>
<td></td>
<td></td>
<td>2,366</td>
<td>2,612</td>
<td>5,790</td>
<td>9,049</td>
<td>19,818</td>
</tr>
<tr>
<td>8</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>0.38</td>
<td>0.50</td>
<td></td>
<td></td>
<td></td>
<td>16,151</td>
</tr>
<tr>
<td>9</td>
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<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>0.37</td>
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<td></td>
<td></td>
<td></td>
<td>15,726</td>
</tr>
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<td>10</td>
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<td></td>
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<td></td>
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<td></td>
<td></td>
<td>0.25</td>
<td>1.00</td>
<td>1.00</td>
<td></td>
<td></td>
<td>10,626</td>
</tr>
</tbody>
</table>
On some routes, the trucks are over capacity, but there is ample room to make marginal shifts between routes to achieve feasibility. This can be verified using the software. Of course, we only have five days of demand. So, we need to make sure that a sufficient number of trucks are back by the end of day 7 so they can be ready to go again next week. In practice, of course, the departure dates for the trucks would be staggered.

Note that this fixed route solution serves Tampa and Raleigh three or more times per week. If these trips are staggered in time, then a major customer is unlikely to have to wait very long for a shipment.

Using the software to play with these allocation, we get the following statistics—a huge improvement.

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<td>miles</td>
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<td>$3,506</td>
</tr>
</tbody>
</table>

Useful Operations Research Techniques

Assignment
Submit a written procedure that documents an algorithm to solve this problem.

Comments
There are many available heuristic solution approaches. Some relatively simple examples include:

NEED TO FILL THIS IN

Assignment
Propose a mixed integer-linear optimization formulation of the problem of assigning demand to routes in such a way as to minimize total transportation costs for the week. Propose an algorithm or heuristic to generate an initial solution. Assume there are N routes pre-selected as likely candidates.

Possible Solution
Decision Variables
\[ w_k = \text{number of trips using route } k \text{ each cycle} \]
\[ x_{ik} = \text{number of square feet shipped to location } i \text{ using route } k \]
\[ z = \text{overtime per cycle} \]

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

Formulation
\[ \min \sum_k a_k w_k + \sum_{i,k} M_{ik} x_{ik} + gz \]
subject to
\[ \sum_k x_{ik} = d_i \text{ for all } i \text{ (demand satisfaction)} \]
\[ \sum_i x_{ik} \leq cw_k \text{ for all } k \text{ (truck capacity)} \]
\[ \sum_k l_k w_k - z \leq f \text{ (driver overtime)} \]
\[ x_{ik} \geq 0 \text{ for all } i, k \]
\[ w_k \text{ integer} \]
\[ z \geq 0 \]
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 can include the total capital cost based on the number of trucks required.

**Heuristic**

Every location will be assigned to one route. For location $i$, pick the route with the smallest $a_i / l_k$ ratio for which $M_{ik} = 0$. Note that a common mistake is the failure to recognize the need for a simple heuristic to get initial solution.

### Possible Solution

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<th>Product</th>
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<td>Jacksonville</td>
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</table>

203,723 total 62,639,147

$/sq_{ft\text{-mile}}$ 0.00005
$/sq_{ft}$ 0.0153736
$/wk$ $3,132

Note that this is the cost without consideration of tax effects.

### General Relationships

After substantial experimentation, each group has a pretty good "feel" for what the issues are for the Atlanta dispatcher. Can we generalize any relationships that might be useful in thinking about these problems in general? Students find it difficult to step back and think about what they have observed in general terms.

**Question**

List the factors affecting cost. We have assumed these are linear. Is that reasonable?
Comments
Key factors include number of miles driven, number of trucks, and driver-days. Key determinants of customer service include the length of the routes, and the time between shipments. The relationships here are pretty simple. Longer routes and less frequent shipments lead to lower customer service. We do not expect these relationships to be linear over a wide range.

Question
All other things being equal, describe in general terms the tradeoff between the number of routes and the total miles traveled, the number of trucks employed and customer service, and the number of routes and customer service (where the number of trucks is fixed). Are there some regions where increasing the number of routes or the trucks is costly without being particularly beneficial?

Comments
XX??Peter. I found this useful in my class, but I wonder if it adds anything here.

Some hypothesis for these relationships are given below
THE ATLANTA TRANSPORTATION SYSTEM: ASSIGNMENTS

Primary Assignment

Propose a detailed plan to handle transportation needs in the Atlanta region.

You may assume the fill-rate problem (the unavailability of stock to completely fill orders) will be solved by the time your recommendations for the transportation system are implemented. The fill-rate problem motivates many of the remaining Llenroc cases.

Review the issues of the case. Identify patterns of demand that can be exploited and propose ways to improve both the short- and long-term profitability of the business.

Probing the Data

General Observations. Summarize the major features of the Atlanta warehouse and transportation center and their impact on cost and customer service.

Discuss how the regularity or predictability of the following factors might affect the dispatcher's task: order size, order frequency, order timing (day of week/day of month), order mix (the nature of items ordered), and emergency stock replenishment orders.

Consider the objective that the dispatcher is encouraged to optimize. How would you characterize the routes that are likely to result? What is the likely impact on customer service measures.

It is possible to focus on the transportation time as the primary component of customer wait time. What else must be included?

Customer Analysis. Perform an ABC analysis of customers according to size. Size, in this case, can be measured by the customer's average weekly demand rate for Llenroc Plastic's products, measured in square feet. Plot the results with the cumulative percentage of customers on the horizontal axis, and the cumulative percentage of sales on the vertical axis.

If there were identifiable patterns to customer orders over time, it might be possible to exploit these patterns to give better delivery service or lower cost. For example, if a group of customers ordered every week the dispatcher could assign one or more trucks to service these customers and put these trucks on fixed routes. However, the dispatcher claims that there is no pattern to the deliveries. What do you think? Do large customers typically place a large number of small orders or do they order infrequently but in large quantities? How regular is the timing of orders?
Explain how it might be possible for the customer ordering behavior to be predictable but the delivery pattern to be chaotic. That is, what features of Llenroc Plastics' distribution system create instability?

How many sheets does Jackson Supplies order per order? What does one of these sheets sell for? Approximately how much money do we make on these orders?

**Evaluating Alternative Strategies**

**Cost Model.** It may be useful to make cost comparisons of strategies for weekly operations that differ in the number of trucks used, the number of miles driven, and the number of driver hours. Build an economic model of transportation costs as follows. Find the equivalent weekly after-tax cost of one truck. Use the economic assumptions in Table 7 to perform the equivalence calculations. Find the after-tax operating cost per mile (that is, compute the total of those after-tax costs that depend on the number of miles driven). Similarly, find the after-tax cost per driver-day (assume a 10-hour day).

Use a discounted cash flow approach for the truck-related costs but not for the mileage or driver costs. The most accurate treatment of truck costs requires an after-tax analysis. Since one cost category is treated after-tax, make sure that all other costs (i.e. mileage and driver) are expressed on an after-tax basis, as well.

You must consider a cash inflow associated with disposing of the truck at the end of its economic life.

You will need to consider the terminal value of the truck in order to compute depreciation. Use the straight-line method of depreciation.

Consider any taxable gain or loss on the sale of the truck.

Assume that truck purchases occur at the beginning of the first year, the tax benefit of depreciation occurs at the end of the year, the truck is sold at the end of the fifth year, and registration and insurance costs are incurred at the beginning of the year.

How will you handle the traffic manager’s salary? Do not allocate it to a volume-based measure; keep it as a fixed cost.

**Base Case Analysis.** Use the Transportation Game software to estimate the cost of the current system. The game costs must be scaled, since the simulated shipping requirements for one week represent about two thirds of the actual average weekly demand.

To do this, you must develop a schedule for each truck showing each trip it makes over the five days and, for each trip, what day it leaves the warehouse in Atlanta, which deliveries it makes, in what sequence it makes the deliveries, and what day it returns to Atlanta. Use the various reporting and scoring features of the game to capture key statistics. Present a total transportation cost report for the simulated week.
Your objective is to minimize total cost, subject to the policy constraint that every order must be shipped on the day it is released and the physical constraint that a truck cannot be loaded with orders in excess of its capacity. For discussion purposes, report the maximum number of driver days on any route that you used and the average and maximum number of days a customer had to wait to receive delivery of a picked order.

Allow two days of driving on the weekend. Allow weekend deliveries. Make sure trucks are available for use on Monday and Tuesday of the following week. Otherwise, you will understate the number of trucks your solution really requires.

Assume returning trucks (even after a 2-hour run) cannot be sent out until 2 hours later (i.e., assume 2 hour loading and driver changeover time). Assume a 10 hour day (to be consistent with the graphical version of the Transportation Game).

Don’t spend too much time on this assignment. Its purpose is to acquaint you with the dispatching problem and the cost and customer service implication of dispatching.

Demand Consolidation. Suppose the policy of shipping product as soon as it becomes available was modified to permit the dispatcher to make better use of the truck capacity. For example, another policy might be to allow the dispatcher to consolidate orders by holding orders up to a maximum number of days with the goal of accumulating enough orders to send a full truckload. What would be the major advantages and disadvantages of this change in policy? Will customers change their order patterns if we practice demand management?

Develop a strategy for dispatching that allows consolidation of orders for up to 5 days. Describe your rational, and use the transportation game to estimate costs.

The Transportation Game does not permit such a change in the rules but you could approximate the impact such a change in policy would have by playing the Transportation Game with a different setting of the order horizon. Order horizon in the game refers to the number of days into the future for which customer orders are known and available for shipping. The current policy corresponds to an order horizon of 1 day (the default setting in the game).

An order horizon of 5 days means that the dispatcher can anticipate customer orders up to 5 days into the future and schedule delivery of any customer order in advance of its due date. (The implicit assumption is that inventory is available to fill these orders.) Since it is a form of demand consolidation, lengthening the order horizon in the game is used as a proxy for simulating a variety of order management strategies.

After changing the order horizon, the “edit shipments” option is used to increase the allocation of a given truck beyond the requirements for the first day. Note that with an order horizon of 5 days, there is no need to “advance to the next day” since we only schedule one week’s demand in the game. Instead, the schedule can be changed and the results obtained without advancing. This facilitates rapid evaluation of several alternatives.
Don't spend too much time on this. Recognize that there should be a cost savings to demand management. What is the impact on customer service? If it is negative, can you think of ways to counteract the negative features in order to achieve the cost benefit?

**Using Operations Research Techniques.** The dispatching task is repetitive in nature. Every day, the dispatcher faces the same sort of problem. Submit a written procedure that documents an algorithm to solve this problem. The procedure should be sufficiently detailed so that a computer programmer could implement it. Your algorithm should be clearly explained, complete, and robust to reasonable shifts in the environment.

There are many opportunities for creativity here. Your chief difficulty might be in explaining the algorithm. Consider a flow chart to express it, but acknowledge that statements such as “select a route” or “pick the best order to add to the route” are too vague.

The problem of assigning fractions of total demand at a location to different routes to minimize transportation cost subject to the constraint that truck capacity is not exceeded can be formulated and solved as a mathematical optimization problem. This problem is NP hard. Though N is small in this game, in the original application upon which the case is based, there were lots of customers.

The combinatorial aspect of the problem can be simplified if we assume that we have already generated a large number of routes. For example, route 1 could be Atlanta-Baltimore-Atlanta; route 2 could be Atlanta-Richmond-Baltimore-Atlanta; and so on. The problem reduces to picking which routes to use and what demand to assign to these routes. Propose a mixed integer-linear optimization formulation of the problem of assigning demand to routes in such a way as to minimize total transportation costs for the week. Propose an algorithm or heuristic to generate an initial solution. Assume there are N routes pre-selected as likely candidates.

Note that for this version of the problem, the routes have already been selected. The issue is to select from among these routes and allocate demand to the different routes. This is an easier problem; it is worthwhile exploring a formal mathematical programming formulation.

There are different formulations of this problem depending on your emphasis (customer service or cost) and your desired detail of model truck scheduling.

Your algorithm to find an initial solution may be the only algorithm that is implemented. Look for a greedy heuristic.

**Wrapping it Up**

**The Common Carrier Alternative.** Why could a common carrier achieve a lower cost than Llenroc Plastics? After all, they face the same or similar costs of trucks, mileage, and driver.

What impact would the use of a common carrier have on customer service?

Should Llenroc Plastics be in the trucking business? Historically, companies such as Llenroc Plastics set up their own transportation systems because the alternatives were so expensive. The
trucking business was deregulated in the early 1980's leading to increased competition and lower trucking rates. Companies that maintain fleets of delivery trucks for their own products now have economic alternatives and should reconsider the design of their transportation systems.

Using the simulated total demand data from Table 9, develop an after-tax cost estimate of satisfying all of Llenroc Plastics' transportation needs in the Atlanta region by common carrier. Mileage can be computed using Table 10. The common carrier quote is found in Table 8. (Actual quotes are by hundred weight-mile, but this has been converted to Llenroc Plastics' unit of measure.) Don't try to estimate the cost of disposing of the existing fleet of trucks.

**Generalized Relationships.** List the factors affecting cost. We have assumed these are linear. Is that reasonable?

All other things being equal, describe in general terms the tradeoff between the number of routes and the total miles traveled, the number of trucks employed and customer service, and the number of routes and customer service (where the number of trucks is fixed). Are there some regions where increasing the number of routes or the trucks is costly without being particularly beneficial?
3. THE ATLANTA DISTRIBUTION SYSTEM

OVERVIEW

Introduction to the Case

We continue to concentrate on improving the fill-rate we provide Atlanta's customers while maintaining consistent lead time.

The previous case focused on transportation time from the regional warehouse to the customer and the frequency of shipments to the customers, both important factors that affect customer service. Now, we turn our attention to policies at the regional warehouses.

The overall purpose of the case is to help the students understand why fill rates are so poor at the Atlanta Distribution Center.

The case offers an opportunity to study many different inventory management issues at a variety of levels. Significant time may be spent studying these issues in general, in addition to the specific situation at Llenroc. Moreover, this case is an excellent preparation for the next case (on the national distribution system).

Learning Objectives

This case assists students in understanding the roles that lead time uncertainty, product variety, demand uncertainty, and multi-echelon coordination play in distribution system performance. In addition, it explores ways to improve customer service and reduce inventory investment.

Software and its Use

The Distribution Game

To fully prepare this case, spreadsheet software is essential. Unlike several others, there is no software provided for the analysis of the issues Llenroc faces in this case.

However, the distribution game is provided for use with this case. Playing the Distribution Game is a useful exercise for several reasons. It dramatizes the concepts of pipeline stock, cycle stock, and safety stock. Secondly, it provides the motivation to review fundamental models and formulas from inventory theory (Little's Law for average pipeline stock, the Economic Order Quantity Model for optimal cycle stock levels, and the simple model of safety stock from Appendix E). Finally, it dramatizes the role of coordination between echelons in a multi-echelon system.
In class, see that they only charge $0.04 per dollar-year of inventory at the regional warehouses (the differential between the stated cost of inventory at the two echelons) when computing regional economic order quantities? After all, the full inventory holding cost was $0.24 per dollar-year. 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 (the central warehouse holding cost rate is $0.20 per dollar-year.)

**Main Issues**

The following suggested progression of issues addressed corresponds to the sequence students might be follow in their analyses.

**Inventory Theory**

Because there is so much data, this case offers an excellent opportunity to explore certain issues which will be useful in analyzing the case. These include the effects of product proliferation and the relationships among safety stock levels, fill rates, order quantities, cycle lengths, and the variability of demand and lead time. The students must realize that the long and variable lead times they face from the factory are a real problem. They must also realize the importance of short and stable lead times for their customers.

**Probing the Data**

The students quickly see that there is a disproportionate amount of inventory held for the low-demand items; these have more volatile demand and longer cycle times (a matter of policy). It is much more difficult for them to understand that the variability of demand at the Atlanta warehouse is so much more variable than the demand the Atlanta customers observe because of lot-sizing policies at Atlanta.

**Using Operations Research**

Some assignments are given to encourage students to use their OR in the case analysis. These assignments can be broken up and given during the analysis of the case data.

**Wrapping it Up**

Students should leave this case with a clear understanding of the propagation of demand variability up the supply chain that results from lot sizing decisions along the chain. In addition, they must see that safety stock requirements are sensitive to increased variability in lead times and, thus, in lead time demand resulting from shortages. From this,
they should see that their primary goal is to reduce lead times, and lead time and demand variability.

With this understanding, students are prepared to present specific recommendations in their primary assignment.

**Class Management**

This case is very rich, and it can easily stand on its own. Students can easily spend three weeks exploring the issues raised.

When the case is used in the Llenroc series and time is severely limited, the instructor can choose to cover the main points of the case in a lecture and not assign any work with the case.

Although a relatively general primary assignment is given here, written solutions to several of the other assignments often comprise the primary deliverable for this case.

An oral progress meeting about one week into the case is often a good idea. It is often difficult for the students to see the relevance of their analysis to the problems at hand, and this meeting will help keep everyone focused. Moreover, many of the key ideas are difficult for students to discover on their own.

If a good rapport has been established with the class thus far, this case can be a challenging and exciting experience. However, it can be an order of magnitude more difficult than the first case, and it has the potential of dampening the whole process. The student’s frustration level should be monitored closely during this case.

**PRIMARY ASSIGNMENT**

The students are asked to list changes in the operation of the supply chain at Llenroc Plastics that could bring about an increase in customer service and a reduction in inventory investment. It is important for the students to recommend specific policies so these can be used as inputs during the next case (The National Distribution System). For example, in that case students must specify fill rates and cycle lengths (order frequencies) for each type of customer.

Many students have a general idea of what needs to be done and why. But, they find it difficult to justify changes in policy in a report. It is good to require them to provide substantiated estimates of the savings Llenroc might expect from the proposed changes.

Students are anxious to use a magic bullet like EDI to solve all of their problems. It is essential that they push these ideas, exploring what the real benefits would be to Llenroc and its customers.

**INVENTORY THEORY**

**Product Proliferation**

Suppose that total demand is fixed (i.e. customers choose between patterns but total demand is unchanged). In this situation, what is the impact of the marketing strategy on the inventory investment required to achieve a desired service level?

**Comments**

Students usually recognize that increasing the number of items for a fixed total demand will increase the safety stock required. We often do not explain risk pooling, since the case on the national distribution system will provide a good opportunity to discuss that.

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 cups are the same size.)

**Safety Stock and Fill Rate**

Plot safety stock as a function of fill rate. Start each plot with a relatively low fill rate.
Observations
From these, we see that it takes increasingly large safety stock levels to achieve fill rates near 100%. Moreover, it takes more SS to achieve any fill rate above zero for the items with the higher CV’s (i.e. the Laplace distributed).

Support

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Derived

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Fill Rates and Order Quantity

Use the second and third items from Table 14 (Almond P 36x120 and Pigeon Blue PF 48x96) to investigate the relationship between the fill rate achieved and the order quantity.

Observation
Longer cycles mean that the same SS level gives a higher fill rate. That is, the less often we place orders, the less SS needed to achieve a given fill rate. (Of course, longer cycles mean more cycle stock.)

Support
Students sometimes find it difficult to see how they can affect customer service by changing the order quantity but not the safety stock. The following graphs correspond to a fill rate of 90%.
To do: Add a graph of the fill rate as a function of the cycle, for a given value of $z$.

Here is the inventory affect of the cycle length. This includes cycle stock as well as safety stock.

**Lead Time and Safety Stock**

Plot safety stock as a function of the length of the lead time for the first item (Almond D 60x144).

**Observation**

Safety stock is proportional to the square root of lead time.

**Support**

Students intuitively know that increasing the lead time will increase the coefficient of variation and therefore increase the safety stock needed. According to the simple model of safety stock, safety stock is proportional to the square root of lead time.

**Lead Time Variability and Safety Stock (or fill rate)**

Consider the first item from Table 14 (Almond D 60x144). Implement a simple fixed-quantity, reorder point model for safety stock under two assumptions.

**Observation**

Need to fill this in! XX

**Support**

Need to fill this in! XX

**CV of Lead Time Demand and Safety Stock**

How does the coefficient of variation of lead time demand affect safety stock requirements?

**Observation**

The SS required increases linearly in the CV.

**Support**

The CV can be thought of as the variability per unit of sales. We can write the SS as $z \mu CV$. So, $z CV$ gives us the amount of SS per unit sales. Thus, low volume items, which typically have a high coefficient of variation, require more safety stock per unit of sales than high volume items.

**Summarizing Observations from Inventory Theory**

More SKUs implies more variability. (Llenroc has many SKUs.)
Achieving fill rates near 100% can require a lot of inventory.

Longer cycles mean that the same SS level gives a higher fill rate.

Safety stock is proportional to the square root of lead time.

The SS required increases linearly in the CV.

**PROBING THE DATA**

**Current Policies**

Why would the current LT and order quantities for A-items be smaller than the others?

**Comments**

The A items are probably produced more often at the factory. Thus, we do not expect to wait long if the central warehouse is out of stock.

From the EOQ formula, all other things being equal, the time between orders increases as the average demand rate decreases. So, we are not surprised the A items are ordered more frequently.

**The Lead Times**

How would you characterize (subjectively) the lead times that Atlanta faces from the central warehouse?

**Comments**

The leads times are both lengthy and uncertain. According to our observations regarding the relationship between lead time length and variability, we conclude that this is a real problem for Atlanta.

**Sheets vs Square Feet**

Categorize the 70 items from Table 14 according to square footage shipped and again on the basis of sheets. Do these results differ? For setting safety stock levels, would you recommend an ABC classification based on square footage or one based on sheets?

**Comments**

Students will be performing many different ABC analyses in Llenroc Plastics, and they need to keep them straight in their minds. In case 1, we looked at an ABC analysis of customers. Here, we look at two different measures of volume. Later, they will group items by sheet dimensions.

In the past, some students have argued that ABC classification is not a good idea and have proposed treating each item equally importantly and make stocking policies sensitive to more information than just average demand. We point 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.

**Possible Solution**

The items are sequenced according to both criteria on the following page. The members of the various classes do differ. Of course, the difference depends on the specific breakpoints chosen.

Production cost and sales price per square foot are roughly the same for all products. Thus, an ABC categorization based on square footage shipped is equivalent to a categorization based on cost or revenue. This corresponds to their current policy.

An ABC classification by sheets is more relevant for inventory stocking policies than ABC by square footage which focuses on the inventory holding cost aspect of the inventory policies. An ABC by sheets is focused on the characteristics of the demand process. Forced to make predictions of stockout probabilities, one would prefer demand-by-sheet data.
<table>
<thead>
<tr>
<th>ABC by Sheets</th>
<th>frac</th>
<th>ABC by Sq Ft</th>
<th>frac</th>
</tr>
</thead>
<tbody>
<tr>
<td>Almond</td>
<td>0.30</td>
<td>Almond</td>
<td>0.42</td>
</tr>
<tr>
<td>D60x144</td>
<td></td>
<td>D60x144</td>
<td></td>
</tr>
<tr>
<td>Walnut</td>
<td>0.46</td>
<td>Walnut</td>
<td>0.53</td>
</tr>
<tr>
<td>V48x96</td>
<td></td>
<td>V48x96</td>
<td></td>
</tr>
<tr>
<td>Teak</td>
<td>0.53</td>
<td>Teak</td>
<td>0.59</td>
</tr>
<tr>
<td>V48x96</td>
<td></td>
<td>V48x96</td>
<td></td>
</tr>
<tr>
<td>Almond</td>
<td>0.58</td>
<td>Mercury</td>
<td>0.63</td>
</tr>
<tr>
<td>P36x120</td>
<td></td>
<td>60x120</td>
<td></td>
</tr>
<tr>
<td>DanishWalnut</td>
<td>0.63</td>
<td>Almond</td>
<td>0.67</td>
</tr>
<tr>
<td></td>
<td></td>
<td>P36x120</td>
<td></td>
</tr>
<tr>
<td>Mercury</td>
<td>0.66</td>
<td>DanishWalnut</td>
<td>0.70</td>
</tr>
<tr>
<td>60x120</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>AlmondTessera</td>
<td>0.69</td>
<td>Almond</td>
<td>0.72</td>
</tr>
<tr>
<td>48x96</td>
<td></td>
<td>60x144</td>
<td></td>
</tr>
<tr>
<td>FineOak</td>
<td>0.71</td>
<td>AlmondTessera</td>
<td>0.74</td>
</tr>
<tr>
<td></td>
<td></td>
<td>48x96</td>
<td></td>
</tr>
<tr>
<td>PrimaryRed</td>
<td>0.73</td>
<td>PrimaryRed</td>
<td>0.76</td>
</tr>
<tr>
<td>48x120</td>
<td></td>
<td>48x120</td>
<td></td>
</tr>
<tr>
<td>CarnationGloss</td>
<td>0.75</td>
<td>FineOak</td>
<td>0.78</td>
</tr>
<tr>
<td>48x120</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Almond</td>
<td>0.77</td>
<td>CarnationGloss</td>
<td>0.80</td>
</tr>
<tr>
<td>60x144</td>
<td></td>
<td>48x120</td>
<td></td>
</tr>
<tr>
<td>Fawn</td>
<td>0.78</td>
<td>BlackGranite</td>
<td>0.81</td>
</tr>
<tr>
<td></td>
<td></td>
<td>PF60x144</td>
<td></td>
</tr>
<tr>
<td>PBV48x96</td>
<td>0.80</td>
<td>Almond</td>
<td>0.83</td>
</tr>
<tr>
<td>Almond</td>
<td></td>
<td>DPF60x120</td>
<td></td>
</tr>
<tr>
<td>DPF60x120</td>
<td>0.81</td>
<td>Fawn</td>
<td>0.84</td>
</tr>
<tr>
<td>ButcherBlock</td>
<td></td>
<td>PBV48x96</td>
<td></td>
</tr>
<tr>
<td>LG36x96</td>
<td>0.82</td>
<td>Leather</td>
<td>0.85</td>
</tr>
<tr>
<td>BlackGranite</td>
<td></td>
<td>PF60x144</td>
<td></td>
</tr>
<tr>
<td>PF60x144</td>
<td>0.83</td>
<td>Slate</td>
<td>0.86</td>
</tr>
<tr>
<td>Slate</td>
<td></td>
<td>48x96</td>
<td></td>
</tr>
<tr>
<td>48x96</td>
<td>0.84</td>
<td>Tapioca</td>
<td>0.87</td>
</tr>
<tr>
<td>Flaxseed</td>
<td></td>
<td>48x144</td>
<td></td>
</tr>
<tr>
<td>PF30x144</td>
<td>0.85</td>
<td>Flaxseed</td>
<td>0.88</td>
</tr>
<tr>
<td>WhiteNugget</td>
<td></td>
<td>PF30x144</td>
<td></td>
</tr>
<tr>
<td>48x96</td>
<td>0.86</td>
<td>ButcherBlock</td>
<td>0.88</td>
</tr>
<tr>
<td>RoyalBlue</td>
<td></td>
<td>LG36x96</td>
<td></td>
</tr>
<tr>
<td>36x96</td>
<td>0.87</td>
<td>WhiteNugget</td>
<td>0.89</td>
</tr>
<tr>
<td>Squash</td>
<td></td>
<td>48x96</td>
<td></td>
</tr>
<tr>
<td>48x96</td>
<td>0.88</td>
<td>Alabaster</td>
<td>0.90</td>
</tr>
<tr>
<td>PrimaWalnut</td>
<td></td>
<td>GlazedStone</td>
<td></td>
</tr>
<tr>
<td>48x96</td>
<td></td>
<td>PF60x144</td>
<td></td>
</tr>
<tr>
<td>Leather</td>
<td>0.88</td>
<td>Squash</td>
<td>0.90</td>
</tr>
<tr>
<td>PF60x144</td>
<td></td>
<td>48x96</td>
<td></td>
</tr>
</tbody>
</table>

We think of A items as high volume, consistent demand items that require little safety stock to protect customer service. With an ABC on square feet, it is conceivable that an item falls in the A category by virtue of having a large sheet size although its demand may be medium volume and highly variable.

Categorization based on square footage makes good sense when dealing with transportation issues (as in Case 1).

**Inventory/Sales Relationship**

Which items require the most inventory relative to their sales?

**Observation**

A disproportionate amount of inventory is held for low-demand items, due in part to higher CVs as well as longer cycles. (This assignment helps lead the students toward a re-design of the system in later cases in which B and C items can be made to order.)

**Support**

From Table 14.
Note that the Pareto curve based on inventory investment is flatter than the curve based on volume measures. In other words, it looks as if we carry a disproportionately high amount of inventory of the items with low demand.

Some of this is explained by the relationship between high the average demand and the CV. That is, low demand items have larger CV’s. This means higher safety stock. Order quantities might also contribute, as explored below.

**CV and Mean Demand**

What is the relationship between the CV of demand and the average demand level at Llenroc?

**Observation**
The lower the average demand, the higher the CV of demand. This is not uncommon. This helps the students understand why the low-demand items require a disproportionate amount of inventory at Llenroc.

**Support**
The coefficient of variation is the ratio of the standard deviation of demand to the mean demand. It is a unitless measure of variability.

Consider Table 14.

**Problems with the Current Inventory Policies**

Explain how Llenroc Plastics’ current inventory policies (e.g. order and safety stock quantities) might cause a disproportionate amount of inventory to be held for low-demand items.

**Observation**
Low-demand items tend to have higher CVs, which means more SS. In addition, their longer cycle times mean higher cycle stock.

**Comments**
For A items, the company restocks every two weeks with a safety stock of two weeks of demand. Hence, the cycle plus safety stock is three weeks of demand for A items. For B and C items, the corresponding figure is six weeks of demand (order every four weeks with safety stock of four weeks).

Let A denote the inventory investment in A items, B denote the inventory investment in B and C items, D denote the total demand for all items per week. Then, $A = 3 \times 0.8D$ and $B = 6 \times 0.2D$. Hence, $B/(A+B) = 1/3$. Even though B and C items account for only 20% of demand volume, they will account for 1/3 of the inventory investment.

Breaking this up into cycle and safety stock. We have cycle stock for A at 1 week = 1 (0.8)D and for B at 2 (0.2)D. So, cycle stock for B represents $B/(A+B) = 0.33$ or 33% of the total cycle stock inventory. Similarly we have safety stock for A at 2 (0.8)D and for B at 4 (0.2)D. Thus, B accounts for $B/(A+B) = 0.33$, or again 33% (just coincidence!!!)

**End-item and Atlanta Demand**

Consider the demand observed by Atlanta’s B and C customers (Table 18). Compare this to the demand observed by Atlanta, from its B and C customers (Table 17).
**Observation**

Earlier, we saw that A and B customers tend to order once per week, many C customers order every day. Now, we see that end-item demand at small customers is much more stable than the orders received at the Atlanta warehouse from the small customers. That is, variability increases as we move up the supply chain. But, why?

**Support**

Table 17 contains monthly orders at the warehouse aggregated across all of Atlanta’s small customers. These CV’s are much higher than the CV’s from the monthly end-item demand.

<table>
<thead>
<tr>
<th>Style</th>
<th>Item</th>
<th>Sales</th>
<th>End Item</th>
</tr>
</thead>
<tbody>
<tr>
<td>Carnation PB V 48x96</td>
<td>1</td>
<td>0.05</td>
<td>0.04</td>
</tr>
<tr>
<td>Almond D PB 48x96</td>
<td>2</td>
<td>0.06</td>
<td>0.06</td>
</tr>
<tr>
<td>Pumice V 48x96</td>
<td>3</td>
<td>0.12</td>
<td>0.07</td>
</tr>
<tr>
<td>Black PB 48x96</td>
<td>4</td>
<td>0.07</td>
<td>0.07</td>
</tr>
<tr>
<td>White PB 48x96</td>
<td>5</td>
<td>0.66</td>
<td>0.08</td>
</tr>
<tr>
<td>Oak 48x96</td>
<td>6</td>
<td>0.14</td>
<td>0.09</td>
</tr>
<tr>
<td>Walnut V 48x96</td>
<td>7</td>
<td>0.31</td>
<td>0.12</td>
</tr>
<tr>
<td>Beige V 48x96</td>
<td>8</td>
<td>0.25</td>
<td>0.13</td>
</tr>
<tr>
<td>Teak V 48x96</td>
<td>9</td>
<td>0.32</td>
<td>0.18</td>
</tr>
<tr>
<td>Gray 48x96</td>
<td>10</td>
<td>0.76</td>
<td>0.29</td>
</tr>
<tr>
<td>Yellow PB 48x96</td>
<td>11</td>
<td>0.70</td>
<td>0.23</td>
</tr>
<tr>
<td>Royal Blue PB V 48x96</td>
<td>12</td>
<td>0.51</td>
<td>0.19</td>
</tr>
<tr>
<td>Squash PB V 48x96</td>
<td>13</td>
<td>0.65</td>
<td>0.26</td>
</tr>
<tr>
<td>Raspberry PB 48x96</td>
<td>14</td>
<td>0.65</td>
<td>0.34</td>
</tr>
<tr>
<td>Amberwood V 48x96</td>
<td>15</td>
<td>0.75</td>
<td>0.19</td>
</tr>
<tr>
<td>Bittersweet V 48x96</td>
<td>16</td>
<td>0.73</td>
<td>0.25</td>
</tr>
</tbody>
</table>

**Comparing Customer Types**

Consider the demand observed by Atlanta, from its B and C customers (Table 17). Compare this to the demand observed by Atlanta, from its A customers (Table 16).

**Observation (1)**

Half of demand comes from B and C customers (a lot). PETER: We have a problem here. This does not agree with an earlier finding (case 1) based on Table 12. There, the sum of the M and S does not equal the total for the L. Did I make an error?
**Support**

**Average Monthly Demand**

** Observation (2)**
The A customers have significantly higher CVs.

**Support**
Monthly Demand CVs for A-type customers is larger than monthly demand CVs from B & C type customers.

Here is a plot of the CVs of the six monthly demands averaged by customer type.

**Observation (3)**
Type A customers order in multiples of 50. Customer types B (probably) and C (definitely) do not. Thus, their demand is less "lumpy."

**Support**
Directly from Tables 16 & 17

Here are plots for two sample items.
Pricing Policy

Does the pricing policy cause any problems related to inventory control?

Comments
From our analysis of customer demand patterns (next), we see that large customers are using the lot-size cost break. Does this really help us? It reduces the cost to prepare orders, since things are wrapped in lots of 50. But, it greatly increases the variability of the order stream.

Summarizing the Last Three Assignments

Observation
From the last three questions we conclude that the lot sizing rules of the customers are causing much of the variability in demand for our product.

Support
In the previous question, we saw that end-item demand at B/C customers is much more stable than the orders received at the Atlanta warehouse from the B/C customers.

Here we see that the orders received from B/C customers are much more stable than orders received from A customers. Type A customers order in multiples of 50. Customer types B & C do not. Thus, their demand is less “lumpy.”

We might think of our B/C customers as the biggest pain. But, since they order daily, their demand pattern is pretty stable in comparison to the large customers. This suggests that we need to either change our policy with respect to orders of 50, or coordinate the ordering patterns of our large customers.

Electronic Data Interchange

Propose an expansion to the electronic data interchange with customers and with suppliers. Of what value would the additional data be? How would you get the customers and suppliers to participate in the expansion?

Comments
The main lesson to draw from the examination of the tables is that even if the ultimate demand is fairly smooth (e.g. Poisson), the lot sizing that our customers prefer induces a considerable degree of variability into our order stream.

There are legitimate reasons for them 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.

Having established relationship between safety stock and the coefficient of variation in an earlier assignment, 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.

The Power Saw

Should the practice of sawing laminates to meet customer orders for smaller product sizes be encouraged or discouraged?

Comments
This question is linked to the product proliferation discussion question given earlier. It is tempting to focus on the waste and conclude that this practice should be discouraged. However, suppose most of the demand for a certain pattern is in the 4'x8' size with occasional demand for a 3'x8' size. Then, the waste is less, and the possibility exists to carry no safety stock in the 3'x8' size. Students might also worry that the information system won't be alerted that a 4'x8' sheet was substituted for a 3'x8' sheet. This is, of course, a valid concern.

USING OPERATIONS RESEARCH

Variable Lead Times

Assume demand over a constant lead time is normally distributed and that lead time is either one week or three weeks, each with probability 0.5. Note that the distribution of demand over a random lead time need not be normally distributed. What is the probability density function of lead time demand? Extend the analysis of Appendix E to cover this case exactly. Apply your technique to the first item from Table 14 (Almond D 60x144).

Comments
Need to fill this in.

Approximating Monthly Demand Variability

Devise a method for approximating the variability in daily demand observed at the Atlanta warehouse as a function of the ordering lot size imposed at the area distributors.

For A Single Customer
A simple (and incorrect) approximation is given by D(Q − D), explained as follows.

Some of the variability in daily demands observed at Atlanta is due, in part, to the inherent variability observed at the end-item level.

Recall that the variance can be thought of as the mean squared error of daily demand.

The expected daily demand is just the mean of the demand at the customer, or D. During the days when the distributor orders, the order size is Q, and the "error" for that day is Q − D. This will occur approximately mD/Q times each month, that is, D/Q is the fraction of days when the error is Q − D. During the days when the distributor does not order, the error is D. This will occur the remaining 1 − D/Q fraction of the time. Thus, if we ignore the inherent demand variability at the end-item level, the mean squared error is approximated by

\[ D/Q \times (Q − D)^2 + (1 − D/Q) \times D. \]

This simplifies to \( D(Q − D). \)

Using this, we have the following predicted weekly variability for Walnut and Teak.
<table>
<thead>
<tr>
<th></th>
<th>Walnut</th>
<th>Teak</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>At the customer</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>avg demand/day</td>
<td>7.0</td>
<td>3.4</td>
</tr>
<tr>
<td>lot size</td>
<td>50</td>
<td>50</td>
</tr>
<tr>
<td><strong>At the warehouse</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>var(d(1 day)]</td>
<td>301</td>
<td>158</td>
</tr>
<tr>
<td>stdev(d(1 day])</td>
<td>17.35</td>
<td>12.59</td>
</tr>
<tr>
<td>days/week</td>
<td>5</td>
<td>5</td>
</tr>
<tr>
<td>stdev(d(wh)]</td>
<td>38.8</td>
<td>28.1</td>
</tr>
<tr>
<td>days/month</td>
<td>22</td>
<td>22</td>
</tr>
<tr>
<td>stdev(d(m-on)]</td>
<td>81.38</td>
<td>59.04</td>
</tr>
</tbody>
</table>

Let $D_m$ and $\sigma_m$ be the average and standard deviation of monthly end-item demand at each of the $N$ customers served by Atlanta. Assume there are $M$ days in each month. Then, in the absence of other factors, the variance of daily demand is given by $\sigma_d = \sigma_m / \sqrt{M}$. But, this is not the only source of variability.

Recall that the variance can be thought of as the mean squared error of daily demand.

The expected daily demand is just the mean of the demand at the customer, or $D_d = D_m/M$. During the days when the distributor orders, the order size is $Q$, and the "error" for that day is $Q - D_d$. This will occur approximately $D_m/Q$ times each month. During the days when the distributor does not order, the error is $D_d$. This will occur approximately $M - D_m/Q$ times each month. Thus, the mean squared error is approximated by $D_d$ ($Q - D_d$). The CV is given by $\sqrt{Q - D_d / D_d}$.

For Multiple Customers
Suppose Atlanta serves $N$ customers. We would expect this to attenuate significantly the variability observed at Atlanta. If we assume that the $N$ customers are identical, then the variance and mean both increase by a factor of $N$. Using the approximation developed for the variance of the order stream from each customer, then we have the coefficient of variation given by $\sqrt{N \cdot \sqrt{\frac{Q - D_d}{D_d}}}$.

An Example.
Suppose the true underlying process at the end-item level has the variance equal to the mean (not unlike Table 18). For a mean daily demand of 3 sheets, the CV of daily demand at the end-item level is only 0.6. For a lot size of 50, using our approximation for daily demand at Atlanta, we have the daily variance given by 141, and the CV = 4.0. Quite a big difference.

Now suppose we have $N$ identical customers. The resulting parameters for the demand observed at Atlanta are given below.

<table>
<thead>
<tr>
<th>$N$</th>
<th>1</th>
<th>5</th>
<th>10</th>
<th>15</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mean</td>
<td>3.0</td>
<td>15</td>
<td>30</td>
<td>45</td>
</tr>
<tr>
<td>Variance</td>
<td>141.0</td>
<td>705</td>
<td>1410</td>
<td>2115</td>
</tr>
<tr>
<td>Stdev</td>
<td>11.9</td>
<td>26.6</td>
<td>37.5</td>
<td>46.0</td>
</tr>
<tr>
<td>CV</td>
<td>4.0</td>
<td>1.8</td>
<td>1.3</td>
<td>1.0</td>
</tr>
</tbody>
</table>

End-Item Demand Distribution
What probability model would you suggest using to describe the demand data? Why?

Comments
The standard deviation of a Poisson process is the square root of its mean. So a classical demand model works for the real consumption rate data. When we study order data however, lot sizing rules make it much more difficult to model.
Poisson Distribution

What evidence does Table 18 give that end-item demand at smaller customers follows a Poisson distribution?

Observation
A quick look at the variance over the mean demand (monthly) indicates that it is a real possibility.

Support
We expect the ratio of the variance to the mean demand to be approximately one for demand distributed Poisson. The following gives this ratio for several of the items.

<table>
<thead>
<tr>
<th>Item</th>
<th>$\sigma^2/\mu$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Carnation PB V 48x96</td>
<td>1.0</td>
</tr>
<tr>
<td>Almond D PB 48x96</td>
<td>1.0</td>
</tr>
<tr>
<td>Pumice V 48x96</td>
<td>0.9</td>
</tr>
<tr>
<td>Black PB 48x96</td>
<td>1.0</td>
</tr>
<tr>
<td>White PB 48x96</td>
<td>0.9</td>
</tr>
<tr>
<td>Oak 48x96</td>
<td>0.8</td>
</tr>
<tr>
<td>Walnut V 48x96</td>
<td>1.0</td>
</tr>
<tr>
<td>Beige V 48x96</td>
<td>0.9</td>
</tr>
<tr>
<td>Teak V 48x96</td>
<td>0.9</td>
</tr>
<tr>
<td>Gray 48x96</td>
<td>1.1</td>
</tr>
<tr>
<td>Yellow PB 48x96</td>
<td>1.1</td>
</tr>
<tr>
<td>Royal Blue PB V 48x96</td>
<td>0.9</td>
</tr>
<tr>
<td>Squash PB V 48x96</td>
<td>0.8</td>
</tr>
<tr>
<td>Raspberry PB 48x96</td>
<td>1.2</td>
</tr>
<tr>
<td>Amberwood V 48x96</td>
<td>0.7</td>
</tr>
<tr>
<td>Bittersweet V 48x96</td>
<td>1.0</td>
</tr>
</tbody>
</table>

Poisson Demand Statistical Tests

Perform a statistical test of the data in Table 18 to see if it is reasonable to assume that demand at smaller customers follows a Poisson distribution. An appendix gives details on the test.

Comments
The appendix seems to be sufficient for the students to conduct the Chi-squared test of the Poisson distribution correctly.

Note that with only a few degrees of freedom it will be difficult to reject even the uniform distribution. Do the students expect that they will have more than 36 months of data to test such hypotheses in practice? This illustrates the practical point that it is very difficult to fit distributions to actual demand data.

Observations
All of the following statistical tests suggest that end-item demand likely to be Poisson distributed.

Support
Many students also performed a Lexis test (to test if the mean is approximately equal to the variance) and some students produced P-P plots. At the 95% level it is difficult to reject the Poisson distribution. (In fact, these data were generated using a Poisson distribution but we never mention that to the students.)

We emphasize with students how difficult it will be to conduct these tests in practice. This is a discouraging realization for the students, but one goal of this series of cases is to direct the students away from planning safety stock on an item by item basis.
THE ATLANTA DISTRIBUTION SYSTEM: ASSIGNMENTS

Primary Assignment

List changes in the operation of the supply chain at Llenroc Plastics that could bring about an increase in customer service and a reduction in inventory investment. You do not need to recommend a complete strategy to improve fill rate performance yet. You will return to this question in case 7.

Assume Llenroc operates either in continuous time, or daily. That is, we observe demand and place replenishment orders every day, as needed.

Tables 14 through 18 will be particularly helpful for this case preparation. Some demand data is given by customer, and other is given by item. Some demand is given by the week, by the month, and by the day.

A “customer” is a customer of the Atlanta warehouse. It is easy to get demand for end-items confused with demand observed at the Atlanta warehouse. So, we will use “demand” or “orders” to refer to the demand at the Atlanta warehouse, and “end-item demand” to refer to the demand at Atlanta’s customers.

There is a lot of data here. Before you do anything, become familiar with the tables.

Table 14. Weekly orders and inventory for 70 items.

Table 15. Monthly orders for high-volume items. There are only two items in common with Table 14. Consequently, a meaningful comparison of weekly to monthly is not possible.

Table 16 Monthly orders for high-volume items, from all A customers

Table 17 Monthly orders for high-volume items, from all B & C customers

Table 18 Monthly end-item demand for high-volume items at all B & C customer locations. So, this is the actual demand pattern observed at the distributors, aggregated across all of Atlanta’s small customers.

Please note the following. (1) Tables 15 - 18 contain data for a common set of items. However, this set has very few items in common with the set covered by Table 14. (2) Inventory ordering decisions might be made daily, or weekly, but most of the data given here is monthly. Thus, we need to extrapolate to the proper unit of measure when fixing policies. However, so long as we make comparisons between data of common time periods, we can use monthly data to investigate many issues.
Inventory Theory

One of the pressures of the business is that the marketing department continues to push for more patterns. Suppose that total demand is fixed (i.e. customers choose between patterns but total demand is unchanged). In this situation, what is the impact of the marketing strategy on the inventory investment required to achieve a desired service level?

Consider three items from Table 14—Almond D 60x144, Almond P 36x120, and Pigeon Blue PF 48x96. Assume that lead time demand is normally distributed for the first item and Laplace-distributed for the second and third items. Use one or more of these three items to explore various relationships between key determinants of safety stock and fill rate. As a base case, assume that the lead time is two weeks, and that the “weeks-of-supply” covered by the item’s order quantities are 2 weeks, 3 weeks, and 3 weeks, respectively. Relate these relationships to issues from the case. Some specific recommendations are given below.

Plot safety stock as a function of fill rate. Start each plot with a relatively low fill rate.

The fill rate achieved is, of course, affected by the safety stock. More safety stock leads to a higher fill rate. Use the second and third items from Table 14 (Almond P 36x120 and Pigeon Blue PF 48x96) to investigate the relationship between the fill rate achieved and the order quantity. Assume that lead time demand is Laplace-distributed.

Plot safety stock as a function of the length of the lead time for the first item (Almond D 60x144).

Consider the first item from Table 14 (Almond D 60x144). Implement a simple fixed-quantity, reorder point model for safety stock. First assume the lead time is a constant two weeks. Next, assume that lead time 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, even if the demand during a fixed lead time is normally distributed. However, for the purpose of illustration, use the assumption of normality to determine safety stock requirements for this variable lead time case.

How does the coefficient of variation of lead time demand affect safety stock requirements?

Probing the Data

Examine the inventory control policies in place. Recall the data given in the following table, where safety stock and order quantities are given in terms of the number of weeks covered by that amount (in expectation). Why would the LT for A-items be smaller? Why would the order quantity be smaller for A items?

<table>
<thead>
<tr>
<th>Assumed LT</th>
<th>Safety Stock</th>
<th>Order Quantity</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>2 weeks</td>
<td>2 weeks</td>
</tr>
<tr>
<td>B</td>
<td>3 weeks</td>
<td>4 weeks</td>
</tr>
<tr>
<td>C</td>
<td>3 weeks</td>
<td>4 weeks</td>
</tr>
</tbody>
</table>
How would you characterize (qualitatively) the lead times that Atlanta faces from the central warehouse?

In the last case, we considered classification of customers according to their sales volume. Now, we must categorize items. As the case notes, Llenroc uses an ABC classification based on item cost. Table 14 gives data for demand in number of sheets and square footage. Categorize these 70 items according to square footage shipped and again on the basis of sheets. Do these results differ? For setting safety stock levels, would you recommend an ABC classification based on square footage or one based on sheets? (Different textbooks give different rules for where to break the parts into A, B, and C categories. You may choose your own breakpoints so long as these are consistent when comparing the two measures of volume.)

Which items require the most inventory relative to their sales? Using Table 14, create a plot showing the cumulative fraction of total demand (in square) relative to the cumulative fractions of items needed to generate that demand. On the same plot, show the cumulative fraction of total inventory relative to the cumulative fraction of items. Use the sequence of items shown in Table 14. What does the plot tell you about the contrast between where inventory is invested and where revenue is generated?

What is the relationship between the CV of demand and the average demand level at Llenroc? How does the coefficient of variation of lead time demand affect safety stock requirements?

Explain how Llenroc Plastics’ current inventory policies (e.g. order and safety stock quantities) might cause a disproportionate amount of inventory to be held for low-demand items. Hint: Suppose A items account for 80% of demand. Write an expression for the cycle plus safety stock for an item based upon the order size and safety stock levels (both measured in weeks of demand).

Consider the demand observed by Atlanta’s B and C customers (Table 18). Compare this to the demand observed by Atlanta, from its B and C customers (Table 17).

Consider the demand observed by Atlanta from its B and C customers (Table 17). Compare this to the demand observed by Atlanta from its A customers (Table 16).

Does the pricing policy cause any problems related to inventory control? Suppose, for example, that an order of 50 laminates for a particular item is equivalent to two months of expected demand by a customer. Furthermore, suppose that there are only a few customers who order this item in large quantities. What problem does the Atlanta warehouse experience in trying to satisfy orders for this item?

Propose an expansion to the electronic document interchange with customers and with suppliers. Of what value would the additional data be? How would you get the customers and suppliers to participate in the expansion?

Should the practice of sawing laminates to meet customer orders for smaller product sizes be encouraged or discouraged?
Using Operations Research

Assume demand over a constant lead time is normally distributed and that lead time is either one week or three weeks, each with probability 0.5. Note that the distribution of demand over a random lead time need not be normally distributed. What is the probability density function of lead time demand? Extend the analysis of Appendix E to cover this case exactly. Begin your analysis with equation (1) of Appendix E. Apply your technique to the first item from Table 14 (Almond D 60x144).

Devise a method for approximating the variability in daily demand observed at the Atlanta warehouse as a function of the ordering lot size imposed at the area distributors. To simplify this analysis, assume there is exactly one distributor, and that the mean and standard deviation of daily demand at that distributor is given by $D$ and $\sigma$, respectively. Also assume the distributor orders in fixed quantities equal to $Q$, and that there are $m$ days in each month. Then, comment on how the variability at Atlanta will be affected by increasing the number of distributors that Atlanta serves.

What probability model would you suggest using to describe the demand data? Why?

What evidence does Table 18 give that end-item demand at smaller customers follows a Poisson distribution?

Perform a statistical test of the data in Table 18 to see if it is reasonable to assume that demand at smaller customers follows a Poisson distribution. An appendix gives details on the test. It is not necessary to test every part number; select three or four part numbers to test.
4. **National Distribution System**

This teaching note is very incomplete. (In fact, all of the remaining teaching notes are far from complete.) Some of the sections are empty. A list of assignments are given, but comments are given for only a few of these.

**Overview**

**Introduction to the Case**

In the first case, we considered how best to ship goods from the Atlanta warehouse to customers in that region. It is clear that some sort of common carrier arrangement is desirable. In this case, we assume that Llenroc ships goods from the central warehouse to the regional warehouses. Then, goods are delivered to break-bulk points where local deliveries are made to customers in the those areas.

In the next case we explored many issues related to the inventory management policies at Llenroc. There we develop some techniques to reduce the variability of orders observed at the regional warehouses. Moreover, we investigate the effects of replenishment frequencies and target fill rates on inventory costs and customer service.

In this case, students must design the national distribution system for Llenroc, including the number, size, and location of regional warehouses. Inventory policies must be set, including the frequency of replenishment and fill rates, by item class. These decisions are driven by economic, customer service, and strategic considerations.

**Learning Objectives**

The specific learning objectives for this case will be determined to some extent by the depth of the material covered thus far. At the very least, we expect students to understand the economic model of warehouse location presented here. With this model as one tool, students will propose and defend a design for a national distribution system on strategic, economic, and customer service grounds.

**Software and its Use**

The Warehouse Location Designer is software that allows students to interactively (and graphically) design the national distribution system for Llenroc. The software derives certain system requirements
from user-specified parameters, and verifies the feasibility of the design. As suggested above, the software contains an economic model used for evaluation of the design. In addition, many performance measures are available to help the students understand the underlying cost and service drivers.

Though the software might seem daunting, the help files are excellent, and it takes most students less than 30 minutes to become proficient. We often walk them through a demonstration of the software. One possible outline for this, which we might distribute to students, is given in the last section of this chapter.

We note that it is easy for students to miss the point of the case. This is avoided if the requirements for the report are comprehensive, forcing them to consider the relevant issues.

THE PRIMARY ASSIGNMENT

The full assignment is given in the last section. In essence, the students must propose a new design for the national distribution, with consideration of strategic, economic, and customer service issues.

Epilog

We point out to students that the real company did, in fact, close warehouses and centralize their stock. It had many of the benefits that they predict in their reports. However, the company did lose business on the west coast as a result of the consolidation because their customers on the west coast perceived this change as one of abandonment: they thought that Llenroc Plastics was leaving the west coast market. Since population growth in the US is concentrated in the southwest, the decision to close a west coast warehouse does have strategic implications.

Class Management

This case brings together issues considered thus far, as well as introducing new ones. It is useful to use this case as a wrap up of the course thus far.

Many students are initially overwhelmed with the apparent demands of this case. 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.

Executive Summary

This is a good opportunity to discuss how to write an effective executive summary with the students. Here is a case of students presenting a radical proposal (eliminating warehouses) to the CEO of a company. The CEO is going to face considerable opposition to implementing such a proposal. What, in a nutshell, are the students providing the CEO to get his attention and anticipate his objections? The executive summary should state the recommendation. Students tend to say things like ”we analyzed the warehouse costs and the transportation plan, etc.” but they never say what the result of this analysis is. Perhaps they are afraid of spoiling the surprise. Then the executive summary should very concisely state the argument in favor of that recommendation. Then the summary should state the estimated impact of the recommendation as concretely as possible: for example, x million dollars profit combined with a reduction in customer wait time to within 10 days. It should do all of this together with a few background statements to position the problem area in a single page.
How Many Warehouses?

As a result of the Case 2 analysis and the Case 3 progress report meeting, most students realize that safety stock requirements decrease as warehouses are eliminated and demand is consolidated in the Nashville warehouse. But, 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.

Three strategies are common: the single warehouse in Nashville, a two warehouse system (Nashville and a facility in the west, either San Francisco or Salt Lake City), and a four warehouse system (Nashville, Chicago, San Francisco, and New York). There are reasonable arguments in defense of each one of these strategies but the students need to make these arguments. One particularly interesting approach is to abandon the western US, concentrating on becoming the "best in the east." The long-term plan under this scenario is to look for a strategic partner to handle the west, or to make the firm a desirable acquisition candidate. Such creative approaches are, however, rare.

Customer Service Issues

Frequently, reports are a disappointment with regard to the customer service dimension. With some exceptions, we don't see in-depth discussions of customer service and innovative ways of serving the customer.

The most common flaw here is to assume that customer service will be great even for a one-warehouse system because the transportation time from Nashville to any other part of the country is only a couple of days. It is true that Nashville is ideally located; but, what is missing from this is the fact that the frequency of shipment also affects the time a customer must wait for product. Even students who understood this expended very little effort in documenting how well a single warehouse can service the country.

Students make no distinction between OEM customers and distributors or between large and small customers. For example, who really needs next-day service? By and large, distributors should be placing replenishment orders and should not require immediate delivery. OEM's should be ordering against a production plan. The only time they would need next day service would be as a result of bad planning. The solution that the company actually adopted was to arrange with nearby distributors to provide emergency shipments to OEM's. The students tend to focus simply on fill rate as the measure of customer service.

Students did do experimentation with the fill rates. A typical shortcoming here is to guarantee very high fill rates for A items (which is easy to do) and only 90% fill rate for B and C items. We point out to students that distributors are likely to be well protected with inventory for the A items as well but poorly protected for B and C items. This results in everyone being out of stock of B and C items on a regular basis. Other teams discover that it really does not cost very much to have 99% fill rate in all items, relative to the other costs that are being considered.

From Inexperience

Students generally do a good job in exercising the software: experimenting with warehouse locations, forming routes, trying different fill rates, and computing costs. However, their general lack of experience is apparent.
They don't translate the cost reductions of centralization into price reductions. They don't compare their performance against Wilson Plastics. They don't discuss the impact EDI might have. (Recall in Case 2 there was a hint that EDI could be quite important for this company.) They don't look at the market analysis that was covered during the introduction to Llenroc Plastics.

There was some confusion between models and reality. Although the economics of the spreadsheet model drive the solution towards closing many warehouses, it is not wise to recommend that warehouses be shut down immediately. The company must embark upon a process of transition which most students ignored. Ask the students to identify which warehouses should be closed in the first year. Atlanta is an obvious choice.

Students also develop some tunnel vision in dealing with the spreadsheet formulation of the problem. For example, if the weekly demand in a city is greater than one truckload they will talk about shipping the difference to that city on a different truck on another route. They do not seem to recognize that this is an aggregate view of a planning problem and that the demand data is a weekly average of an annual total. They treat the routing problem as a deterministic scheduling problem. All that is really important is to get a good estimate of the transportation costs and to understand what the average frequency of shipments to a particular location will be. The average frequency does not need to be an integer.

**Some Miscellaneous Observations**

The effort spent in optimizing transportation routes varied between groups. It is particularly easy to see this effort in the plans for multiple warehouses. For example, when recommending more than one warehouse, students often have material backtrack across the country. For example, if the students plan to serve Texas out of a facility in Salt Lake City, we point out how they are shipping material from Nashville across the Rockies and then from Salt Lake City back across the Rockies to Dallas. This is not efficient.

Some students tried different ABC classifications but often got confused in this. For example, reclassifying all the B items as A items and all the C items as B items got one team into trouble.

Some students talked about the reduction in variance as demand is consolidated when they should have said the standard deviation is reduced.

**UNDERSTANDING THE MODEL**

**Questions**

The SS required at a warehouse is driven by the fill-rate for that location, and the cycle at that location. Explain why.

Look at expected replenishment days. This depends on fill rates at both echelons. Explain the dynamics behind this.

**Comments**

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.

Question
What are the components of the warehouse, transportation, and inventory costs. Pay particular attention to the effect of the number of warehouses. What other factors drive these costs?

Comments: Warehouse Costs

The warehouse operating costs are related to volume. The more warehouses there are, the smaller the volume per warehouse. Inventory policies also drive these costs.

Volume-variable costs vary according to the number of transactions. Constant, from Table 19 at $7.50 / warehouse order placed.

Capacity must be sufficient to carry cycle and safety stock of all items, which is driven by the inventory policies set. Capacity costs exhibit economies of scale.

Note on Table 23a: Fixed Costs. Sales and Dispatcher salaries included. Also management salaries.

See Table 23 b for capacity cost.

Marginal Cost of Capacity as Capacity Increases

![Marginal Cost Graph]

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### Comments: Transportation Costs

The number of warehouses does affect transportation costs. But, since the product must travel from Nashville 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.

**From Bulk-Points to Customers**
Proportional to the sales volume in that sales region. Prices for each region are given in Table 20, but these are unaffected by our decision.

**From Central to Regional**
Long-haul carrier from central to regions. Recall the cost is given in Table 7 (I think this is what we use.???)

**From Regional to Bulk-Points**
Long-haul carrier from region to bulk-point.

Assume full-truck load cost, even if shipping partial trucks.

Cost is determined by the distance between central and region, the trucking rate ($/full truckload-mile from Table 19), and the frequency that trucks are sent from central to the region.

The frequency that trucks are sent, a decision variable, must meet the sales volume in that region. A higher frequency improves the service provided to the region. OR We assume trucks are sent whenever there is sufficient demand in the region to fill a truck. Thus, from the sales volume we can approximate the frequency that trucks must be sent.

Note that the set of possible regional warehouse locations is a sub-set of bulk-points. Presumably, we would send a truck
from central to only one regional warehouse, but a truck from the regional warehouse might service multiple bulk-points.

We can consolidate sales from multiple bulk points, so we can effect the costs according to the routes we choose and the frequency we want those routes to be followed. Tables 21 and 22 give distances.

Comments: Inventory Costs

Specifying an Inventory Policy
Must specify the cycle stock weeks of supply and the safety stock target fill rate for each of the three categories

Pipeline Stock
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.

Cycle Stock
Does the number of warehouses affect the investment in cycle stock? We remind students that in the Distribution Game they had to determine economic order quantities for regional warehouses.

Why, in the Distribution Game, did we only charge $0.04 per dollar-year of inventory at the regional warehouses when computing regional economic order quantities? After all, the full inventory holding cost was $0.24 per dollar-year. 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 (the central warehouse holding cost rate is $0.20 per dollar-year.)

Similarly, for Llenroc Plastics, the total amount of cycle stock in the system is determined by the order quantities placed by the central warehouse. The number of warehouses and the order quantities of 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 modeling transportation and warehousing costs explicitly.) Consequently, cycle stock is unaffected by the number of warehouses.

Safety Stock
Here, we use what we did in case 2. We can estimate the safety stock required to meet a given fill rate for any order quantity. The order quantity is derived from the cycle stock weeks of supply. (See it? Cycle stock weeks of supply is just the order quantity / mean demand rate. Or, the order quantity is just the weeks of supply * mean demand rate.)

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 3.7 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 3.7 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").

CUSTOMER SERVICE

Questions

Make an argument in favor of more warehouses.

Comment

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. We note that that is typically what the marketing department wants to do and that is why Llenroc has so many warehouses.

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.

Wilson Plastics promises delivery within 10 days. 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 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.

Question

One possible inventory strategy to consider is to stock some items only at the central warehouse.

Comments

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. Since the software provides so much performance data, it can be used creatively to approximate the costs and service implications of this 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.

Ask the students how long it takes to drive a truck from Nashville to Maine, or from Nashville to Los Angeles. Long haul carriers put two drivers in a truck so that an 18 hour trip can be accomplished in a single day. Tell the students to look at a road map of the United States to see how many major highways pass through Tennessee.

The last thing to observe is that customer service doesn't have to be measured uniformly. Customers in Montana do not expect the same level of service as customers in Illinois 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.

**USING OPERATIONS RESEARCH**

**Question**

Develop a simpler economic model of warehouse Why, in the Distribution Game, did we only charge $0.04 per dollar-year of inventory at the regional warehouses when computing regional economic order quantities? After all, the full inventory holding cost was $0.24 per dollar-year. 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 (the central warehouse holding cost rate is $0.20 per dollar-year.)

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using optimization techniques which could be used to suggest designs to evaluate in greater detail using the Warehouse Location Designer.
Comment

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THE NATIONAL WAREHOUSE SYSTEM: ASSIGNMENTS

Primary Assignment
Propose a new design for the national distribution system of Llenroc Plastics. Defend your design on strategic, economic, and customer service grounds. You may repeat or modify in case 3 any recommendations you made in earlier cases.

Level of Detail
Include a warehousing plan with regions assigned to warehouses, a transportation plan with routes and frequency of use, an inventory plan with fill rates and lead times for both regional and national warehouses, and a discussion of the customer service implications of the revised distribution system.

If your design involves closing any existing warehouses then provide a discounted cash flow justification for incurring the warehouse termination costs (Table 24). For the discounted cash flow analysis, use the economic assumptions of Table 7.

Format
This should be a formal report in the style that you would use at the completion of a consulting contract with Llenroc Plastics.

Include a 1-2 page executive summary at the beginning of the report that presents a synopsis of the problem situation, the scope and structure of the analysis (an outline of the report), a concise statement of your distribution system design recommendations, and a brief summary of the costs and benefits of your recommendations, preferably in a quantitative form.

The body of the report should be designed to present your distribution system design in more detail and to buttress the arguments for your recommendations.

The text of the report should not exceed 10 pages, double-spaced, in a 12-point font, including the executive summary and any tables, maps, and graphs. This forces you to be selective in terms of the summary information you present to the reader. It is more difficult to summarize effectively than it is to provide detail. If you wish to provide detail, you may use appendices. However, like all readers, we will assume that anything that is interesting or important in the appendices is summarized in the body of the report.

General Questions
Describe how a break-bulk point might operate.
Identify the sales regions with the highest current sales.

Why would you expect the coefficient of variation of weekly demand to be lower nationally than for the Atlanta region (Table 26)?

Comment on the strengths and weaknesses of the model implemented in the Warehouse Location Designer. In particular, identify what performance measures it might overestimate or underestimate.

**Understanding the Model**

What role does the production lead time (Table 19) play in the Warehouse Location Designer? Refer to Appendix I for details.

The production lead time is affected by the frequency of a trip from the central to the regional warehouse. Explain how this works. What else changes as we change the frequency of a trip from the central warehouse? From the regional warehouse to the break-bulk points?

The SS required at a warehouse is driven by the fill-rate for that location, and the cycle at that location. Explain why.

Look at expected replenishment days. This depends on fill rates at both echelons. Explain the dynamics behind this.

What are the components of the warehouse, transportation, and inventory costs. Pay particular attention to the effect of the number of warehouses. What other factors drive these costs?

**Customer Service**

Make an argument in favor of more warehouses.

One possible inventory strategy to consider is to stock some items only at the central warehouse. Customer orders for these items at a regional warehouse could be redirected quickly to the central warehouse. Describe how such a strategy could be implemented. That is, describe how to select items for central stocking and how to satisfy customer orders for these parts in a timely, cost-effective manner. What are the advantages of such a strategy?

**Using Operations Research Techniques**

Develop a simpler economic model of warehouse location and solve it using optimization techniques which could be used to suggest designs to evaluate in greater detail using the Warehouse Location Designer.
INTRODUCTION TO THE SOFTWARE

The steps we will take in our initial exploration are described roughly below.

Load the Llenroc file
This is your access to the main menu items.

Examine the Current Design

*The Current Routes.*
[mode: plan routes]

   [route: show all]

*The Current Cost*
[mode: check assignment]

[mode: check assignment]

Now, we can access the reports.

[mode: view reports]

*The Assignment of Demand to Warehouses*
[mode: assign demand to routes]

Light gray boxes are where you can edit.

Routes down the side. Cities across the top.

Second line gives unassigned demand.

Last columns for policies and effects.

*The Design of the Warehouse*
You can't get here until you have a good route plan.
But, we have already checked that.

[mode: Design Warehouse]

Note that you control fill rates at central and at each warehouse.

Look around.

Make Changes.

*Usual Sequence*
Select warehouse locations.

Assign sales regions to warehouses.

Plan routes.

Assign demand to routes.

Check assignment.

Design Warehouse

Check warehouse design.

*Evaluate*
View reports

modify, evaluate, etc.

*As Always*
Save often, though it is fairly bullet-proof.
5. LLENROC PLASTICS FACTORY TOUR

OBJECTIVES

Understand the layout of the Llenroc Plastics factory, the nature of the production process, and the flow of material. Understand the current production planning, scheduling and control system. Identify objectives for the detailed re-engineering studies to follow and relate these objectives to the overall business strategy.

DISCUSSION QUESTIONS

1. Rolls of Kraft paper are treated in their entirety. That is, a complete roll of Kraft paper will be treated, cut, and stored. For many patterns, only partial rolls of printed paper are treated. The unused portion of the printed paper rolls are returned to raw material storage. Why are printed paper rolls not treated in their entirety?

2. What are the advantages of an MRP II planning system such as used by Llenroc Plastics in comparison with a simpler system that does not forecast demand? Older systems would simply attach order points and order quantities to on-hand inventory levels. In such a system, when on-hand inventory (plus known orders in production) of a particular item falls below an order point, a replenishment order of fixed size would be generated. This is the way much of the distribution system operates. The same system could be applied to finished goods, cut paper, and paper rolls.

3. Identify possible reasons to explain the high degree of production lead time variability experienced in the Llenroc Plastics factory.

4. Relate the problem areas of the next three chapters to the opportunities for business growth (Chapter 1), and the impact that manufacturing performance has on the distribution system (Chapters 2-4).

5. One inventory strategy to consider is to switch to a make-to-stock, make-to-order system. Under this strategy, only certain items would be stocked in finished goods. Production for these items would be controlled by production scheduling techniques similar to those in place now. The remaining items would be produced only when ordered by an OEM or distributor. For such a strategy to be competitive with the service levels provided by other companies (Chapter 1), the production lead times for these make-to-order items would have to be very short. Based on your understanding of transportation and order processing times in the distribution system (Chapter 4), identify the maximum production lead time that could be allowed in order to implement such a strategy.
6. PRESS 7 OPERATIONS

OBJECTIVES

Understand the current operations of the newest, most cost-efficient press. Propose capital investments and changes in operating procedures to increase the capacity and reliability of this press. Justify the recommendations using simulation and economic analysis.

ASSIGNMENTS

1. (Optional: graduate study) Develop a computer simulation model of Press 7 to help answer the questions in the remaining assignments. It is a non-trivial exercise to model the operation of input and output accumulators. An animated simulation model of Press 7 is provided as a software supplement to this case, but the learning experience is more complete if you develop your own model.

2. On average, how many laminates can Press 7 produce per day under current operating conditions? How does the number of laminates produced per day vary from day to day?

3. What improvements would you recommend for implementation to increase capacity and reduce operating costs? By how much will these changes increase capacity over your answer to 2.

4. Justify your recommendations in assignment 3 with an economic analysis. Use the economic assumptions from Table 7. The current average weekly production from Press 7 is 100 press loads. This production target can only be met using expensive weekend shifts.

If your recommendation results in improved yield you should include the annual savings in material cost. Material costs are approximately 18.3 cents per square foot and the average laminate size is 36 square feet.

If your recommendations result in increased capacity, value that increase simply in terms of direct labor savings as follows. Using the throughput rates computed in response to questions 1 and 2, estimate the number of days per week needed to produce 100 press
loads under current operating conditions and under your recommended change. Compute the number of worker-days saved per year based on this estimate and apply the operator salary from Table 28.

Can your recommendations be justified on the basis of material and direct labor savings alone? What other economic costs or benefits would result from implementing your recommendations? How would you quantify these costs or benefits?

5. If your recommendations involve shutting down the press for installation time, describe how the factory is to function with reduced capacity for this period.

CASE 4 FINAL REPORTS

The students should be able to verify using simulation that Press 7 is currently having difficulty meeting a production target of 100 press loads in 5 days. It needs about 6 days to complete this production. When viewed on a daily basis, the current capacity seems to be about 16 press loads per day and there is considerable variability about that average. Most groups simulate the system for one full week; some groups simulated as many as 30 days. Bar charts of daily output illustrate the variability nicely: the press breakdowns create a serious problem.

[1992: Reports differ in the assumptions used within the simulation. For example, some groups assumed 44 carriers while others assumed 47 carriers in the system. Some groups modelled worker breaks in detail using SIGMA, others approximated the breaks using the breakdown feature of XCELL+.] In Fall 1993 at Cornell all students used PRESS7N.XL4.

The investment in new platens is easily justified. The annual material savings is between $210,000 and $220,000 per year, depending on assumptions. The material savings alone are sufficient to justify the investment. The reduction in output variability, and the increase in throughput by eliminating breakdowns are additional benefits. Labor savings varied between student teams due to differing assumptions.

Many students included the cost of downtime to install the equipment as part of the economic analysis. This is fine, but they generally overestimated the cost of downtime by assuming that it represented a period of lost revenue. The point is that if they built up inventory in advance of the shutdown, there would be little, if any, lost revenue. The appropriate cost is the holding cost of the inventory, which is small compared to other costs and benefits of the case.

By including an overestimate of the cost of downtime, some students missed the economic advantages of synchronization and process control equipment.

In evaluating the process control equipment to replace the press operator, many students failed to note that a press operator is required three shifts per day. Therefore, the annual savings are on the order of $75,000 per year, rather than $25,000. Students were generally reluctant to implement the process control equipment. They are unwilling to reduce the work force even when it is clear that an individual is not contributing to the economic well-being of the firm. I point out to them that that individual need not be laid off since many of the teams recommended hiring additional workers in order to keep the presses running during worker breaks.

The students should discover that all the suggested changes in the case should be implemented.
Most students recognized that material would have to be built up in advance of equipment installation. I wrote on each of reports asking them to consider what type of inventory should be built in anticipation of the shutdown (A, B, or C items). During the oral presentations of Case 7, I returned to this question. All the students recognized that it makes most sense to build A items in that situation. They would not have been able to answer this question at the beginning of the course, but they have seen this idea enough times during Llenroc Plastics that it comes very easily to them.

**CASE 4 ORAL PROGRESS REPORT: 1993**

We introduce Case 4 in a laboratory session to demonstrate the simulation software available. Students are required to have read the case prior to coming to lab.

We begin with a review of the issues of the case. There is the clearly stated problem of capacity: the press is only yielding fourteen press loads per day. The company must work weekends to keep up with demand. This causes preventive maintenance schedules to slide. This results in deteriorating equipment. The problems compound. The case mentions that the company is considering acquiring more presses to keep up with demand. In fact, the company purchased another factory in order to acquire this pressing capacity. This created serious financial difficulties for the firm. Analysis such as conducted in case 4 revealed that this investment in pressing capacity was unwarranted.

The problem of the leaky platens is more than just a cost inefficiency. Raise the point that a press load is not a homogeneous collection of laminates. Any given press load will contain A, B, and C type items (part numbers). What happens if the spoiled laminate is an A item? It is no big deal, because inventories of these items are high. What happens if the spoiled laminate is a C item? There is a good chance that there is a customer (probably a distributor) waiting for this item. That item will have to be rescheduled for production. This will likely take several days. Suppose there is no more treated printed paper for that pattern. Then the treater will have to be rescheduled to produce that paper. This could add several days. Furthermore, it can be a day or more before the MRP system (case 6) is notified that the laminate is spoiled. There are all sorts of delays that can happen. This should make clear how a little variability in the production process can create significant variability in the manufacturing lead time and how customer service in the distribution system is affected by that variability.

Before introducing any simulation model, create a "sanity check" using the following simple calculations. The underlined numbers are numbers we ask students to provide. The basic question is "how many press loads could we expect to see produced in a day?" Our analysis is below.
Time per pressload:

Breakdown station:

Avg. time per carrier * # carriers per press load
= 2.65 min. / carrier * 22 carriers / press load
= 58.3 min. / press load

Buildup stations:

Avg. time per carrier * # carriers per press load
+ avg. delay between press loads
= 3.00 min. / carrier * 22 carriers / press load + 7 min. / press load
= 66 min. / press load + 7 min. / press load
= 73 min. / press load

Press:

MTTF = "mean time to fail"
= 8 shifts * 480 min./shift assuming continuous processing
= 3840 min.

MTTR = "mean time to repair"
= 1 shift * 480 min. / shift = 480 min.

Avg. availability = MTTF / (MTTF + MTTR)
= 3840 / (3840 + 480) = 0.89

Avg. processing time per press load
= probability of PB,VD,V4 * 56 min./load
+ probability of OH,OS,O8 * 58 min. / load
= 57 min. / load assuming equally likely construction type

Avg. time per press load
= avg. processing time / load / avg. availability
= 57 min. / 0.89 = 64 min. / load

Maximum processing time per press load
= 73 min. / press load (build-up)

We should see that the press is idle on occasion, waiting for the input accumulator to fill.

Productive time available per shift at buildup station

= time / shift - contracted break time / shift
= 480 min. / shift - 50 minutes / shift = 430 min. / shift

Avg. number of press loads / shift
= Productive time available / 73 min. / press load
= 430 min. / shift / (73 min. / press load)
= 5.89 press loads per shift.

Avg. number of press loads / day
= 5.89 press loads per shift * 3 shifts per day = 17.67 press loads / day
One student asked how the workers would respond to be asked to work through the breaks. In the ensuing discussion, students quickly rejected that idea and generated the idea that extra workers could act as "floaters", relieving other workers to take breaks but keeping the process going.

Yield loss has no essential place in the simulation. We asked the students to compute whether the material cost savings alone would justify the replacement of the platens. The reduction in variability could be presented in their reports in a qualitative discussion.

We explain the nature of the synchronization improvements. The current system has the buildup operators wait for an overhead crane to bring the stainless steel plate from #82 to #32. The synchronization option is simply some automation that brings the steel plate to the halfway point between #82 and #32 where it waits until the operators are ready to position it. This cuts the time per carrier load by almost 30 seconds. The same idea can be applied at the teardown station as well. Is it worth it?

The press control operator sits in a little booth near #15. His task really is very simple and can be replaced with process control equipment. He spends much of his time doing paperwork.

This case can be used as a challenge to students to develop an appropriate simulation model. It is a nontrivial modelling task. Given the time pressure to complete all the cases in one semester, we have now opted to give students a working simulation model of the press. With that, they should have no difficulty in completing the case in one week. The educational objective becomes simply to show students the role that simulation models can play in industrial engineering. The model used at Cornell in Fall 1993 is PRESS7N.XL4, a model constructed using XCELL+. Students can easily vary the processing times at the build-up and teardown stations and the breakdown characteristics of the press. Under development is a Windows 3.1 animation of Press 7 that can be used to conduct the required experiments.

Whatever model is used, part of the lab session is devoted to showing students how to change parameters and how to record daily variation in the number of press loads processed.

The only guidelines offered on the case 4 written report are that it should not exceed 7 pages in length, including a one page executive summary.

CASE 4 ORAL PROGRESS REPORT: 1992

One of the main things to convey to students is the overall lesson of this case, which is that relatively small investments and changes in operating procedures can have a significant impact on capacity. The company upon which this case is based actually purchased another small company in order to acquire that company's pressing capacity. The acquisition cost millions of dollars and was a serious drain on the company's finances. After the fact, the analysis suggested in this case revealed that this acquisition was unnecessary. The existing presses had adequate capacity provided certain improvements were made.

The technical details of the case require a combination of a simulation study and an economic analysis to find the best set of options to recommend. Qualitative recommendations in terms of work force
organization and the handling of press shutdowns are also required.

For the simulation studies, the students may use any simulation package with which they are familiar. Our students use either SIGMA or XCELL+. I help a little with the modelling assumptions that are possible. For example, I first explain the difference between carrier plates and separator plates. There is one carrier plate per carrier and five laminate separator plates. The separator plates get moved by overhead cranes with suction cups from the teardown station (31 in figure 4.1) to a table with rollers (80). From there, the plate rolls to another table (180), then through a cleaner (81) to a final roller table (82). From there, the separator plates are moved by overhead cranes with suction cups to the buildup station (32). Note that there are three tables on which separator plates can sit (80, 180, and 82). The carrier plate is moved directly from the teardown station (31) to a roller table (131) and then to the buildup station (32). Thus, there is only one table for a carrier plate to sit on (they do not stack). I tell the students to ignore simulating the separator plates. The buildup station hardly ever waits for a separator plate. There are times however, when the buildup station waits for a carrier plate. Consequently, the whole simulation can be written in terms of simulating the circulating flow of carrier plates. In XCELL+, table 131 can be modelled as a buffer of 1 unit.

It is tricky in a factory simulation language such as XCELL+ to model a press, which operates on multiple units (carriers) at once. Here is how I explain it: Model the press (10) as a workstation with a single process that draws inventory from an input buffer (capacity 22, the number of carriers in a press load) and deposits it in an output buffer (also with capacity 22). The process is triggered "high" (an XCELL phrase) when inventory in the input buffer hits 22. Once triggered, the process works on carriers one at a time until all 22 units have been processed. Set the time per unit to be the average length of a press cycle divided by 22. Similarly, the next downstream workstation (12) has a single process that is triggered "high" when inventory in the output buffer hits 22. This is the basic idea of how to mimic the press cycle but it could be more complicated to implement. For example, how do you model the steady accumulation of carriers in the input accumulator while the press cycle is in progress? Model the input accumulator (11) as a buffer with capacity 22. Then we need a dummy workcenter between that buffer and the press input buffer that is triggered "high" when the inventory in the press output buffer hits 22 and rapidly processes all the carriers in the input accumulator buffer and puts them into the press input buffer. Table 4.2 suggests that it should take about 7 minutes to move all 22 carriers from the input accumulator into the press. Similarly, model the output accumulator (22) as a workstation that rapidly unloads the press output buffer (using trigger "high") and puts the carriers into a output accumulator buffer. The unload process should take about 7 minutes. Note that both the load and the unload process trigger high on the contents of the press output buffer. A problem could arise if the unload process triggered before the load process so that the number of carriers in the press output buffer immediately dropped below 22. The load process would never again get triggered. Which process gets triggered first may depend on which workstation was entered into the model first. If you suspect that is the case, make sure the load workstation is entered into the model first (deleting workstations and re-entering them, if necessary).

Some student groups report that this approach doesn't work. They introduced an additional buffer with a zero-time workstation and more complicated trigger
rules to make it work. Other groups reported that it did work.

More XCELL+ modelling hints: the movement time from the output accumulator to the teardown station can be modelled by introducing a dummy workstation that represents the material transport step. Also, keep the same process name in all the workstations.

Students ask how long they should run their simulations. I leave this to their judgment, realizing that with only a week to perform the analysis of this case, they will be hard pressed to develop and test a model and make extensive simulation runs of many scenarios.

Students wonder about the option of replacing the press operator. It doesn't seem to affect the performance of the equipment to replace the operator. They are right. Physically, the press operator sits in front of a control panel by station (11) that controls the loading and unloading of the press. The control panel is largely automated. The operator does next to nothing but watch the panel and throw a switch when it is time to begin the next unload/load cycle. That operation can be entirely automated for $45,000. It is obvious that this automation is a money-saver. The point is that some recommendations for improvements come easily. Others need more extensive justification.

The main purpose of the simulations is to estimate the average number of days required to produce the weekly demand of 100 press loads. This is what is needed in the economic justification of the investments. However, we do ask them to look at variability in the output as well. The reason is that in Case 5 students will be trying to eliminate inventory and turn the fabrication room into a just-in-time shop. That will be difficult to accomplish if the output of the presses is highly variable. If the improvements they are making to the presses result in a significant reduction in variability, the benefits to the fabrication room are a qualitative justification for the improvement.
7. FABRICATION AND INSPECTION OPERATIONS

OBJECTIVES

Understand the current fabrication and inspection operations. Propose and defend a new design for the layout and operation of the Fabrication and Inspection Rooms.

DISCUSSION QUESTIONS

1. Can Llenroc Plastics afford the inspection and material costs of a zero defect policy?

2. Identify the points in the production process where production orders could be split with the result that laminates for the same production order end up on different skids prior to sorting at the sanders.

3. Why have the Fabrication and Inspection Rooms been targeted for operational improvements, rather than, say, the Treating Rooms?

4. Comment on the causes and consequences of low worker morale.

PRIMARY ASSIGNMENT

Propose and defend a detailed plan for reducing the operational costs and improving efficiency in the Fabrication and Inspection Rooms. Since the financial situation is extremely tight at this time, you should be especially careful to seek a low cost but effective solution to the problems described above. You are responsible for determining the scale, scope, and methodology for this analysis.

ORAL PROGRESS REPORT: 1993

In the team meetings for this case, I did most of the talking but left some time for questions at the end. I drew the student's attention to the contrast between Table 5.1 and Table 5.4. Table 5.4 could be called engineering data. That is data that specifies what level of productivity the individual operations could achieve. Table 5.1 measures actual performance. The productivity is
that it is between 560 and 880 pounds. The skid cannot be moved out of the way except by forklift truck. If there is no truck available, what should they do? Well, if the next press load has the same dimensions, they will continue stacking laminates on top of the same skid. At some point, a forklift truck comes and moves the skid and replaces it with an empty skid. So, the skid may consist of 21/2 press loads of material. At that point, you have lost "press load integrity." Press load integrity means that all the laminates for a press load move through the remaining operations together. Press loads are now split between multiple skids and each skid has a life of its own.

What problems does this create? Well, at the sanding operation, there is an adjustment to make depending on the desired thickness of the laminates. All laminates in the same press load have the same desired thickness, but a skid consists of laminates from several different press loads. This explains why the sanding operator is counting laminates: he needs to know how deep to go in the stack before changing the thickness setting.

The problem is more serious. Not only have you lost press load integrity but you have also lost production order integrity. Each press load consists of several production orders. A production order is series of identical laminates: all with the same part number and destined for the same customer. For example, a production run could be 75 sheets of Cloud Marble 3x8 for Herman Miller. The customer may be simply the national warehouse: that is, it may be an order to replenish stock in the distribution system. On the other hand, there may be a large customer order that cannot be satisfied from inventory and so a production order is scheduled to cover it. If press loads are split between skids, production orders may be split between skids. Imagine an expeditor who is asking the sanding operator to work
on the Herman Miller order quickly. The operator can locate 25 of the sheets of that production order but cannot find the other 50. It is up to the fork lift truck drivers to track it down. The whole system depends on fork lift truck drivers and they are free to roam around unsupervised.

On the output side of the sanders, the operators are sorting (not inspecting) the laminates onto different skids. For example, the Herman Miller order may be put on a separate skid so that it can be expedited through the remaining process steps. The skids are heavy so once the loading has been completed, the sanding operation must stop until a fork lift truck comes to remove the skids. Once again, material handling problems bring the operation to a standstill.

Because of these inefficiencies at the sanders there is not a continuous flow of material from the trimmers to the sanders. Instead, the fork lift drivers move skids away from the trimmers and find a place to store it. They bring skids out of storage to the sanders as needed. Thus, there is little incentive at the trimmers to work efficiently: their output is simply going to storage and there is no rush for that to happen.

All the student teams accepted this as a plausible explanation for the current behavior of the system. I pointed out that the solution that was implemented had the following features: a continuous flow was established from trimmers to sanders to inspection. Overtime was used to flush the current level of inventory out of the system. A rule of Press Load Integrity was enforced: teardown operators at the presses were not allowed to mix press loads on the same skid; fork lift truck operators were dedicated to the task of removing the skids at the end of each press cycle. Finally, the investment required to implement the changes was very small. The results were dramatic: reduction of inventory, increased productivity at the trimmers and sanders, rapid flow times, and less confusion. I was able to relate these results to the students' experience with Just-In-Time games we had played the week before in lab.

The problem the students face is to design a system that has these characteristics. We ask for a qualitative description of the design. We do not ask for a simulation (in spite of what the text of the case suggests). There was a collective sigh of relief when I announced this.

At this point, I asked the students the difference between a transfer batch and a process batch. Most were unfamiliar with the terminology. I asked them to identify the process batch at the trimmers. They recognized that this was 2, 3, or 4 laminates per process batch, depending on the dimensions. I asked what the process batch size at the sanders was. They answered that the sanders operated on laminates one at a time. I asked what the process batch size at the presses was. Answer: a press load (140 - 220 laminates). Now, in response to the question "what is a transfer batch?" they recognized that it was the number of laminates that transferred at a time from one operation to the next. Currently, the transfer batch size is a skid of material which is several press loads of laminates. If the transfer batch size is changed to a press load, then the number of transfers must increase. Material handling activity must increase. I point out that one of the concerns in switching over to Press Load Integrity was the availability of fork lift truck drivers. So, part of their design should be to estimate the number of material moves that are required, the estimated time requirement for the moves, and the estimated number of people and fork lift trucks required to support this activity. There is little data in the case to support this, but they could measure the
distances from the plant layout and rough out some travel time estimates.

Of course, if they choose to use conveyors, then the transfer batch could be as small as one laminate moving between operations. If they choose this idea, then I ask them to pay close attention to the issue of production order integrity. When a laminate comes out of a sander, how will they know to what customer it is destined? How does information flow in this system? Student teams in the past have done a good job of analyzing material flow but a very poor job of analyzing information flow. They wave their hands and say "a computer system" will track it. I encouraged teams to come to grips with this issue and be specific, avoiding computer solutions if possible ("Could you do it with ping pong balls?").

The design should emphasize low-tech low cost solutions. For example, automated guided vehicles, automatic storage and retrieval systems, computer vision, and bar coding are not appropriate solutions. Simple roller conveyors or carts are allowed. Photoelectric cells to count laminates are also allowed. Moving equipment is discouraged. It is obvious that you should move one of the sanders to be closer to MJ1 but that is costly (the sanders are connected to a blower system that removes the sawdust up through the roof). The point is, can they achieve 80% of the productivity of the ideal solution with minimal investment and minimal delay? Defer equipment moves to a second phase of their proposal. They do not need to estimate the cost of their solution except in rough terms (less than $10,000, less than $50,000, etc.).

If they propose conveyors then note that the transfer batch size affects what weight the conveyor must support: a conveyor that transports a press load at a time must be very rugged. Ask them to worry about turning angles in the conveyor. If it is gravity fed, then worry about the length and drop rate requirements: you couldn't go all the way from sanding to inspection with gravity feed.

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The machine locations on the shop floor are permanent.

The simulation should not be the center of case or discussion. Use simulation as support for recommendations. The use of a computer for the simulation is optional.

[The data in Table 5.4 seen inconsistent with the data in Table 5.1 For example, the time per run batch in practice is 18 min. on average but that doesn't agree with Table 5.4 (7 sec. per process batch, avg. of 3 laminates per process batch [table 5.2], and 140-220 laminates per run). Also, given sanding speeds, the number of sheets per minute at the sanders seems unrealistically high. Also, how many inspection teams are there per shift? Also, if 20% of all inspections are class A, how is it that the average inspection time is 21 minutes. That is mathematically too high given the data of Table 5.4. We will work on these problems this summer.]

The main problem is that the presses, the MJ's, the sanders, and the inspectors are all working independently with the result that there is a lot of work in process inventory. The central problem to attack is the lack of coordination between these areas. It is possible to solve these problems with low-tech, low budget solutions.

Students want guidelines on how much they can spend on this problem. Can they build
shelves, conveyer belts, computer-vision systems, etc.?

Advise them not to unbrick the wall to the inspection room unless they can solve the problem of fork lift truck drivers hitting their masts. They may recommend unbricking the wall if they plan to use conveyors through the opening.

The students should consider the frequency, and variability, at which press jobs finish and get delivered to the fabrication room.
8. MANUFACTURING PLANNING, SCHEDULING AND CONTROL

OBJECTIVES

Understand reasons for the failure of the existing planning and control system. Develop a cyclic scheduling alternative.

DISCUSSION QUESTIONS

1. What changes in the production process and information system would you suggest to solve the problem of database accuracy?

2. How could the treated paper roll-up alternative be used to advantage?

3. The airline analogy has many implications for scheduling the Press Room but these are left for you to explore. For example, what is the advantage of short cycles or of multiple runs of the same job type per cycle? (Contrast the situation of a size-thickness combination that is produced once per cycle in a two week cycle with one that is produced twice a cycle in a one week cycle. Which results in the fastest response time to changes in customer demand?) What does it mean in the Press Room to "manage" the waiting list? What is the smallest acceptable lot size for an item? How far in advance should "tickets" be sold?

4. Are there ways to cope with variation in demand without changing the cyclic schedule and without adding weekend shifts? In what classes of items should stock be concentrated? Be careful not to confuse an A-B-C classification by sheet size and thickness (for scheduling purposes) with the A-B-C classification by part number (Chapters 3 and 4). Inventory, and safety stock in particular, is held in part numbers.

5. What significant changes must occur in the information system to accommodate a cyclic scheduling approach to operating the Press Room? If the cycles are extremely short, then perhaps a kanban system would work (Ref.: McClain, Thomas, and Mazzola [1992]). How will this approach affect operations in the Fabrication/Inspection Room? What impact will cyclic scheduling have upon finished goods inventory? Should it change the way in which lot sizes for items are computed?
THE EQUIPMENT DEDICATION ALTERNATIVE

One of the ideas that arise from studying these tables is the idea of dedicating certain of the presses to specific size and thickness combinations. For example, there is sufficient volume in the 4' x 8' size to dedicate at least one press to this size alone. The advantage of dedicating equipment to certain combinations is that it reduces the time spent in changeovers. To a certain extent, schedulers follow this practice but expedited jobs often force them to deviate from it.

THE CYCLIC SCHEDULING ALTERNATIVE

Another idea is to put the Press Room on a repetitive or cyclic schedule. For example, every Tuesday in the first shift, Press 1 could be scheduled to run press loads for the 3' x 8' OH combination; Press 2 could have the 5' x 12' OH combination, and so on. That is, pre-schedule all the size and thickness changeovers and approximate run lengths for each press for an entire two week period and then repeat that schedule every two weeks. This cyclic schedule could be developed to keep changeovers to a minimum while at the same time retaining sufficient flexibility to respond to the demand variability evident in Table 36. Of course, the schedule would need to be revised if the demand mix for size and type combinations shifted dramatically but it would likely be stable for long periods of time.

Note that production by part number would not necessarily be cyclic. What is repetitive is the schedule of size and thickness combinations by press. Allocating orders for specific part numbers (combinations of size, thickness, and print paper) to press loads would not be according to a fixed schedule. It would depend on actual demand and on orders generated by the MRP system.

The advantages of a cyclic schedule for the Press Room are that equipment utilization should be higher (less time would be lost in changeovers) and the entire production process should become more predictable. If the supervisor of the Fabrication Room knows that every Tuesday there are large runs of 5' x 12' laminates, he or she can be better prepared to accommodate this particular size. Similarly, upstream of the presses, the construction of books and the treating of paper will become synchronized with the Press Room cycle. In particular, if the Press Room schedule calls for a run of 5' x 12' OH laminates then the Preparation Room will create books for that size-thickness combination out of items for which an order has been released and for which paper is available. Note that a cyclic schedule will not solve the database accuracy problem. Nevertheless, organizing the Press Room around pre-defined job types with pre-defined production times should allow most items to proceed through the production cycle in a timely fashion.

To see this, think of a press load of a certain size and thickness combination as an airplane with a scheduled departure time. Ordered items are like passengers who purchase tickets for that plane. Under the current system, the plane waits to leave until all of the passengers who have purchased tickets for that plane have arrived. With the current database inaccuracy, many planes run late and the system as a whole is unpredictable. For a cyclic schedule to work, the planes must leave on time. Therefore, if a passenger cannot catch the plane, the seat should be sold to any passenger on the
waiting list. Passengers who miss the plane must wait for the next available plane. Their waiting time can be as long as one full cycle if the plane they need flies only once per cycle. On the other hand, the passengers who catch their plane arrive at their destination at the time printed on their ticket: their travel time is not a function of the most tardy passenger. Predictability of travel time in general will improve if the planes leave on time. Furthermore, the waiting list can be managed to achieve high utilization.

ASSIGNMENTS

1. Develop a cyclic schedule for the Press Room that both uses the presses efficiently (minimizes changeovers) and achieves a high frequency of job types being produced. That is, it is important to meet the demand targets through efficient use of the presses, but it is also important to keep inventories low by using small lot sizes and to ensure that if an item misses its scheduled production time, it does not have to wait too long before that size-thickness combination is produced again. Note that these can be competing objectives.

Ask the following questions of your schedule:

(a) If demand materializes exactly equal to the mean demands listed in Table 36, how much idle capacity will there be on each of the six presses? Express the idle capacity roughly in terms of the number of additional sheets that could be produced during a week. The greater this idle capacity, the better your schedule will be able to adapt to variation in demand. For each press, compare this idle capacity to the standard deviation of demand in the size-thickness combinations scheduled for that press.

(b) If an item misses its scheduled production time, what is the longest time it would have to await production?

(c) What fraction of total mean demand is scheduled for production only once per cycle?

2. The seventy items in the sample used in Table 26 have been classified into size and thickness combinations in Table 38. For each item in this sample, propose an inventory stocking policy for the central warehouse. Assume that treated printed paper is always available as needed. In your analysis, you will need to estimate the lead time needed for a production order to gain access to an appropriate slot on the cyclic schedule, and to move through the pressing, fabrication, and inspection processes. Table 29 shows processing times in fabrication and inspection. The queue factor in the Fabrication and Inspection Rooms is currently 8.7. (Multiply the processing times by the queue factor to get an estimate of lead times required.) Use a lower factor if you have completed the assignment of Chapter 7.

ORAL PROGRESS REPORT

Discussion 1

Ask the students to describe the problem with database accuracy in their own words. Essentially, there is a mismatch between the information system's view of the world and the actual situation. The inventory of treated printed paper is often less than indicated by the database system due to scrap (the printed paper is brittle and breaks due to excessive handling). There are two possible approaches for improvement. One is to improve the database accuracy. The other is to make the
system less sensitive to errors in the database.

How could the software be changed to make the system less sensitive to database errors? One method would be to allow a more dynamic creation of press loads. The software could indicate production orders for different part numbers and sort them into press load groupings, but it should be possible for the build-up operators to cancel or modify production orders when there are shortages of treated printed paper. The composition of the press load should be determined when build-up is completed and the database tracking of press loads should be updated at that point. Under the current system, there is no way to change the composition of a press load once the computer has issued the paperwork.

What is the problem with treating partial rolls of printed paper? The open rolls collect dirt which contaminates the resin. What are possible solutions? One solution would be to treat whole rolls at a time and re-roll them. The disadvantage with this is that the treated paper is stiff and requires a large diameter roll when re-rolled. There is not sufficient storage space to re-roll every pattern of printed paper. Another solution is to cover the partial rolls of untreated paper with plastic. This simple idea was implemented by the company. A significant improvement in product quality (due to cleaner resin) was noticed soon afterwards. The point here is that simple changes in one part of a manufacturing process (eg. raw material storage) can have significant effects on other parts of the process (eg. laminate quality).

What are the benefits of re-rolling treated paper? It should result in less breakage (sheet storage exposes paper to damage more than re-rolling does). It should reduce cycle counting and estimation problems. The re-rolling process could include a precise way to measure the number of feet wound onto the roll. Unrolling and cutting has a very high yield so the number of feet left on the reel after sheets are cut could be estimated accurately. There should be a reduction in safety stock requirements because cutting to specific lengths would only occur as needed. (Review with students the notion of risk pooling from case 3.)

Because of space restrictions, the idea of re-rolling paper can be applied only selectively. How would the students decide where to apply the idea? Study the derived demand data for the printed paper. (These data are not provided in the case. The question is on how they would proceed with the analysis if the data were available.) Look for situations in which the demand for paper of a certain pattern and width is highly variable across more than one length. This drives a safety stock investment in each length of this pattern/width combination. By re-rolling the paper and cutting to length as needed, there will be a reduction in variability and therefore, a reduction in safety stock requirements. In most patterns, demand is concentrated in a particular length, so re-rolling would have only marginal benefit in terms of reducing safety stock.

Discussion 2

Ask the students to review the analogy of a plane schedule to explain the benefits of a cyclic schedule. In particular, short cycles and frequent runs will reduce cycle stock and improve response times to order placement.

Some ideas for managing the waiting list and lot sizes:

give priority to backorders over replenishment orders
item lot sizes may be extremely small from the perspective of press room scheduling; however, some item lotsizing will probably be induced by the cutting operation if the treated, printed paper is stored in rolls.

the decision of exactly which items will be placed in the next load can be postponed until that load is being built up. Items are chosen from those with available material.

Ask the students to study the demand data in Table 6.1. For any of the items do they notice any trends in the demand data over the four weeks considered? The answer is "no." Now look at Table 6.2. Is the demand highly variable? The answer again is "no." The coefficient of variation is extremely low. This illustrates that when the demand data are aggregated nationally and aggregated by size and thickness classifications the coefficient of variation drops dramatically. This is another illustration of risk pooling. The demand for pressing capacity by size and thickness classification is reasonably stable. If this were not the case, a cyclic schedule probably would not make sense. The students should realize that another aggregation is possible: there are only two thickness/construction types that are relevant for scheduling: the PB, VD, V4 constructions can be grouped together and the OH, O5, and O8 can be grouped together. This will further reduce the apparent variability.

The story we tell of the real company is that there was initially a great deal of skepticism as to the possibility of a cyclic schedule for the press room. However, after the data of Table 6.2 were presented, the chief production scheduler was challenged to develop a cyclic schedule. She did so and was excited by the short cycle length that was possible (it was much less than two weeks). She became an enthusiastic proponent of the idea thereafter. Furthermore, she was fully aware of all the scheduling complications (more than we have presented in this case) and was able to defend her cyclic schedule against the objections of the other schedulers far better than a consultant would have been able to. The purpose of the case is for the students to discover the same sense of possibilities that the chief scheduler did.

There is no software provided for this case. All the necessary calculations can be made using a spreadsheet. Typically, one student in a team will develop the spreadsheet and other students will exercise it.

In Fall 1993, we told the students to concentrate their reports and presentations on Assignment 1 and part 2 of Assignment 2. Discussions 1 and 2 were only to give a flavor of the larger setting for the case. Nothing of these discussions had to appear in the reports.

The students asked whether they could apply ideas from case 4 such as the swing crews to cover presses during breaks. The answer is an emphatic yes. It is not possible to meet the demand otherwise.

CASE 6 WRITTEN REPORT

Assignment 1

1. Production can be scheduled during a normal 5 day week using 3 shifts. There is enough capacity so that at least one press can be idle for one shift on any given day giving us a "free" shift.

2. Swing crews should be used to cover the presses during breaks. The breaks should be staggered so that only a couple of crews are needed. These crews might be responsible
9. INTEGRATION

OBJECTIVES
Integrate and extend the analysis of the previous assignments to create a comprehensive manufacturing and distribution strategy.

ISSUES
The study of Llenroc Plastics began with an analysis of the distribution system and concluded by examining the operation of its manufacturing facility. Each case concentrated on one or more problems that affected Llenroc Plastics' ability to improve customer service or to reduce operating expenses and inventory investment. Each assignment helped to achieve these goals. These incremental changes are important. However, to insure long term profitability, these ideas must be integrated to establish a new and comprehensive manufacturing and distribution strategy. Only by improving communications (both internally and externally), reducing lead times, altering the frequency of shipments and production runs, improving the quality and predictability of its processes, changing operating policies and control systems, and re-configuring and refining its physical infrastructure can Llenroc Plastics succeed in the long term.

ASSIGNMENT
Present a logistics strategy for Llenroc based on velocity, quality and consistency. Specifically, present comprehensive recommendations that establish:

- customer service objectives (types of services, levels of service, marketing goals),
- information system structure (information requirements at each process step, information exchange with customers and suppliers),
- performance measurement systems (ways to assess how well each segment of the system adheres to its planned performance goals, methods to monitor customer service),
- the location and function of each facility (break-bulk points, distribution centers, manufacturing facilities),
transportation system policies and structure (frequency of shipments to each region, routes, modes of transport, lead times),

manufacturing control system (methods for scheduling of jobs and equipment, determining frequency of production runs),

quality management system (methods for detecting and correcting deviations from planned performance targets, ways to insure improvement will continue to occur), and

layout for the manufacturing facility.

Your recommendations should reflect a total systemic viewpoint. Solutions you suggested in earlier cases can be revised at this point. Feel free, however, to use materials you developed earlier. The goal is to create a workable and effective manufacturing logistics strategy that will provide Llenroc Plastics with significant enhancement in service to its customers, reduction in operating costs, and continuous improvements in all aspects of its business activities.

**FINAL REPORT REQUIREMENTS AND GUIDELINES**

The Final Report must not exceed 15 pages, double spaced of textual material. It should include an Executive Summary and an Introduction that includes one paragraph of background description of Llenroc Plastics. You must also hand in copies of all your previous reports (Cases 1-6).

The content of the report is suggested in the description of Case 7. Your major problem is to organize and summarize your strategy for the company. The structure of the report does not have to follow the series of topics listed in Case 7. You may reorganize these topics into a structure that makes sense to you. All the topics are important, however, and you should address them somewhere in your report.

There are two unacceptable extremes that you should avoid. One extreme is a "pep talk" report that is filled with enthusiastic platitudes ("Llenroc Plastics must cut costs, reduce leadtimes, and improve customer service") without a concrete plan to achieve those objectives. The other extreme is a report that gets bogged down in detail (truck routes, economic calculations, Gantt charts, simulation outputs, and so on). Remember that your earlier reports have already covered most of the details. You are handing in copies of those reports as supplements to the final report. This report should summarize the positive steps that you would take to transform Llenroc Plastics into a world-class manufacturing company.

Your audience for this report is the chief executive officer of the corporation. You must offer specific recommendations, describe or quantify the anticipated benefits, explain why the recommendations will create the benefits, and suggest a program of action to implement the recommendations. Anticipate the objections the CEO is likely to encounter in trying to implement your recommendations and give him or her the basic arguments to overcome these objections.

You are comfortable with the detailed analysis you conducted in the first six cases but you are, no doubt, uncomfortable with the less well-defined issues raised in Case 7 (customer service, performance measurement, quality management). You must use your imagination here. Recall that we have talked about different kinds of customers (OEM's, distributors, large customers, small customers) and different markets (specification, direct, residential) and different geographical regions. Does one manufacturing-distribution strategy serve all of these customers and markets equally well? Imagine, too, the possible conflicts if you emphasize customer fill rate as the single performance measurement. For example, does it make sense to measure the press operators on fill rate? For what decisions are they responsible that affect fill rate? Can you design a
performance measure or measures for the fabrication room that guides the individuals in this room to make Llenroc a world-class competitor? Are these measures consistent with the press room performance measures and the dispatcher's objectives? How will you measure overall logistical success?

You are not bound by the solutions you proposed to earlier cases and you may use ideas developed by other teams. Give credit for borrowed ideas. Let's hear the best ideas possible for this company!

**ORAL FINAL REPORTS**

Jotting down notes:

mostly a review of major recommendations to date. We had no oral reports after cases 4, 5 or 6 so we focussed on these recommendations. Case 3 was well taken care of earlier.

space limitations prevent rolling all sizes. what sizes of paper to roll up: answer: low volume widths (3 foot). Refer to table 6.3

how to bar code? a common solution: usually vague "computer systems"

what performance measures to post in fab room, in press room: average time a press load takes to move through, scrap rate

how to measure customer service: what specific questions would you ask customer? Order timeliness, order completeness, response to emergencies

how to enter specification market: since spec orders have long lead time, it suffices only to have extra capacity and wider variety of printed papers. Case 4 indicates that there is excess capacity. Cyclic scheduling (case 6) reveals further excess capacity

scheduling: if a press load is incomplete, what would you produce? answer: an A item or a bit towards a committed specification order in the future.

press shutdown for equipment installation, what inventory would you build up in advance? answer A items.
for material handling and staging when they're not covering breaks. They can also run extra loads during the "free" shift.

3. The longest cycle is at most 3 days. The majority of demand can be produced on dedicated presses or in 1 day cycles. Can eliminate plate changes on all presses except press 7.

4. The two lowest demand groups, PB-VD-V4 36x120 and 36x144, may be left out of the cyclic schedule. Orders for items in these groups may be filled by cutting larger boards, 48x120 and 48x144, which have much higher demand and may be included in the schedule without much difficulty. Alternatively, these categories may be run on press 7 every couple of weeks. If necessary, the "free" shift may be used to cover part of the workload on press 7. In either case, these items constitute such an insignificant fraction of total demand that they should not be allowed to seriously disrupt the production schedule.

Assignment 2

1. The MRP system is no longer used to schedule press loads. The cyclic schedule is fixed and the determination of which items are assigned to a particular load can be made on the floor. Kanbans can be used for the items that are produced on dedicated presses.

2. Fabrication/Inspection will benefit from the predictability of its input from the press room.

3. Demand variation is an extremely important consideration. Extra loads may be run during the "free" shift. Press loads should be as full as possible, especially during low demand periods. Loads may be "tapped off" with "filler" items that have high demand and low variation. The idea is to store this excess production capacity in material that we can expect to sell during peak periods so that additional production capacity will be available for the unstable, lower demand items during those same peak periods.

4. The potential effects of variation can be analyzed in at least two ways. First, we can compare the relative magnitude of the excess capacity of a press with the standard deviation of the daily demand assigned to it. Second, we can plot the (cumulative) daily production capacity versus the (cumulative) daily demand for each of the presses using the four weeks of sales data provided in the case.
DISTRIBUTION SYSTEM DESIGN

The Amos Tuck School
Dartmouth College
Fall 1997

Professor K. Bourland
Room 316, Tuck Hall
646 3579
448 3893 (before 10 PM)

In this course we consider many inter-related problems encountered in the design of a distribution system. These are presented in a series of cases, which lead us through the design of a national distribution system for Llenroc Plastics, a supplier of laminates. Though our focus is on the distribution system, we consider it in the larger context of the supply chain and address issues that might require changes at upstream stages. These production stages are treated in another set of Llenroc cases which we will not consider explicitly in this "mini" course.

These case studies are based on an actual project, and the sequence in which the problems are presented coincides with the sequence in which they were actually confronted. However, many liberties have been taken with the material. Hence, we must consider it a work of fiction.

We will employ an approach to education known as experiential learning. In this approach, the problem receives central attention and the student assumes the responsibility of solving the problem. As the instructor, I do not tell you what to learn. Instead, I provide a structured environment for discovery, and provide guidance and feedback.

The Llenroc materials used in this course were developed by Peter Jackson and Jack Muckstadt of Cornell University. The techniques for experiential learning in general, as well as the specifics of this course, are experimental in nature. Several instructors in the operations field, including myself, are committed to developing and exploring these techniques, and we rely on your feedback to guide us. Please provide feedback throughout the course to help improve the learning experience.
ASSIGNMENTS AND DUE DATES

THE LENROC PLASTICS CORPORATION

Background
Read Chapter 1, “The Llenroc Plastics Corporation,” which gives an overview of the company, its markets and competitors, and the different segments of the supply chain controlled by Llenroc.

Primary Assignment
There is no primary assignment for this chapter; it serves as an introduction.

Class 1 (Monday ??XX)

Discussion Questions
What consequences do you predict if Llenroc Plastics pursues a "business-as-usual" strategy?

How could Llenroc Plastics achieve a growth rate greater than the growth rate of the HPDL market?

Is a new domestic manufacturer likely to enter the market?

What should be the strategic response of a domestic manufacturer if a foreign manufacturer enters the market through an importer?

Do Llenroc Plastics' competitors possess any inherent advantages or disadvantages? If so, how can Llenroc Plastics compensate for competitors' advantages or exploit their own advantage?

What are the principal characteristics of competition in the HPDL industry? That is, on what aspects of competition must Llenroc Plastics focus? What specific performance measures would you use to assess performance and what target values for these measures would you recommend?

In Class
We will meet first in the classroom for a discussion of Chapter 1. Then, we proceed with a discussion of Chapter 2.
THE ATLANTA TRANSPORTATION SYSTEM

Background

Read Chapter 2, "The Atlanta Transportation System." This is the first case in the Llenroc sequence.

Many factors affect customer service at Llenroc Plastics. This case considers cost and customer-service issues in the Atlanta region. The primary issue is how to ship goods from the regional warehouse to the customers so as to achieve good customer service at a reasonable cost—just the opposite of what Llenroc is now achieving. The Atlanta region is considered representative, and hence, this study should suggest improvements applicable to the entire system.

Primary Assignment

Propose a detailed plan to handle transportation needs in the Atlanta region.

You may assume the fill-rate problem (the unavailability of stock to completely fill orders) will be solved by the time your recommendations for the transportation system are implemented. The fill-rate problem motivates many of the remaining Llenroc cases.

This report is due [Class 4].

Class 1 (Monday ??XX)

Discussion Questions
Summarize the major features of the Atlanta warehouse and transportation center and their impact on cost and customer service.

Discuss how the regularity or predictability of the following factors might affect the dispatcher's task: order size, order frequency, order timing (day of week/day of month), order mix (the nature of items ordered), and emergency stock replenishment orders.

Consider the objective that the dispatcher is encouraged to optimize. How would you characterize the routes that are likely to result? What is the likely impact on customer service measures.

It is possible to focus on the transportation time as the primary component of customer wait time. What else must be included?

Assignment

It may be useful to make cost comparisons of strategies for weekly operations that differ in the number of trucks used, the number of miles driven, and the number of driver hours. Build an economic model of transportation costs as follows. Find the equivalent weekly after-tax cost of one truck. Use the economic assumptions in Table 7 to perform the equivalence calculations. Find the after-tax operating cost per mile (that is, compute the total of those after-tax costs that depend on the number of miles driven). Similarly, find the after-tax cost per driver-day (assume a 10-hour day).

Use a discounted cash flow approach for the truck-related costs but not for the mileage or driver costs. The most accurate treatment of truck costs requires an after-tax analysis. Since one cost category is treated after-tax, make sure that all other costs (i.e. mileage and driver) are expressed on an after-tax basis, as well.
You must consider a cash inflow associated with disposing of the truck at the end of its economic life.

You will need to consider the terminal value of the truck in order to compute depreciation. Use the straight-line method of depreciation.

Consider any taxable gain or loss on the sale of the truck.

Assume that truck purchases occur at the beginning of the first year, the tax benefit of depreciation occurs at the end of the year, the truck is sold at the end of the fifth year, and registration and insurance costs are incurred at the beginning of the year.

How will you handle the traffic manager's salary? Do not allocate it to a volume-based measure; keep it as a fixed cost.

In Class
We will discuss the assignment and come to an agreement about the cost figure we will use for the rest of the case. Then play with the software that accompanies this case.

Class 2 (Wednesday ??XX)

Assignment
The instructor or teaching assistant will be in the lab to help with this preparation from ??XX to ??XX on Wednesday.

Use the Transportation Game software to estimate the cost of the current system. The game costs must be scaled, since the simulated shipping requirements for one week represent about two thirds of the actual average weekly demand.

To do this, you must develop a schedule for each truck showing each trip it makes over the five days and, for each trip, what day it leaves the warehouse in Atlanta, which deliveries it makes, in what sequence it makes the deliveries, and what day it returns to Atlanta. Use the various reporting and scoring features of the game to capture key statistics. Present a total transportation cost report for the simulated week.

Your objective is to minimize total cost, subject to the policy constraint that every order must be shipped on the day it is released and the physical constraint that a truck cannot be loaded with orders in excess of its capacity. For discussion purposes, report the maximum number of driver days on any route that you used and the average and maximum number of days a customer had to wait to receive delivery of a picked order.

Allow two days of driving on the weekend. Allow weekend deliveries. Make sure trucks are available for use on Monday and Wednesday of the following week. Otherwise, you will understated the number of trucks your solution really requires.

Assume returning trucks (even after a 2-hour run) cannot be sent out until 2 hours later (i.e. assume 2-hour loading and driver changeover time). Assume a 10 hour day (to be consistent with the graphical version of the Transportation Game.

Don't spend too much time on this assignment. Its purpose is to acquaint you with the dispatching problem and the cost and customer service implication of dispatching.

Discussion Questions
Perform an ABC analysis of customers according to size. Size, in this case, can be measured by the customer's average weekly demand rate for Llenroc Plastic's products, measured in square feet. Plot the results with the cumulative percentage of customers
on the horizontal axis, and the cumulative percentage of sales on the vertical axis.

If there were identifiable patterns to customer orders over time, it might be possible to exploit these patterns to give better delivery service or lower cost. For example, if a group of customers ordered every week the dispatcher could assign one or more trucks to service these customers and put these trucks on fixed routes. However, the dispatcher claims that there is no pattern to the deliveries. What do you think? Do large customers typically place a large number of small orders or do they order infrequently but in large quantities? How regular is the timing of orders?

Explain how it might be possible for the customer ordering behavior to be predictable but the delivery pattern to be chaotic. That is, what features of Llenroc Plastics' distribution system create instability?

How many sheets does Jackson Supplies order per order? What does one of these sheets sell for? Approximately how much money do we make on these orders?

In Class
We will begin in the classroom with a discussion of open issues. Then, we move to the lab to begin preparation of the next assignments.

Class 3 (Monday ??XX)

Assignment
Suppose the policy of shipping product as soon as it becomes available was modified to permit the dispatcher to make better use of the truck capacity. For example, another policy might be to allow the dispatcher to consolidate orders by holding orders up to a maximum number of days with the goal of accumulating enough orders to send a full truckload. What would be the major advantages and disadvantages of this change in policy? Will customers change their order patterns if we practice demand management?

Develop a strategy for dispatching that allows consolidation of orders for up to 5 days. Describe your rational, and use the distribution game to estimate costs.

The Transportation Game does not permit such a change in the rules but you could approximate the impact such a change in policy would have by playing the Transportation Game with a different setting of the order horizon. Order horizon in the game refers to the number of days into the future for which customer orders are known and available for shipping. The current policy corresponds to an order horizon of 1 day (the default setting in the game).

An order horizon of 5 days means that the dispatcher can anticipate customer orders up to 5 days into the future and schedule delivery of any customer order in advance of its due date. (The implicit assumption is that inventory is available to fill these orders.) Since it is a form of demand consolidation, lengthening the order horizon in the game is used as a proxy for simulating a variety of order management strategies.

After changing the order horizon, the “edit shipments” option is used to increase the allocation to a given truck beyond the requirements for the first day. Note that with an order horizon of 5 days, there is no need to “advance to the next day” since we only schedule one week’s demand in the game. Instead, the schedule can be changed and the results obtained without advancing. This facilitates rapid evaluation of several alternatives.

Don’t spend too much time on this. Recognize that there should be a cost
savings to demand management. What is the impact on customer service? If it is negative, can you think of ways to counteract the negative features in order to achieve the cost benefit?

Discussion Questions
Why could a common carrier achieve a lower cost than Llenroc Plastics? After all, they face the same or similar costs of trucks, mileage, and driver.

What impact would the use of a common carrier have on customer service?

Should Llenroc Plastics be in the trucking business? Historically, companies such as Llenroc Plastics set up their own transportation systems because the alternatives were so expensive. The trucking business was deregulated in the early 1980's leading to increased competition and lower trucking rates. Companies that maintain fleets of delivery trucks for their own products now have economic alternatives and should reconsider the design of their transportation systems.

Assignment
Using the simulated total demand data from Table 9, develop an after-tax cost estimate of satisfying all of Llenroc Plastics' transportation needs in the Atlanta region by common carrier. Mileage can be computed using Table 10. The common carrier quote is found in Table 8. (Actual quotes are by hundred weight-mile, but this has been converted to Llenroc Plastics' unit of measure.) Don't try to estimate the cost of disposing of the existing fleet of trucks.

In Class
We will begin in the classroom with a discussion of open issues. This should be a short class.

Time permitting, we will think about relationships that might be generalizable beyond Llenroc.

The instructor will hold open office hours the rest of the evening to help prepare the primary assignment.

Class 4 (Wednesday ??XX)

Turn in Today
The primary assignment is due today. See the report guidelines at the end of this document for additional information.

In Class
Each group will present their recommendations and analysis to the class. Each group will have around one half hour.
THE ATLANTA DISTRIBUTION SYSTEM

Background

The previous case focused on transportation time from the regional warehouse to the customer and the frequency of shipments to the customers, both important factors that affect customer service. Now, we turn our attention to policies at the regional warehouses. The overall purpose of the case is to help you understand why fill rates are so poor at the Atlanta Distribution Center.

The case also offers an opportunity to study many different inventory management issues at a variety of levels. We will consider the roles that lead time uncertainty, product variety, demand uncertainty, and multi-echelon coordination play in distribution system performance.

Primary Assignment

List changes in the operation of the supply chain at Llenroc Plastics that could bring about an increase in customer service and a reduction in inventory investment.

This report is due [Class 8].

The Data

Tables 14 through 18 will be particularly helpful for this case preparation. Some demand data is given by customer, and other is given by item. Some demand is given by the week, by the month, and by the day.

A “customer” is a customer of the Atlanta warehouse. It is easy to get demand for end-items confused with demand observed at the Atlanta warehouse. So, we will use “demand” or “orders” to refer to the demand at the Atlanta warehouse, and “end-item demand” to refer to the demand at Atlanta’s customers.

There is a lot of data here. Before you do anything, become familiar with the tables.

Table 14. Weekly orders and inventory for 70 items.

Table 15. Monthly orders for high-volume items. There are only two items in common with Table 14. Consequently, a meaningful comparison of weekly to monthly is not possible.

Table 16 Monthly orders for high-volume items, from all A customers.

Table 17 Monthly orders for high-volume items, from all B & C customers.

Table 18 Monthly end-item demand for high-volume items at all B & C customer locations. So, this is the actual demand pattern observed at the distributors, aggregated across all of Atlanta’s small customers.

Please note the following. (1) Tables 15 - 18 contain data for a common set of items. However, this set has very few items in common with the set covered by Table 14. (2) Inventory ordering decisions might be made daily, or weekly, but most of the data given here is monthly. Thus, we need to extrapolate to the proper unit of measure when fixing policies. However, so long as we make comparisons between data of common time periods, we can use monthly data to investigate many issues.
Class 5 (Monday ??XX)

Discussion Question
One of the pressures of the business is that the marketing department continues to push for more patterns. Suppose that total demand is fixed (i.e., customers choose between patterns but total demand is unchanged). In this situation, what is the impact of the marketing strategy on the inventory investment required to achieve a desired service level?

Assignment
We begin with a review of inventory theory, applying it to sample items from Llenroc. You will need to review relevant material from the core.

Consider three items from Table 14—Almond D 60x144, Almond P 36x120, and Pigeon Blue PF 48x96. Assume that lead time demand is normally distributed for the first item and Laplace-distributed for the second and third items. Use one or more of these three items to explore various relationships between key determinants of safety stock and fill rate. As a base case, assume that the lead time is two weeks, and that the “weeks-of-supply” covered by the item’s order quantities are 2 weeks, 3 weeks, and 3 weeks, respectively. Relate these relationships to issues from the case. Some specific recommendations are given below.

Plot safety stock as a function of fill rate. Start each plot with a relatively low fill rate.

The fill rate achieved is, of course, affected by the safety stock. More safety stock leads to a higher fill rate. Investigate the relationship between the fill rate achieved and the order quantity (or, equivalently, the order replenishment order cycle).

Consider the first item from Table 14 (Almond D 60x144). Implement a simple fixed-quantity, reorder point model for safety stock. When you design this spread sheet, think about how you might want to use it in the future. Consider cells for the CV of the lead time, the CV of demand per unit time, the length of the lead time, the replenishment order cycle, . . .

In Class
We will work together to resolve any open issues. Then, we move to the lab to play The Distribution Game.

The Distribution Game is a microcomputer game in which the player must manage the inventories in a two-echelon distribution system to maximize profit. Refer to Appendix H for details on game-play. The game parameter file "llenroc.prm" is designed to approximate the situation of the central warehouse in Nashville supplying a low demand rate product (Select Walnut 36x96 in Table 14) to three regional warehouses similar to Atlanta. Interpret the transportation time from the supplier to the central warehouse as the production lead time required to replenish orders at the central warehouse. Interpret the retailers in the Distribution Game as regional warehouses and the customers as OEMs and distributors.

Class 6 (Wednesday ??XX)

Discussion Questions
Examine the inventory control policies in place. Recall the data given in the following table, where safety stock and order quantities are given in terms of the number of weeks covered by that amount (in expectation).

Why would the LT for A-items be smaller? Why would the order quantity be smaller for A items?
<table>
<thead>
<tr>
<th>Assumed LT</th>
<th>Safety Stock</th>
<th>Order Quantity</th>
</tr>
</thead>
<tbody>
<tr>
<td>A 2 weeks</td>
<td>2 weeks</td>
<td>2 weeks</td>
</tr>
<tr>
<td>B 3 weeks</td>
<td>4 weeks</td>
<td>4 weeks</td>
</tr>
<tr>
<td>C 3 weeks</td>
<td>4 weeks</td>
<td>4 weeks</td>
</tr>
</tbody>
</table>

How would you characterize (qualitatively) the lead times that Atlanta faces from the central warehouse?

In the last case, we considered classification of customers according to their sales volume. Now, we must categorize items. As the case notes, Llenroc uses an ABC classification based on item cost. Table 14 gives data for demand in number of sheets and square footage. Categorize these 70 items according to square footage shipped and again on the basis of sheets. Do these results differ? For setting safety stock levels, would you recommend an ABC classification based on square footage or one based on sheets? (Different textbooks give different rules for where to break the parts into A, B, and C categories. You may choose your own breakpoints so long as these are consistent when comparing the two measures of volume.) Note: If time is tight, you may omit this element of the preparation.

**Assignment**
Which items require the most inventory relative to their sales? Using Table 14, create a plot showing the cumulative fraction of total demand (in square) relative to the cumulative fractions of items needed to generate that demand. On the same plot, show the cumulative fraction of total inventory relative to the cumulative fraction of items. Use the sequence of items shown in Table 14. What does the plot tell you about the contrast between where inventory is invested and where revenue is generated?

What is the relationship between the CV of demand and the average demand level at Llenroc? How does the coefficient of variation of lead time demand affect safety stock requirements?

Explain how Llenroc Plastics' current inventory policies (e.g. order and safety stock quantities) might cause a disproportionate amount of inventory to be held for low-demand items. Hint: Suppose A items account for 80% of demand. Write an expression for the cycle plus safety stock for an item based upon the order size and safety stock levels (both measured in weeks of demand). Note: You may consider this “extra credit.” That is, it is optional.

Consider the demand observed by Atlanta’s B and C customers (Table 18). Compare this to the demand observed by Atlanta, from its B and C customers (Table 17).

Consider the demand observed by Atlanta from its B and C customers (Table 17). Compare this to the demand observed by Atlanta from its A customers (Table 16).

Summarize your findings.

**In Class**
We will find our way through this morass of data!

**Class 7 (Monday ??XX)**

**Discussion Questions**
Does the pricing policy cause any problems related to inventory control? Suppose, for example, that an order of 50 laminates for a particular item is equivalent to two months of expected demand by a customer. Furthermore, suppose that there are only a few customers who order this item in large quantities. What problem does the Atlanta
warehouse experience in trying to satisfy orders for this item?

Propose an expansion to the electronic document interchange with customers and with suppliers. Of what value would the additional data be? How would you get the customers and suppliers to participate in the expansion?

Should the practice of sawing laminates to meet customer orders for smaller product sizes be encouraged or discouraged?

Class 8 (Wednesday ??XX)

Turn in Today
The primary assignment is due today. See the report guidelines at the end of this document for additional information.

In Class
Each group will present their recommendations and analysis to the class. Each group will have around one half hour.
THE NATIONAL DISTRIBUTION SYSTEM

Background

In the first case, we considered how best to ship goods from the Atlanta warehouse to customers in that region. It is clear that some sort of common carrier arrangement is desirable. In this case, we make a shared assumption regarding this.

In the second case we explored many issues related to the inventory management policies at Llenroc. There we developed some techniques to reduce the variability of orders observed at the regional warehouses. Moreover, we investigate the effects of replenishment frequencies and target fill rates on inventory costs and customer service.

In this case, we consider the national distribution system for Llenroc, including the number, size, and location of regional warehouses. Inventory policies must be set, including the frequency of replenishment and fill rates, by item class. These decisions are driven by economic, customer service, and strategic considerations.

Primary Assignment

Propose a new design for the national distribution system of Llenroc Plastics. Defend your design on strategic, economic, and customer service grounds. You may repeat or modify in case 3 any recommendations you made in earlier cases.

Include a warehousing plan with regions assigned to warehouses, a transportation plan with routes and frequency of use, an inventory plan with fill rates and lead times for both regional and national warehouses, and a discussion of the customer service implications of the revised distribution system.

If your design involves closing any existing warehouses then provide a discounted cash flow justification for incurring the warehouse termination costs (Table 24). For the discounted cash flow analysis, use the economic assumptions of Table 7.

Class 9 (Monday ??XX)

Discuss Questions
Identify the sales regions with the highest current sales.

Why would you expect the coefficient of variation of weekly demand to be lower nationally than for the Atlanta region (Table 26)?

Comment on the strengths and weaknesses of the model implemented in the Warehouse Location Designer. In particular, identify what performance measures it might overestimate or underestimate.

Assignment

The Warehouse Location Designer is software that allows you to interactively (and graphically) design the national distribution system for Llenroc. The software derives certain system requirements from user-specified parameters, and verifies the feasibility of the design. As suggested above, the software contains an economic model used for evaluation of the design. In addition, many performance measures are available to help you understand the underlying cost and service drivers.
Play around with the software. The instructor or teaching assistant will be available on ??XX from ??XX to ??XX and on ??XX from ??XX to ??XX to assist.

What role does the production lead time (Table 19) play in the Warehouse Location Designer? Refer to Appendix I for details.

The production lead time is affected by the frequency of a trip from the central to the regional warehouse. Explain how this works. What else changes as we change the frequency of a trip from the central warehouse? From the regional warehouse to the break-bulk points?

The SS required at a warehouse is driven by the fill-rate for that location, and the cycle at that location. Explain why.

Look at expected replenishment days. This depends on fill rates at both echelons. Explain the dynamics behind this.

What are the components of the warehouse, transportation, and inventory costs. Pay particular attention to the effect of the number of warehouses. What other factors drive these costs?

In Class
We will discuss the assignment and work together to resolve any open issues. Time permitting, we will move to the lab work on the primary assignment for this case.

Class 10 (Wednesday ??XX)

Turn in Today
The primary assignment is due today. See the report guidelines at the end of this document for additional information.

In Class
Each group will present their recommendations and analysis to the class. Each group will have around one half hour.

Exam Week: Final Report
Each student must individually prepare a final report. This is due on or before ??XX on ??XX. Please turn in two copies. I will return one and keep the other for my files.
REPORT GUIDELINES

The final, individual report, should be a formal report in the style that you would use at the completion a consulting contract with Llenroc Plastics. If you choose, the group reports (the “primary assignments”) may rely heavily on bullet points. However, recall that your final assignment will draw from the three primary assignments from the course. Thus, it may be wise to be as complete as possible on each of these.

Each report should begin with an executive summary that presents a synopsis of the problem situation, a concise statement of your recommendations, and a brief summary of the costs and benefits of your recommendations (preferably in a quantitative).

The body of the reports should be designed to present your recommendation in more detail and to buttress the arguments for your recommendations. The body should be single spaced, with a wide right-hand margin for comments from the instructor. Specifically, use a 1.5 inch top, bottom, and left-hand margin. Use a 3 inch right-hand border. Use 12-point Palatino or Times for the body. Make sure there is a line between paragraphs—do not rely on indentation.

You may use exhibits. However, like all readers, we will assume that anything that is interesting or important in an exhibit is summarized in the body of the report.

Reports will be grades based on many criteria, including creativity, clarity, and the quality, breadth, and depth of the analysis.
# Syllabus (Subject to change if necessary) (Revised as of 4/3/95)

<table>
<thead>
<tr>
<th>Week</th>
<th>Lecture Topics</th>
<th>Room: Lab Topic</th>
</tr>
</thead>
<tbody>
<tr>
<td>Jan 23</td>
<td>M2: Cumulative Flow Plot</td>
<td>4176 Etch: Manufacturing/Operations Game</td>
</tr>
<tr>
<td></td>
<td>W3: Manufacturing/Operations Game Intro</td>
<td></td>
</tr>
<tr>
<td>Jan 30</td>
<td>M4: Basic Inventory Models</td>
<td>4167 Etch: Finish Operations Game</td>
</tr>
<tr>
<td></td>
<td>W5: Wrap-up Inventory Models/Discreet Game</td>
<td></td>
</tr>
<tr>
<td>Feb  6</td>
<td>Homework Due Monday, Feb 6, noon.</td>
<td>4176 Etch: &quot;Trucks&quot; Software Demo</td>
</tr>
<tr>
<td></td>
<td>M6: Llenroc Plastics Case 1 Introduction</td>
<td></td>
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<tr>
<td></td>
<td>W7: Economic Analysis</td>
<td></td>
</tr>
<tr>
<td>Feb 13</td>
<td>M8: How to Hold Meeting / Give Oral Report</td>
<td>4176 Etch: Distribution Game</td>
</tr>
<tr>
<td></td>
<td>W9: Distribution Systems</td>
<td></td>
</tr>
<tr>
<td>Feb 20</td>
<td>M: Presidents' Day Holiday!!</td>
<td>1169 Etch: Case 1 Presentations</td>
</tr>
<tr>
<td></td>
<td>W10: Case 1 Progress Reports</td>
<td></td>
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<tr>
<td>Feb 27</td>
<td>Case 1 Report Due, Feb 27, noon.</td>
<td>No Lab</td>
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<tr>
<td></td>
<td>M11: Case 2 Introduction</td>
<td></td>
</tr>
<tr>
<td></td>
<td>W12: ProbStat Review/Safety Stock Model</td>
<td></td>
</tr>
<tr>
<td>Mar  6</td>
<td>Case 2 Report Due, Mar 6, noon.</td>
<td>4176 Etch: &quot;Warehouse&quot; Software Demo</td>
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<tr>
<td></td>
<td>M13: Case 3 Introduction</td>
<td></td>
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<tr>
<td></td>
<td>W14: Case 3 Introduction</td>
<td></td>
</tr>
<tr>
<td>Mar 13</td>
<td>M15: Case 3 Progress Reports</td>
<td>1169 Etch: Guest Lecture -- Plant &quot;Tour&quot; of Llenroc Plastics</td>
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<tr>
<td></td>
<td>W16: Case 3 discussion</td>
<td></td>
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<tr>
<td>Mar 20</td>
<td>Case 3 Report Due, Mar 20, noon.</td>
<td>4176 Etch: &quot;Press/&quot; Software Demo</td>
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<tr>
<td></td>
<td>M17: Case 4 Introduction</td>
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<tr>
<td></td>
<td>W18: Simulation/Output Analysis</td>
<td></td>
</tr>
<tr>
<td>Mar 27</td>
<td>SPRING BREAK!!</td>
<td></td>
</tr>
<tr>
<td>Apr  3</td>
<td>M19: Kanban Systems</td>
<td>1169 Etch: Cases 1-4 Discussion, Mid-term participation &amp; course evaluations.</td>
</tr>
<tr>
<td></td>
<td>Case 4 Report Due, Apr 5, noon.</td>
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<tr>
<td></td>
<td>W20: Case 5 Introduction</td>
<td></td>
</tr>
<tr>
<td>Apr 10</td>
<td>M21: Case 5 Progress Reports</td>
<td>No Lab (Good Friday)</td>
</tr>
<tr>
<td></td>
<td>W22: Cyclic Scheduling</td>
<td></td>
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<tr>
<td>Apr 17</td>
<td>M: Case 5 Presentations, 2-4 pm, 1169 Etch</td>
<td>F24: MRP Systems</td>
</tr>
<tr>
<td>W:</td>
<td>Case 5 Report Due, Apr 17, noon.</td>
<td></td>
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<tr>
<td></td>
<td>W23: Case 6 Introduction</td>
<td></td>
</tr>
<tr>
<td>Apr 24</td>
<td>M25: Guest Lecture -- Eileen Neary from Motorola: Topic TBA</td>
<td>Extra Office Hours for Case 6</td>
</tr>
<tr>
<td>W:</td>
<td>No Lecture</td>
<td></td>
</tr>
<tr>
<td>May  1</td>
<td>M26: Case 6 Progress Reports</td>
<td>1169 Etch: Case 6 Presentations</td>
</tr>
<tr>
<td></td>
<td>W27: Case 7 Discussion</td>
<td></td>
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<td></td>
<td>Case 6 Report Due, May 8, noon.</td>
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<tr>
<td></td>
<td>Assessment Report Due, May 10, noon.</td>
<td></td>
</tr>
</tbody>
</table>

Final report due at noon on the day of the regularly scheduled final exam period for this course. There is no written final examination for this course.

Late assignment policy: All written assignments are due in my office (4145 Etch) by noon on the day noted above. Late assignments turned in by 2pm on the due-date will be penalized 10%. Late assignments turned in by 4pm on the due-date will be penalized 20%. No assignments will be accepted after 4pm on the due-date.
DEPARTMENT OF INDUSTRIAL ENGINEERING AND ENGINEERING MANAGEMENT

Spring Quarter 1995

Professor R.C. Carlson

REENGINEERING THE MANUFACTURING FUNCTION
IE 265

**Week 1 (April 3-7)**
- Apr 4 Tue 1 hour Course Introduction
- Apr 6 Thur 1 hour How to Hold a Meeting / How to Give an Oral Report
- Apr 6 Thur 2 hours Material Flow and Manufacturing/Operations Game Introduction

**Week 2 (April 10-14)**
- Apr 11 Tue 2 hours Manufacturing/Operations Game
- Apr 13 Thur 3 hours Manufacturing/Operations Game

**Week 3 (April 17-21)**
- Apr 18 Tue 2 hours Llenroc Introduction/Basic Inventory Models
- Apr 20 Thur 2 hours Trucks software demonstration

**Week 4 (April 24-28)**
- Apr 27 Thur 3 hours Plant Tour

**Week 5 (May 1-5)**
- May 2 Tue 2 hours Case 1 Progress Reports/Distribution Systems
- May 4 Thur 2 hours Distribution Game

**Week 6 (May 8-12)**
- May 9 Tue Case 1 Report due at 11:00 am
- May 9 Tue 1 hour Calculations for Distribution Game and Sensitivity to Variability
- May 9 Thur 1 hour Case 1 Presentations
- May 11 Thur 2 hours Probability and Statistics Review/Case 2 Introduction

**Week 7 (May 15-19)**
- May 16 Tue 2 hours Case 3 Introduction
- May 18 Thur 2 hours Warehouse software demonstration

**Week 8 (May 22-26)**
- May 23 Tue Case 2 Report due at 11:00 am
- May 23 Tue 1 hour Case 3 Progress Reports
- May 23 Tue 1 hour Case 4 Introduction
- May 25 Thur 1 hour Case 3 Discussion
- May 25 Thur 1 hour Simulation/Output Analysis

**Week 9 (May 29 - June 2)**
- May 30 Tue Case 3 Report due at 11:00 am
- May 30 Tue 2 hours Press 7 software demonstration
- June 1 Thur 2 hours Cases 1-4 Discussion

**Week 10 (June 5-9)**
- June 6 Tue Case 4 Report due at 11:00 am
ORIE 416/515
Design of Effective Manufacturing Systems
4 credits
Fall, 1993

Faculty:
John A. Muckstadt, Professor and Director
School of Operations Research and Industrial Engineering
E&TC 214
255-9123

Peter L. Jackson, Associate Professor
E&TC 218
255-9122
e-mail: pj16@cornell.edu
Office Hours: W,F 1:15-2:15 p.m. or by appointment (afternoons). Use e-mail to suggest appointment times.

John M. Jenner, Senior Lecturer, Cornell, and Partner, ChangeLab International.
E&TC 274

Teaching Assistants:
Felipe Sardi (ORIE 416)
Carolyn Torras (ORIE 416)
Juan Pereira (ORIE 515)

Meeting Times:
Lecture: T,R 1:10-2:25 p.m. HO314
Lab: OR416 (Seniors) R 2:30-4:30 p.m. E&TC 253
ORIE515 (Grads) F 2:30-4:30 p.m. E&TC 253
+ Weekly team meetings

Prerequisites:
ORIE 410 or graduate standing. ORIE416 enrollment is limited to seniors. ORIE 515 enrollment is limited to graduate students. Course involves the application of operations research methodologies at a basic level but the focus is on issues in manufacturing system design. Familiarity with spreadsheet software and graphical operating systems is assumed.

Purpose:
To give students an experience in the design of an integrated manufacturing and distribution system.
Topics:

Methodology:
Team-based case study analysis and design activity resulting in oral and written presentations. Cases are structured to present context, raise issues, suggest approaches, and specify design parameters. Cases are supplemented with lectures on related topics (see above list). Microcomputer games and modeling tools are an integral part of the analysis and design activity. Team building skills and an awareness of group dynamics are stressed.

Course Materials:
Packet of reproduced materials from Campus Publishing. Purchase at Campus Store. Packet includes manufacturing game description, case study (Llenroc Plastics), most lecture notes, and supplementary readings. Custom software will be loaded on ORIE network drive and supplied to Hollister 172. Non-proprietary software may be copied and used on home computers.

Microcomputer Resources:
Engineering College PC lab in Hollister 172. Graduate students will have controlled access to Upson 360 ORIE Master of Engineering lab. Report abuse of access to T.A.'s. Teaching lab in E&TC 253 is reserved for faculty-directed activities.

Grading:
Letter grade only. Emphasis on teamwork extends to grade sharing. Each written and oral presentation is assigned a grade. Each team member receives the same grade for the presentation except under exceptional circumstances. Failure to assume a fair share of the workload within a team, as established by attendance and peer evaluations, will result in a lower individual grade and could be grounds for a failing grade in the course.

A significant portion of the grade is based on individual performance. There are no written examinations. Attendance will be used to measure a student's degree of involvement in the course. There is one homework assignment. Each student is responsible for organizing one team meeting and submitting a report detailing the agenda, attendees, and resulting conclusions and action items of that meeting. Each student is required to articulate the principal lessons learned from the course in the form of an assessment report. To encourage candid responses, the identity of the report author will be hidden from the grader. Finally, a portion of the grade is reserved to measure each student's intellectual contributions to the presentations and discussions.
Grading Weights (Tentative: subject to revision based on evolution of course):

Team-Based
15% Case 1 Presentations
3% Case 2 Presentations
10% Case 3 Presentations
10% Case 4 Presentations
15% Case 5 Presentations
15% Case 6 Presentations

Individual
2% Lecture Attendance
2% Homework Assignment
10% Participation in the Manufacturing Operations Game
2% Lab Attendance
3% Meeting Report
3% Grader-blind Assessment Report
10% Intellectual Contribution

Feedback:
Experiential learning is fundamentally different from traditional teaching methods in engineering. In experiential learning, we do not tell you what to learn. Instead, we provide a structured environment for discovery. The techniques for experiential learning are experimental in nature. We are committed to developing and exploring these techniques and we rely on your feedback to guide us. There will be several opportunities for you to provide anonymous critiques of different aspects of the course. Please treat these opportunities seriously and give thought to what you are learning and how you are learning it. The final assessment report will force you to articulate the impact of the course on your own professional development.
ORIE 416/515  
Design of Manufacturing Systems  
Fall, 1993

Tentative Schedule

<table>
<thead>
<tr>
<th>Week</th>
<th>Week of</th>
<th>Lecture Topics</th>
<th>Lab Activity</th>
<th>Faculty</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Aug. 22</td>
<td>Introduction</td>
<td>canceled</td>
<td>Jackson</td>
</tr>
<tr>
<td>2</td>
<td>Aug. 29</td>
<td>Material logistics/Group Dynamics</td>
<td>canceled</td>
<td>Jackson/Jenner</td>
</tr>
<tr>
<td>3</td>
<td>Sept. 5</td>
<td>Fundamental models/Manufacturing Operations Game Intro</td>
<td>Manufacturing Operations Game</td>
<td>Jackson/Jenner</td>
</tr>
<tr>
<td>4</td>
<td>Sept. 12</td>
<td>Fundamental models</td>
<td>Finish Operations Game (in evening if necessary)</td>
<td>Jackson/Jenner</td>
</tr>
<tr>
<td>5</td>
<td>Sept. 19</td>
<td>Llenroc Plastics Case 1 Intro</td>
<td>&quot;Trucks&quot; Software demo</td>
<td>Jackson</td>
</tr>
<tr>
<td>6</td>
<td>Sept. 26</td>
<td>Manufacturing Information Systems/ Distribution Systems</td>
<td>Distribution Game</td>
<td>Jackson/Muckstadt</td>
</tr>
<tr>
<td>7</td>
<td>Oct. 3</td>
<td>Material Requirements Planning / Case 2 Intro</td>
<td>Oral Presentations of Case 1</td>
<td>Jackson/Muckstadt</td>
</tr>
<tr>
<td>8</td>
<td>Oct. 10</td>
<td>Fall Break/ Case 3 Intro</td>
<td>&quot;Warehouse&quot; Software demo</td>
<td>Jackson</td>
</tr>
<tr>
<td>9</td>
<td>Oct. 17</td>
<td>Case 3 Progress Reports / Scheduling</td>
<td>&quot;CGANTT&quot; Software demo</td>
<td>Jackson</td>
</tr>
<tr>
<td>10</td>
<td>Oct. 24</td>
<td>Factory &quot;Tour&quot; / Case 3 Discussion / Case 4 Intro</td>
<td>&quot;Press7&quot; Software demo</td>
<td>Muckstadt/Jackson</td>
</tr>
<tr>
<td>11</td>
<td>Oct. 31</td>
<td>Kanban systems / Case 5 Intro</td>
<td>Cyclic Scheduling Game</td>
<td>Muckstadt</td>
</tr>
<tr>
<td>13</td>
<td>Nov. 14</td>
<td>Case 6 Intro / Observational Studies</td>
<td>Observational Studies</td>
<td>Jackson/Heath</td>
</tr>
<tr>
<td>14</td>
<td>Nov. 21</td>
<td>Progress Reports / Thanksgiving Break</td>
<td>Thanksgiving Break</td>
<td>Jackson/Muckstadt</td>
</tr>
<tr>
<td>15</td>
<td>Nov. 28</td>
<td>Progress Reports / Case 7 Discussion</td>
<td>Case 6 Oral Presentations</td>
<td>Muckstadt/Jackson</td>
</tr>
</tbody>
</table>
ORIE 416/515  
Design of Manufacturing Systems  
Llenroc Plastics Case 1 Schedule

Team Formation
You must organize yourselves into teams by Thursday, September 23.
   Guidelines:  6 people per team.  
               Interdisciplinary.  
               Graduate/Senior segregation.  
   Teams will be unchanged for all six Llenroc Plastics cases (i.e. for the balance of semester).

Submit a list of your proposed team members in lecture on Thursday.  
For each team member, indicate Graduate/Senior and program.  
Indicate chief contact member of team with e-mail address.

Case 1 Schedule
Read Introduction and Case 1 of Llenroc Plastics by Thursday.
Thurs. Sept. 23, Lecture: Introduction to Llenroc Plastics
Thurs., Sept. 23 and Fri. Sept. 24, Lab: Demo of Trucks Software
Tues. Sept. 28. Lecture: Cancelled
Tues. Sept 28 thru Wed. Sept. 29, Special Office Hours: Case 1 Oral Progress Reports
               (come prepared to answer Discussion questions in Case 1). Sign-up list will be
               posted on Professor Jackson's door. We will meet with two teams per session.
Tues. Oct. 5, 4:00 p.m. Written reports for Case 1 due. Guidelines attached.
Wed. Oct. 6-Fri. Oct. 8, Special Office Hours: Case 1 Oral Final Reports

Meeting Leaders
Each student in ORIE 416/515 must plan, lead, and report on one team meeting. Each case will require several team meetings so there will be many opportunities to satisfy this requirement.
For Case 1, two students must submit meeting reports attached to the Case 1 Final Written Report.

Content of Meeting Report:
Name of meeting leader
Date, Time, Place of Meeting
Pre-arranged agenda
Attendees
Brief synopsis of what was discussed
Action items and individuals responsible
Date, Time, and Place of next meeting.
<table>
<thead>
<tr>
<th>Week</th>
<th>Week of (Sun.)</th>
<th>Lecture Topics</th>
<th>Lab Activity</th>
<th>Reports</th>
<th>Faculty</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Aug. 27</td>
<td>Supply Chain Mgmt.</td>
<td>Overview of Ind. Sys. Analysis</td>
<td></td>
<td>Jackson/ Muckstadt</td>
</tr>
<tr>
<td>2</td>
<td>Sept. 3</td>
<td>Material Logistics/ Operations Game Intro</td>
<td>Manufacturing Operations Game</td>
<td></td>
<td>Jackson/ Jenner</td>
</tr>
<tr>
<td>3</td>
<td>Sept. 10</td>
<td>Llenroc Plastics Intro/ Case 1 Intro/ Trucks Software Demo</td>
<td>Finish Operations Game (in evening if necessary)</td>
<td></td>
<td>Muckstadt/ Jackson</td>
</tr>
<tr>
<td>4</td>
<td>Sept. 17</td>
<td>Group Dynamics/ How to Give an Oral Report</td>
<td>Case 1 Progress Reports</td>
<td>Lessons Essay Sept. 21</td>
<td>Jenner/ Jackson</td>
</tr>
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<td>5</td>
<td>Sept. 24</td>
<td>Fundamental Models</td>
<td>Case 1 Oral Presentations</td>
<td>Case 1. Sept. 26</td>
<td>Jackson</td>
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<td>6</td>
<td>Oct. 1</td>
<td>Distribution Systems/ Case 2 Intro</td>
<td>Distribution Game</td>
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<td>7</td>
<td>Oct. 8</td>
<td>Distribution Systems/ Case 3 Intro</td>
<td>Warehouse Location Designer Demo</td>
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<td>8</td>
<td>Oct. 15</td>
<td>How to Take a Factory Tour/ Case 4 Intro/ Press 7 Demo/ Cups Game Video</td>
<td>Cups Game Redesign Challenge</td>
<td>Case 2. + Hmwk Oct. 17</td>
<td>Jackson/ Muckstadt</td>
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<tr>
<td>9</td>
<td>Oct. 22</td>
<td>Llenroc Plastics Factory Tour/ Role of Variability</td>
<td>Cups Game Simulation</td>
<td>Case 3. Oct. 24</td>
<td>Jackson/ Muckstadt</td>
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<td>10</td>
<td>Oct. 29</td>
<td>Continuous Flow Manufacturing/ Business Systems Reengineering/ Case 5 Intro</td>
<td>CGANTT Cyclic Scheduling</td>
<td>Case 4. Nov. 2</td>
<td>Holden/ Jackson</td>
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<tr>
<td>11</td>
<td>Nov. 5</td>
<td>Manufacturing Planning, Scheduling and Control</td>
<td>Cyclic Scheduling Game</td>
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<td>Muckstadt</td>
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<td>12</td>
<td>Nov. 12</td>
<td>Manufacturing Planning, Scheduling &amp; Control/ Case 6 Intro</td>
<td>Case 5 Oral Presentations</td>
<td>Case 5. Nov. 14</td>
<td>Muckstadt</td>
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<td>13</td>
<td>Nov. 19</td>
<td>Case 6 Progress Reports</td>
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<td></td>
<td>Jackson / Muckstadt</td>
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<tr>
<td>14</td>
<td>Nov. 26</td>
<td>Case 6 Progress Reports</td>
<td>Hmwk Nov. 30</td>
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<td>Jackson / Muckstadt</td>
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<tr>
<td>15</td>
<td>Dec. 3</td>
<td>Case 7 Discussion</td>
<td>Case 6 Oral Presentations</td>
<td>Case 6 Dec. 5 Lessons Dec. 8</td>
<td>Muckstadt / Jackson</td>
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<td>Week</td>
<td>Week of (Sun.)</td>
<td>Lecture Topics</td>
<td>Lab Activity</td>
<td>Reports</td>
<td>Faculty</td>
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<tr>
<td>1</td>
<td>Aug. 25</td>
<td>The Engineering Mentality</td>
<td>Overview of Ind. Sys. Analysis</td>
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<td>Jackson</td>
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<td>2</td>
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<td>Supply Chain Mgmt./ Operations Game Intro</td>
<td>Manufacturing Operations Game</td>
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<td>Roundy/Jenner</td>
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<td>3</td>
<td>Sept. 8</td>
<td>Fundamental Models</td>
<td>Finish Operations Game (in evening if necessary)</td>
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<td>Jackson</td>
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<td>4</td>
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<td>Fundamental Models / Cups Game Video</td>
<td>Cups Game Redesign Challenge</td>
<td>Lessons Essay Sept. 21</td>
<td>Roundy/Jenner</td>
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<tr>
<td>5</td>
<td>Sept. 22</td>
<td>Numetrix Speaker / Role of Variability</td>
<td>Multi-Panel Simulation</td>
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<td>Guest/Jackson</td>
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<td>6</td>
<td>Sept. 29</td>
<td>Business Process Re-engineering/ Manufacturing Planning, Scheduling and Control</td>
<td>Cyclic Scheduling Game</td>
<td>Hmwrk 1 Oct. 2</td>
<td>Jackson/Roundy</td>
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<td>7</td>
<td>Oct. 6</td>
<td>Manufacturing Planning, Scheduling and Control</td>
<td>Cyclic Scheduling Exercise</td>
<td>Multi-Panel Oct. 9</td>
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<td>8</td>
<td>(Break) Oct. 13</td>
<td>No B/C Stock Policy</td>
<td>Michigan Integrated Logistics Simulator</td>
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<td>9</td>
<td>Oct. 20</td>
<td>How to Write a Project Proposal/ Velocity Kickoff</td>
<td>Velocity Training</td>
<td>Cyclic Sched. Oct. 23</td>
<td>Jackson/Roundy/Muckstadt</td>
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<tr>
<td>10</td>
<td>Oct. 27</td>
<td>Manufacturing Economics</td>
<td>Velocity Factory Operations</td>
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<td>Jackson</td>
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<tr>
<td>11</td>
<td>Nov. 3</td>
<td>Demand and Operations Analysis</td>
<td>Velocity Financials</td>
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<td>12</td>
<td>Nov. 10</td>
<td>Group Dynamics</td>
<td>Progress Reports</td>
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<td>Jenner</td>
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<td>13</td>
<td>Nov. 17</td>
<td>Guest lecture: Logistics</td>
<td>Progress Reports</td>
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<td>14</td>
<td>(Break) Nov. 24</td>
<td>How to Give an Oral Report</td>
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<td>Dec. 1</td>
<td>Final Presentations</td>
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<td>Velocity C.A.R.</td>
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</table>
### ORIE 416/515
**Design of Manufacturing Systems**
**Fall, 1997**
**Schedule**

<table>
<thead>
<tr>
<th>Week</th>
<th>Week of (Sun.)</th>
<th>Lecture Topics</th>
<th>Lab Activity</th>
<th>Reports</th>
<th>Faculty</th>
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</thead>
<tbody>
<tr>
<td>1</td>
<td>Aug. 25</td>
<td>Introduction; the Business Environment</td>
<td>Overview of Ind. Sys. Analysis</td>
<td>Velocity and other readings</td>
<td>Muckstadt</td>
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<td>3</td>
<td>Sept. 7</td>
<td>Roles of Inventory / Variability Experiments</td>
<td>Velocity Factory Operations</td>
<td>Inventory Readings</td>
<td>Jackson / Muckstadt</td>
</tr>
<tr>
<td>4</td>
<td>Sept. 14</td>
<td>Review of Gameplay / Financial Analysis</td>
<td>Velocity Financial Simulator</td>
<td>Inventory Assignment</td>
<td>Muckstadt / Jackson</td>
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<td>5</td>
<td>Sept. 21</td>
<td>Inventory Models / Capital Investment</td>
<td>Velocity Progress Reports</td>
<td>Financial Problems</td>
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<td>Inventory and MRP / How to Give an Oral Report</td>
<td>MRP Assignment</td>
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<td>Muckstadt / Jackson</td>
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<td>7</td>
<td>Oct. 5</td>
<td>Group Dynamics / Oral Reports</td>
<td>Velocity Oral Reports</td>
<td>Team Readings</td>
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<td>8</td>
<td>Oct. 12</td>
<td>Review of Velocity Reports and Concepts</td>
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<td>Muckstadt</td>
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<td>9</td>
<td>Oct. 19</td>
<td>Multi-Stage Inventory Models / Overview of MILS</td>
<td>Michigan Integrated Logistics Simulator #1</td>
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<td>Jackson / Muckstadt</td>
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<tr>
<td>11</td>
<td>Nov. 2</td>
<td>Information Systems / Velocity: 2 years later</td>
<td>Production Scheduling Gameplay #1</td>
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<td>Murray / Muckstadt</td>
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<tr>
<td>12</td>
<td>Nov. 9</td>
<td>Gameplay Debrief / Demand Analysis</td>
<td>Demand Analysis Assignment 1</td>
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<td>Muckstadt / Slate</td>
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<td>13</td>
<td>Nov. 16</td>
<td>Velocity Simulation Trial</td>
<td>Production Scheduling Gameplay #2</td>
<td>Assignment #2</td>
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<td>Nov. 23</td>
<td>Final Presentations</td>
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<td>Prod’n Control Sys. Report</td>
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<td>Nov. 30</td>
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</table>
Confidential Peer Evaluation of Student Contributions

Peer evaluation is a critical aspect of team-based education. You must complete this form in order to receive a grade.

In the table below, score the contribution of each member of your team, including yourself, for each of the five categories indicated. Make allowance for a reasonable number of plant trips and other commitments. In scoring yourself, estimate the average score your teammates would assign to your contribution. Use the following scoring system:

<table>
<thead>
<tr>
<th></th>
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<th>2</th>
<th>3</th>
<th>4</th>
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<tbody>
<tr>
<td>Unsatisfactory</td>
<td>Adequate</td>
<td>Excellent</td>
<td></td>
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</table>

**Contribution Categories:**
A. Overall Contribution: Is this individual a critical reason for your team's success?
B. Level of Effort: Did this individual carry a fair share of the workload?
C. Contribution to Reports: Was this individual an important contributor in preparing text and graphics for presentation?
D. Effectiveness as a Team Member: Did this individual attend meetings, participate in discussions, cooperate with team strategies, and coordinate their activities with you? Was it pleasant to work with this individual?
E. Leadership: Did this individual initiate discussions, generate enthusiasm, build a consensus, and organize your efforts?

*Note: a score of less than adequate (3) in any category may reduce that individual's grade from the team average.*

<table>
<thead>
<tr>
<th>Team Member</th>
<th>A. Overall</th>
<th>B. Effort</th>
<th>C. Reports</th>
<th>D. Team-Play</th>
<th>E. Leadership</th>
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</thead>
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</table>

Other confidential comments related to team member contributions: