Digital Equipment Corporation's XCON

In the 1970s and 1980s, Digital Equipment Corporation (DEC) was the second-largest computer manufacturer in the United States. Digital's culture is highly focused on engineering, and the company has a history of innovation. Its corporate strategy was based partly on well-engineered products that offered a superior price/performance ratio. A second critical element of its strategy, the subject of this case study, was flexibility—flexibility that enabled DEC to configure a computer system to meet very precisely the customer's needs. In 1975, DEC offered 50 types of central processors with 400 core options. The estimated possible number of configurations at that time was already in the millions. DEC's flexibility worked so well that equipment sales revenue grew 29 percent per year compounded from 1972 to 1985.

System configuration was the key process in DEC's flexibility strategy, for it converted a customer's order into a fully configured system that was designed, checked and ready for delivery. This process involved three separate reviews of each order. The first two steps relied upon highly skilled and talented technical editors (TEs) who learned their craft through a long apprenticeship. The final review was FA&T (fast assembly and test)—an actual assembly of the system prior to delivery. In 1975, DEC maintained a 13-acre, $15 to $20 million facility to carry out these test assemblies. Elapsed time from signed order to delivery was ten to fifteen weeks, extending at times even up to six months. Growth projections indicated that DEC would need three more FA&T facilities over the next ten years, an enormous expense just to maintain the already slow delivery time. In addition, estimates were that the configuration expert staff of 50 to 60 would have to increase to perhaps 200. To make matters worse, computers were growing more complex, increasing even further the number of configuration options. DEC had to find a new way to configure its orders, and so XCON, DEC's configuration system, was born.

DIGITAL'S XCON: LEARNING BY DOING

XCON was one of the first expert systems in daily production use in industry. The project was established in 1979 with a staff of two and an expert rule base of 250 rules. The project, which was called CSDG (the Configuration System Development Group), was originally a research effort composed largely of engineers and technologists. Today the rule base has expanded to over 10,000 rules. CSDG has grown to maintain a staff of over 60. The system continues to function and has grown in strategic significance for the company. Several related expert systems have spun off the original XCON: XSEL, XFL, XCLUSTER, XNET, and SIZER.

Before XCON, DEC's technical editors (TEs) were critical to configuration, which means they were critical to sales, field service, and manufacturing. The position required a great deal of technical knowledge and skill. DEC maintained a permanent apprenticeship program to develop the essential skill pool. The TE staff had to be large enough to handle orders during peak periods. TEs were dispersed and in daily contact with sales, field service, and manufacturing personnel.

Today the crucial knowledge base that had resided within the TEs has migrated to CSDG, a centralized and somewhat isolated organization of programmers. TEs still exist in DEC but the position has become more clerical; activities tend to concern reviewing rather than decision making. They are consulted much less than in the past and no longer have the authority to block an order pending the solution of technical problems.

Manufacturing, sales, and other operating units were strongly supportive of efforts to solve the configuration problems and to use results from configuration systems to solve other problems. Development of XCON did not involve major turf battles within DEC.

As XCON grew in power, informal contacts with business planners and leaders who strongly supported the project were the primary means of linking the programmers to the business. Later the Configuration Systems Steering Committee (CSSC) was formed, made up of strategically focused managers representing XCON's major business constituencies.

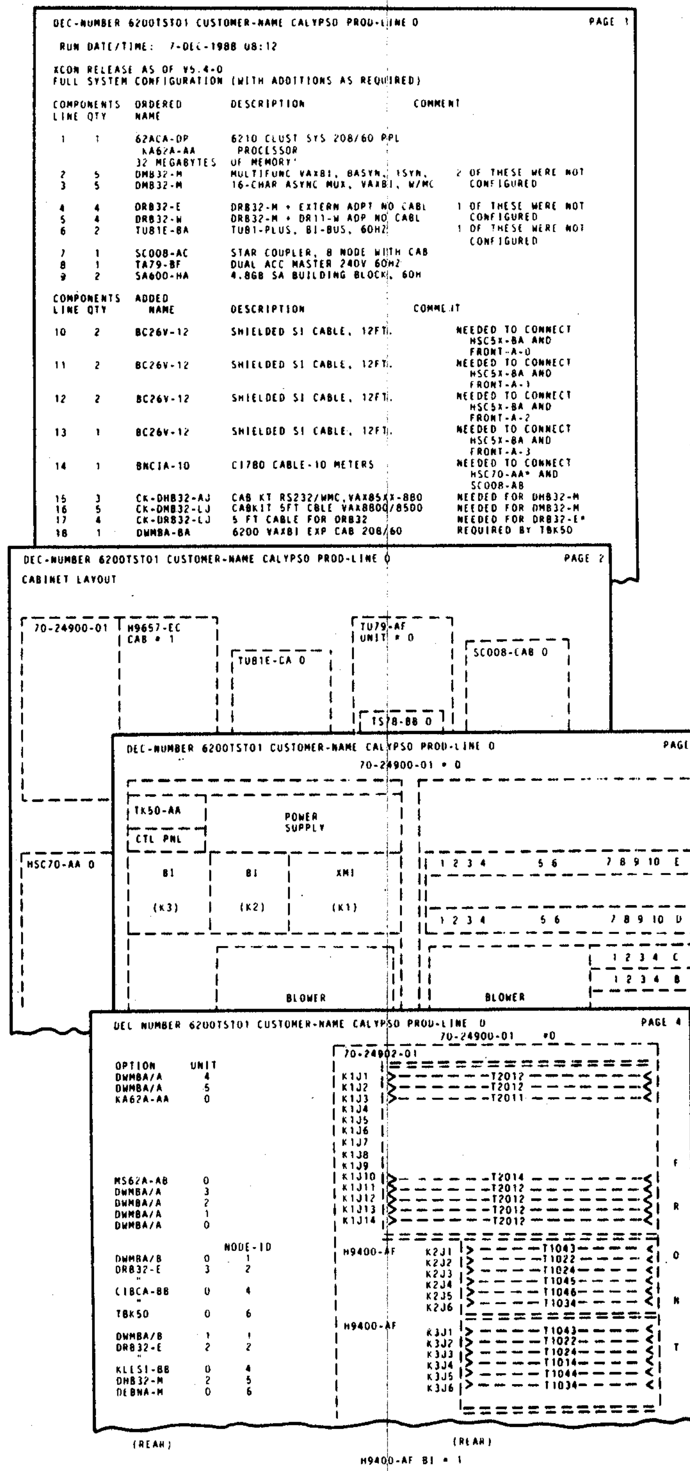

Figure 17.18
Sample output from XCON. The information provided by XCON will assist a broad set of users from sales, manufacturing, and field service by configuring a customer's order. *Adapted from: Virginia E. Barker and Dennis E. O'Connors "Expert Systems for Configuration at Digital: XCON and Beyond."* Communications of the ACM, *March 1989. Copyright 1989, Association for Computing Machinery, Inc. Reprinted by permission.*

WHAT THE XCON SYSTEMS CAN DO

XCON is used to configure customer orders and to guide the assembly of these orders at the customer site. Using the customer order as input, it provides the following functionality:

- Configures CPUs, memory, cabinets, power supplies, disks, tapes, printers, and so on.
- Diagrams complete system configuration (See overlay samples of XCON output, Figure 17.18).
- Determines and lists cabling information.
- Lists components ordered with configuration-related comments.

- Generates warning messages on issues affecting technical validity.

XSEL, which relies on XCON's data, is used interactively to assist in the selection of saleable parts that make up a customer order. Begun in 1981, it provides the following functionality:

- Allows interactive selection by generic component name, and by partial or full model number.
- Performs completeness checking, while adding and suggesting required parts.
- Checks software compatibility, prerequisites, license and media completeness.
- Provides computer room environmental data and requirements.

XFL, begun in 1986, is used to diagram a computer-room floor layout for the configuration(s) under consideration. XCLUSTER is used to assist in configuring computer clusters.

Besides these four systems currently in production use, two other configuration systems are under development. XNET is used to design local area networks, to select appropriate components for such networks, and to validate the technical correctness of the resultant network configurations. SIZER assists in sizing computing resources required for any of a wide variety of uses in various types of organizations. See Figure 17.19 for system architecture supporting peripherals and software.

SCOPE OF XCON AND RELATED SYSTEMS

The configuration systems provide full product coverage for Digital's current product set. In 1990, this product set consisted of 42 different families of central processor types and their supporting peripherals and software. To be useful business tools, released versions of the CSDG systems must include configuration knowledge of Digital's newest products at the time of the product announcement. In practice, this means that CSDG provides major releases of its systems once each quarter, with at least one interim upgrade to ensure adherence to the time-of-announcement requirement.

The configuration systems are used worldwide, throughout the corporation. The user profile of the configuration systems has expanded dramatically (see Table 17.3). The initial purpose of XCON was to assist manufacturing plant personnel in validating the technical correctness of system orders about to be filled. It is now used by a broad set of

Figure 17.19
XSEL/XCON architecture. *Adapted from Virginia E. Barker and Dennis E. O'Connor, "Expert Systems for Configuration at Digital: XCON and Beyond."* Communications of the ACM, *March 1989. Copyright 1989, Association for Computing Machinery, Inc. Reprinted by permission.*

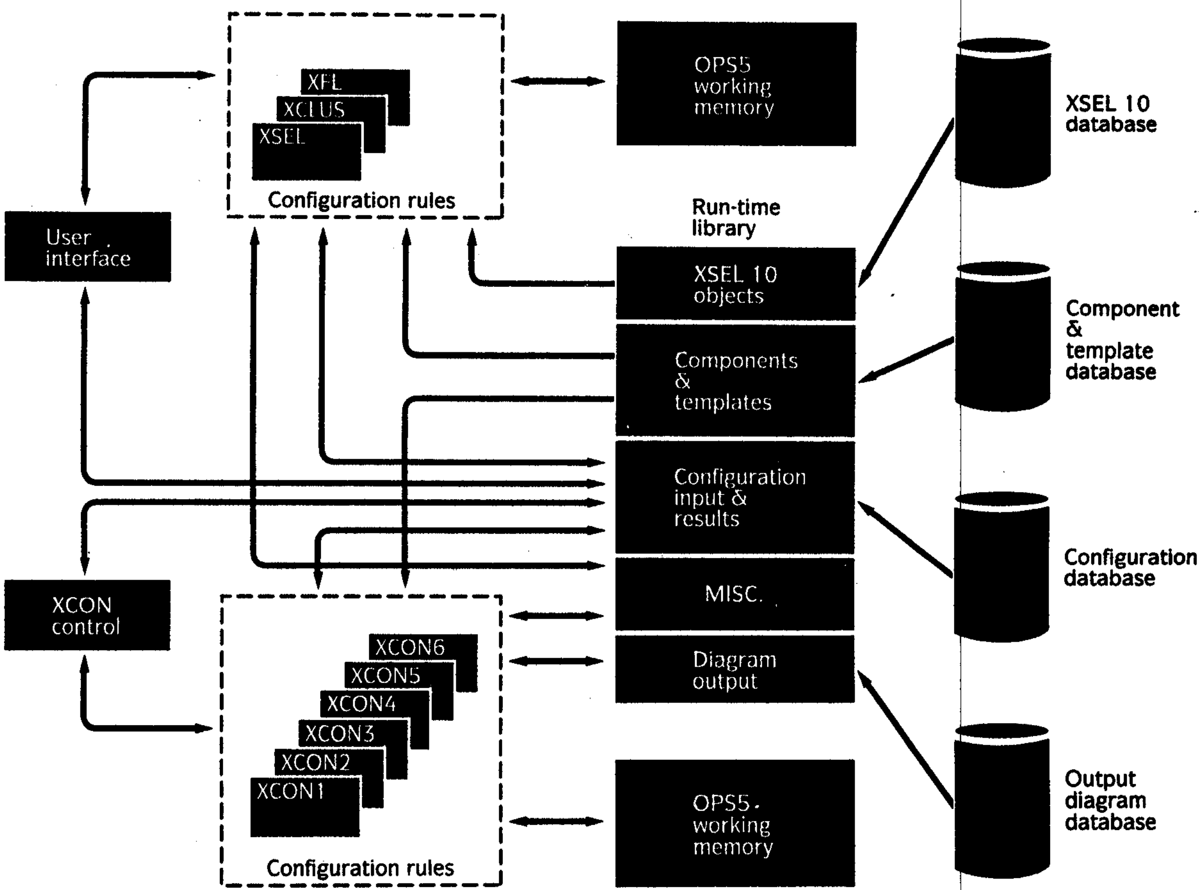

Table 17.3 DIGITAL CONFIGURATION SYSTEMS TIMELINE.

	1979	1980	1981	1982	1983	1984	1985	1986	1987	1988	1989
STAGE OF LIFE	XCON Proof of Concept →	Useable prototype →		Evolving production system →					Rewritten using RIME methodology →	Evolving production system →	→
		Limited field test									
				XSEL Proof of Concept →	Limited field test →	Evolving production system →	→	XFL developed	XCLUS developed →	XSEL/XCLUS Evolving production systems →	→
									XNET Proof of Concept →	Multiple useable prototypes →	Field Test →
										SIZER Proof of Concept →	→
SCOPE AND SIZE Configuration Task Definition	Single CPU system →	→	→	→	→	→	Clusters of CPUs →	Network of CPUs clusters →	Software/Hardware interdependency →	→	→
				New buses →	FCC regulation, new		enclosures,	marketing strategies, etc. →	→	→	→
CPU family coverage #	1 →	→	2 →	→	3 →	10 →	14 →	18 →	23 →	32 →	42 →
Component data coverage (# parts in database)	100 →	500 →	800 →	→	→	5,100 →	8,600 →	10,600 →	14,800 →	25,100 →	31,100
Number of rules (total all systems)	250 →	750 → 500 →	850 →	→	2,200 →	4,900 →	7,200 →	9,100 →	10,700 →	14,600 →	17,500
MANAGEMENT Development process	Frequent, irregular releases →	→	→	→	Monthly releases →	Quarterly releases →	→	Quarterly releases w/ interim upgrades →	→	→	
Development Group Size	2 → 4 →	11 →	→	21 →	→	22 →	25 →	→	33 →	45 →	59 →

Aapted from Virginia E. Barker and Dennis E. O'Connor, "Expert Systems for Configuration at Digital: Xcon and Beyond," *Communications of the ACM* (March 1989). Copyright 1989, Association for Computing Machinery, Inc., Reprinted by permission.

users across the company's major functions: sales and marketing, manufacturing and production, field service, and engineering. The users of these systems perform functions that span Digital's complete order flow and manufacturing cycle; thus they are involved with many different business processes. This is a large and varied constituency to support—each has different needs and takes a different perspective on the configuration information provided.

- *Sales* uses the configuration systems as an integral part of the automated process to generate quotations for customers and to ensure that every order is technically valid.
- *Manufacturing* uses the information to verify buildability of all incoming orders, to understand physical partitioning of an order into various subassemblies, to determine which plants should build which segments of an order, to guide the assembly of all orders, and to determine the optimal set of diagnostics to run on each order.
- *Field service* has the perspective of assembling the order in the customer's unique environment, possibly consolidating it with existing equipment already installed.
- *Manufacturing and engineering* benefit from the configuration systems' focus on system integration, as analysis of product knowledge for inclusion in the configuration systems, and can identify potential problems in system-level design and manufacturability.

XSEL was originally designed for use by sales representatives and is now used by Original Equipment Manufacturer (OEM) customers as well. Implementation of XNET will add specialized field support personnel to the user list in the near future. There are additional "indirect" users of these systems through automated linkages to other software systems (both traditional and expert systems) that depend on the configuration information supplied.

Overall, the CSDG configuration systems support over 50 production installation sites as well as traditional and expert systems that depend on their data.

BENEFITS

XCON plays a strategic role for DEC, permitting DEC to deliver to customers, in a timely fashion, precisely what they require. Using XCON, DEC was able to eliminate FA&T and to reduce average shipping time to three or four weeks, sometimes even to only two or three days. As the computer market changed in the 1980s, rapid turnaround of orders became a requirement for survival. Because of XCON, DEC was ready. These systems allowed DEC to remain competitive and even to thrive in the 1980s as DEC's sales mushroomed and the market demanded shorter response time.

DEC is highly dependent on its configuration systems. It considers them to be a solid success for the company by contributing to customer satisfaction, lower costs, and higher productivity. They are viewed as absolutely critical to the strategy of customizing applications for customers. Specific benefits include the following:

- Only complete and consistent orders are shipped.
- Systems are optimized for the customer and confusion is minimized.
- A single source of configuration information for the company aids in the introduction of new products by showing how they fit into the whole DEC product line.
- Flexible manufacturing is aided by the precise knowledge of which parts are needed in inventory.
- Flexible distribution is aided by allowing system field experts rapidly to assemble parts originating from different factories. There is no need for independent assembly, test, and disassembly before shipping to the customer.

DEC has never conducted a formal study of the benefits of XCON and its related systems, and although the costs might be known, they are not published. Officials estimate that the configuration systems save $40 million per year net of all costs.

OTHER CHALLENGES

Massive technological change creates many and sometimes severe challenges. Along with some of those raised already, DEC found itself facing a number of other issues, some of which are described here.

Tools

Expert system tools today are highly limited. They tend not to produce efficient systems. Often they are hard to maintain, and are not easily connected to existing business system data flows or databases. XCON was originally written in a proprietary language called OPS5, which is very good at situation recognition but poor at algorithmic controls. To extend the power of OPS5, over 350 programs and 50,000 lines of code were written in traditional languages like BASIC and C.

When XCON first started, there was no architectural concept, everything was experimental, and there was no systems development methodology. After ten years of development, the entire system was redeveloped using a more explicit and efficient methodology called RIME. RIME has simplified the rule base and made it easier for people to learn and understand the system.

Size

Today XCON is large and complex by any standard. XCON alone has over 10,000 rules, and the related systems have another 8000 rules. But these numbers do not portray the representational complexity of the rule base (see Table 17.4). Consider, for instance, that

- The average number of condition elements per rule (the "if" portion) is 6.
- The average number of attributes per condition (tests, patterns, etc.) is 5.
- The average number of action elements per rule (the "then" portion) is 4.

Thus, the average number of tests that each rule must make on each cycle to determine whether it is applicable is $6 \times 5 = 30$.

Table 17.4 SAMPLE RULES FROM XCON.

Rule Name: R1a-unmounted-ubx-options		Comments
IF		
C1	The current step in the configuration process involves mounting options in containers;	*This condition is used to distinguish the group of rules that can potentially activate.*
C2	and the system being configured is not a vax11/780, vax11/782, vax11/785, vax8650, or vax8600;	*This rule is not applicable to those types of hardware systems.*
C3	and there is no unconfigured disk which sits on the idc bus;	*This condition ensures that the rule will not activate before all disks on an idc bus have been configured. ("Disk" actually means "disk drive.")*
C4	and there is an unconfigured r102-type disk which needs to mount inside a cabinet and whose pre-assigned controller sits on a unibus and it is the first disk assigned;	*This identifies the properties required of an appropriate disk to be configured by this rule.*
C5	and there is no unconfigured r102-type disk assigned to a controller that is placed closer to the cpu than the controller assigned to the aforementioned disk;	*Disks assigned to controllers that are closest to the cpu need to be placed first, in case there is insufficient capacity for all of them.*
C6	and there is a requirement to cable the disk to be configured to a controller;	*Part of the activity of this rule is to determine that cabling. There may be several possibilities.*
C7	and there has been no connection made between the disk to be configured and anything else;	*This indicates that some of the activities that this rule will perform have not yet occurred.*
C8	and there is a controller to which the disk to be configured has been pre-assigned and which sits on a unibus;	*This identifies the appropriate controller.*
C9	and there is a requirement to cable the controller to a disk whose type and quantity of cable match one of the possibilities specified for the disk;	*This identifies the type and quantity of cable needed for this particular disk/controller combination.*
C10	and there has been no connection created yet to this controller from any disk;	*Another indication that the activities to be performed by this rule have not occurred.*
C11	and there are no unused disk spaces in any unibus cabinet;	*This ensures that any spaces appropriate for disks in this type of cabinet will be filled before the rule can activate.*
C12	and there is a description for the capacity of a disk cabinet, whose name is not "h9643";	*This identifies a special type of cabinet that can only contain disks. An "h9643" is one variation of a cabinet to which the rule does not apply.*
C13	and there is an unconfigured disk cabinet;	*This identifies an appropriate cabinet in which the disk to be configured will be placed by the rule.*
C14	and the top space available for disk placement is unused;	*This identifies a location in the aforementioned cabinet where the disk to be configured can be placed. It needs to be on the top because of the removable medium.*
THEN		
A1	mark the disk configured;	
A2	and update the top space in the cabinet to be used;	*The location needs to be marked so that nothing else will be placed there.*
A3	and create a connection relationship between the disk and its controller, fully specifying the identifying information for the disk, controller, cabinet, and the type and quantity of the cable to be used for the connection;	*This establishes the connection between the disk and its controller. Other rules will determine the length and choose the exact cable(s).*
A4	and create a containing relationship between the disk and the cabinet, specifying the identifying information for the disk and cabinet as well as the location of the placement;	*This establishes the placement of the disk in the cabinet.*
A5	and create labels for the output diagram showing the disk within the cabinet for both the skyline view of the cabinet layout and the detailed view of the particular cabinet.	*This ensures that the output diagram will display this information correctly.*

Adapted from Judith Bacharat and Elliot Soloway, "The Engineering of Econ" In Virginia E. Barker and Dennis E. O'Connor, "Expert Systems for Configuration at Digital: Xcon and Beyond," *Communications of the ACM (March 1989). Copyright 1989, Association for Computing Machinery, Inc.; Reprinted by permission.*

In 1989 there were 5 databases in XCON containing information on 30,000 parts, with 25 to 125 fields per part. The databases are so large that they are compiled, compressed, and kept memory resident, with multiple indices to speed processing.

Maintenance

Maintainability is a critical issue. Each year about 40 percent of the 18,000 rules change because of changes in marketing, manufacturing, and engineering. Major and minor new products are always being introduced. As computer architectures move away from the single computer and toward clusters of machines and networks of components, the configuration options have exploded. The learning curve for new developers is about 12 months. The system is so complex that even experienced software engineers require a long training period.

Testing

Testing poses difficult issues in expert systems. Can you evaluate XCON as if it were a human? As the system improves over time, you have to readjust tests. What is correctness? Can we differentiate between optimal solutions and workable solutions? What about where experts disagree? What about the situation where the system comes up with the right answer for the wrong reasons?

Expansion

The uses and users of XCON have changed over the years, and new demands are being placed on the system. New types of users with new perspectives generate new requirements that were not foreseen. For instance, when plant technicians began using XCON configuration diagrams as the official document from which to construct a computer system, a whole new set of requirements was generated. The original "working diagram" had to be more carefully constructed, new code for diagram creation had to be written, and a whole new database defined.

Human Resource and Organizational Challenges

Over the years, CSDG has learned to appreciate the many different kinds of roles involved in building a complex system like XCON. Some of the key roles are as follows:

- *Champion:* Executives with strategic vision and a knowledge of what the technology can do. They must have strong connections with sponsors.
- *Sponsor:* Business people who want to solve problems and can get things done, deliver the budget and protect from enemies.
- *Program manager:* An integration role, filled by a person with a keen sense of the business rather than a technical focus.
- *Technical team:* Composed of knowledge engineers, who develop the knowledge base, and software systems integration engineers who develop the overall software and hardware foundation.
- *Experts and users:* People who provide domain knowledge and insight into the business problem.

Development Tasks

The development of these expert systems has spanned over ten years. In this time, CSDG has gained considerable understanding of all phases of the life cycle of production quality expert systems. The XCON team developed a general model of expert systems development based on four major tasks. These tasks are the following:

- Defining and redefining the system.
- Extending and refining the system.
- Delivering the system.
- Evaluating the system.

The team has found that delivering expert systems resembles traditional systems development. The only exception is that the technology is less settled, reliable, and predictable. The business problems are not often well understood when compared to, say, an accounting system. And the business being served will itself often change greatly as a result of the expert system, sometimes in unpredictable ways. However, DEC's experience indicates that once the managerial and technical problems are solved or at least addressed, it is possible to develop systems capable of saving millions of dollars and providing a strategic platform for the corporation.

Sources: Virginia E. Barker and Dennis E. O'Connor, "Expert Systems for Configuration at Digital XCON and Beyond," *Communications of the ACM* (March 1989); John J. Sviokla, "An Examination of the Impact of Expert Systems on the Firm: The Case of XCON," *MIS Quarterly* 14, no. 5 (June 1990).

Case Study Questions

1. Why do major technology projects like XCON result in such significant, unforeseen organizational changes? If you were the corporate sponsor of a project of this type at its beginning, how would you prepare for and anticipate this problem? With your project team (use several of your classmates), define your goals for this aspect of the project.
2. Before a system like XCON can help a company, management must first determine that the problem to be solved is appropriate and that the risk (including cost) is worth it. As well as you can, define and quantify the risk DEC was taking when it began this project. If you were the CEO at that time, how would you evaluate the risk against the size of the problem and against the projected benefits? Remember, you are making this evaluation in 1979 and so you cannot know that the market will change or that the 29 percent annualized growth will continue.