Dorfman, Paul Samuelson, and Robert Solow published their landmark book *Linear Programming and Economic Analysis* (McGraw-Hill Book Company, 1958). (Two of these authors would later win the Nobel Memorial Prize in economic science.) In 1975, the Nobel Memorial Prize in economic science was awarded to Tjalling Koopmans and Leonid Kantorovich specifically for the application of linear optimization to economic science.

The next significant event in the development of linear optimization took place in 1984, when Dr. Narendra Karmarkar of AT&T Bell Laboratories developed a radically different and more efficient method for solving linear optimization problems using what is now called the "interior-point method." News of Dr. Karmarkar's algorithm was reported on the front page of the *New York Times*, as well as in the *Wall Street Journal*, *Time* magazine, and in other major periodicals around the world. Interior-point methods are now used to solve gigantic linear optimization problems (that is, problems with ten million decision variables or more). Today, managers and scientists routinely solve linear optimization models with thousands of constraints and decision variables on their personal computers. Larger computers are used to solve problems with one million decision variables or more.

7.9 CASE MODULES

SHORT-RUN MANUFACTURING PROBLEMS AT DEC

Introduction

Digital Equipment Corporation (DEC) is the world's leading manufacturer of network computer systems and associated peripheral equipment and is the industry leader in systems integration with its networks, communications, services, and software products. Recent annual revenues were over $12 billion. Two-thirds of the revenue is derived from hardware sales and one-third is from software sales and services.

Successful introduction of new computer hardware products is important in the competitive computer industry. Rapid advances in chip technology have caused product life cycles to be short and steep, typically 2-3 years. Transitions from older products to new products must be carefully planned and executed. Both production shortfalls and obsolescence expense must be avoided.

The case before us examines one aspect of introducing and "ramping" a major new computer hardware product family. In the industry jargon, "ramping" refers to bringing a product into full production and sales.

Organization

The Manufacturing organization is comprised of several segments, see Figure 7.17. The External Procurement and Chip groups are responsible for supplying hardware components to internal (i.e., in-house) manufacturers of saleable (i.e., final) computer products. The Memory and Disk groups are responsible for supplying products that are either sold

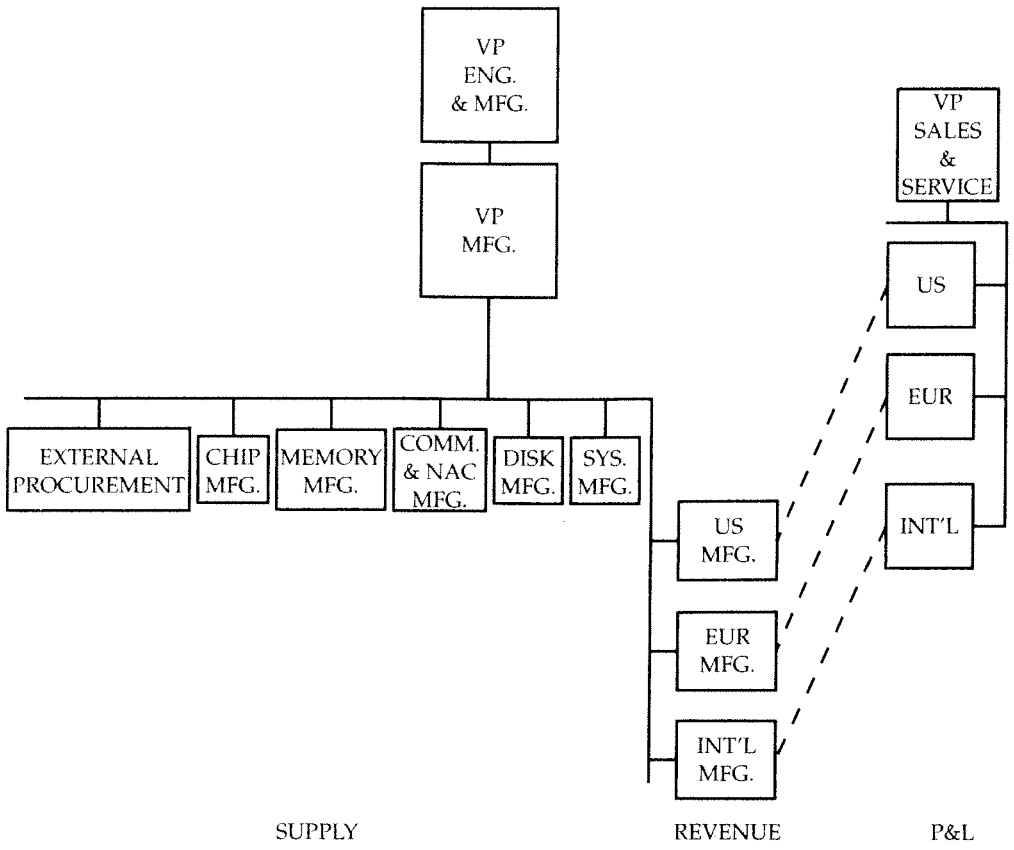

FIGURE 7.17
The Manufacturing organization at DEC.

separately as "add-ons" to customers' computer systems (such as extra hard disks or additional memory) or are used by the in-house computer System manufacturers. The computer System groups manufacture completely configured computer systems for sale to customers.

The Geographic Manufacturing groups are responsible for generating shipments to customers. They are the interface between Field groups and Manufacturing groups. It is their job to ensure that demand and supply are in balance and that orders are properly filled.

The Sales & Services organization (Field) generates sales and is responsible for the company P&L (profit and loss).

The Corporate Demand/Supply organization has an oversight role and ensures integration across the diverse Manufacturing and Field organizations.

Background

A new family of general purpose computer systems and workstations was announced in Q2-1988 (i.e., second quarter, 1988). (See Table 7.15 for a brief description.) This family represented a significant price/performance improvement over the existing products. Customer acceptance of the new product family was very strong.

Shipments of this new family of products had commenced in Q3-1988 and ramped slower than planned during the current quarter, Q4-1988. Two problems prevented supply from meeting overall demand. Chip supply from the in-house supplier had been limited as the chip manufacturing group worked to de-bug the new chip process technology. Similarly, the in-house disk drive manufacturing group was

TABLE 7.15
Product description of new family of products.

GP-1	High-end general purpose computer system. Large memory, disk storage, and expansion capability.
GP-2	Intermediate general purpose computer system. Moderate memory, disk storage, and expansion capability.
GP-3	Interim replacement for GP-2 using older disk storage devices.
WS-1	High-end workstation based on the GP-2 system.
WS-2	Entry-level workstation using older disk storage devices and enclosure. Limited memory and expansion capability.

TABLE 7.16
Revenue for each system.

System	*List Price*
GP-1	$60,000
GP-2	$40,000
GP-3	$30,000
WS-1	$30,000
WS-2	$15,000

- List price is an average across the 3 major Geographies. Effect of varying memory and new disk content on list price and mark-up is negligible.
- Allowances and discounts are roughly the same across the products and Geographies.
- Mark-up percentages are roughly the same across the products and Geographies.
- Most costs can be considered fixed over the one quarter time-frame.

TABLE 7.17
CPU chip set requirements.

System	*# CPU Chip Set*
GP-1	1
GP-2	1
GP-3	1
WS-1	1
WS-2	1

- Chip Manufacturing is a long lead time process. Chip supply is fixed at 7,000 sets for Q1-1989 with no possibility of an increase. This volume was based on prior market sizing estimates.

de-bugging the new state-of-the-art disk manufacturing process. While it wasn't unusual for problems to exist during the initial phases of a new product ramp, the anticipated continuation of these problems into Q1-1989 was becoming a serious concern.

The Revenue managers (whose job is to ensure that supply of products is delivered to meet demand) had responded to the shortages in a simple, straightforward way in Q3-1988. On the supply side, the majority of the scarce CPU chips were used to build the more valuable general purpose computer systems. (See Table 7.16 and Table 7.17 for product list price and chip set requirements.) On the demand side, customers were encouraged to order these more valuable systems through short-term marketing programs.

At least one of the new type of disk drives is required for the GP-2 and WS-1 system (see Table 7.18) and is a popular "add-on" in extra numbers on these two systems as well as the GP-1 system. (See Table 7.18. For example, the average demand for the new disk drive in the GP-2 system is 1.7 drives per computer system.) Due to the scarcity of these disk drives, the placement of disk drives were reduced as shown in the third column of Table 7.18 with a commitment to those customers who wanted additional add-ons to provide the additional drives when these restrictions were lifted.

Several new developments occurred in the middle of Q4-1988 that had a further impact on supply of systems in Q1-1989. The in-house disk supplier reduced com-

TABLE 7.18
Disk usage per system.

System	Average Disks Per System: Customer Preference	Constrained
GP-1	0.3	0
GP-2	1.7	1
GP-3	0	0
WS-1	1.4	1
WS-2	0	0

- GP-3 and WS-2 use other (non-constrained) disks. GP-1 use of the new disks is optional.
- Estimates are world-wide averages. Geographic estimates vary ±10%.
- Committed availability for Q1-1989 was recently reduced by 50% to 3,500 units. Further small reductions are possible and recovery to the previous level is also possible.
- The usage rate has been held at the constrained level since Q3-1988. Customer discontent has been increasing. Some key customers are insisting on greater than one disk per unit on their systems but the number of systems involved is unknown.
- Any spare drives will be shipped as add-ons to prior customers who were constrained at one drive per system.

mitted Q1-1989 availability by 50% to 3,500 units. The chip manufacturing group stated that CPU chip supply was capped at 7,000 sets. Industry-wide supply of 256K DRAMs had tightened. These were used on many system and memory products and were used extensively in the new family of computer systems. Supplies would fall about 10% short of the company's total need. Furthermore, there were unquantified potential shortages of communication modules and module handles, both of which were used in the new family of products. Finally, after two previous quarters of delayed delivery of the add-on disks (discussed herein), key customers were demanding shipment of their constrained computer system and disk orders.

It was clear to the Manufacturing staff that the problem had become much more complex. Emotions were running high. Revenue, profitability, and customer satisfaction were all at risk. They needed a rational analysis that would distill the multiple interrelated factors into something more manageable. A set of recommendations would have to be made to the manufacturing staff that was easily understood, supportable by all affected parties, and conducive to fast implementation. They needed to know which problems to focus on and what actions to take.

What recommendations would you make?

Key Issues and Uncertainties

One of the decisions that management must make concerns disk usage per system (see Table 7.18). Should they plan to satisfy customer preference for disks per system, or should they continue to manufacture products in the constrained mode of disks per system?

Another decision that management must make concerns configurations of DRAM usage in products. See Table 7.19. The first column shows the number of 256K DRAM boards required in each product. However, the GP-1 could be produced with two 1-meg DRAM boards instead of the four 256K DRAM boards. A decision needs to be made whether to produce the GP-1 with four 256K DRAM boards or with two 1-meg DRAM boards.

A third decision that must be made is where to start tackling the shortages of disks and of 256K DRAM boards. Manufacturing staff would like to concentrate their troubleshooting efforts on either decreasing the shortage of disks or decreasing the shortage of 256K DRAM boards. They would like a recommendation on which problem to concentrate their efforts.

TABLE 7.19
Memory usage of DRAMs.

System	256K Boards Per System	1-Meg Boards Per System
GP-1	4	2
GP-2	2	—
GP-3	2	—
WS-1	2	—
WS-2	1	—

- Use of 1-meg DRAM boards on GP-1 has been technically qualified but not yet announced. An announcement could be made quickly.
- 1-meg DRAM boards will not be technically qualified on the other systems until Q2-1989.
- 256K DRAMs are used on roughly a dozen different steady-state memory and system products. A 10% shortfall in Q1-1989 on a base of several million DRAMs is expected. Assume enough sets of 256K DRAMs will be available to support 10–15,000 memory boards.
- 1-meg DRAMs are used on several new memory and system products and are in tight supply. Assume enough sets of 1-meg DRAMs will be available to support 4,000 1-meg boards.

TABLE 7.20
Demand mix.

System	Estimated Maximum Q1-1989 Customer Demand
GP-1	1,800
GP-3	300
GP FAMILY	3,800
WS FAMILY	3,200

- GP-1 demand capped due to market saturation in the prior two quarters.
- GP-3 is a temporary fill-in due to lack of GP-2 availability. Demand is limited.
- Total GP and WS family market size is based on previous market studies, though lack of supply in the prior two quarters could distort demand.

TABLE 7.21
Customer satisfaction data.

System	Estimated Minimum Acceptable Supply
GP-2	500
WS-1	500
WS-2	400

- Supply had been skewed to the higher valued general purpose systems in the prior two quarters. Key customers are demanding that their workstation orders be filled as well.

Probably the most important uncertainties are the availability of the new disks and the availability of 256K DRAM boards. From the notes in Table 7.18, disk unit availability will be in the range of 3,000–7,000 units. From the notes in Table 7.19, 256K DRAM board availability will be in the range of 10,000–15,000 units.

Assignment:

(a) Formulate a linear optimization model that describes DEC's manufacturing problem.

(b) The spreadsheet DEC.XLS contains various data for this case. Using the data in this spreadsheet, construct a spreadsheet version of your linear optimization model and solve the model for the optimal solution.

(c) Solve other versions of the model for different assumptions on the data values and to help analyze some of the key issues in the case. What conclusions can you draw?

(d) Prepare a brief (two pages or less) but pointed memo of summary recommendations for action addressed to the manufacturing staff.