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Investing to Develop Future Capabilities Technology

We have described how companies today are striving to (1) enhance their capabilities for delivering outstanding products and performance to customers in targeted segments, (2) develop new products and services, (3) enhance existing processes, and (4) provide their employees with advanced information technology. Few of these capabilities, however, come for free. Companies must invest today to obtain products, services, and capabilities for the future. How should such investments be guided? Should they be made on the basis of faith, by appealing to the organization's commitment to its mission and strategy? Or is there still a role for careful financial analysis? Can financial analyses, developed for capital investments in industrial age companies, be made relevant for investments in an era that stresses organizational capabilities?

Linking to other topics covered earlier in the book, the chapters on cost behavior made a strong distinction between committed and flexible costs. Activity-based costing concepts demonstrated how to measure and assign the costs of using both committed and flexible resources to cost objects, such as products, services, and customers. We noted that the supply of many organizational resources gets committed well in advance of realizing the demands for the resources.

In this chapter, we examine the decision making for acquiring resources, especially resources that are expected to produce benefits for several periods in the future. At the most familiar level, such multiyear resources include machinery and information systems for which the spending occurs first and then the resource provides a stream of benefits for several years in the future. But the initial spending could also be in new products and processes (such as in research and development), in which case the investment is expected to be repaid in the future with sales from the new products and cost, quality, and cycle time efficiencies from improved processes.

Whenever spending to acquire a resource or capability is expected to yield benefits in future periods, the problem arises of how to compare the cash inflows in future periods with the cash outflows occurring at the start of the project. Anyone who puts money in a savings or money market account, or who is paying off a mortgage or loan, understands that cash flows received or paid in the future are worth less than the same cash flows being received or paid today. Discounting future cash flows provides the logic by which cash paid out and cash received in many different years can be made commensurate so that all the cash flows can be summed together to provide an overall measure of investment worth.

Discounting procedures for evaluating investments in long-lived assets became widely adopted in corporations during the mid-1950s. Students today are trained extensively in these procedures in introductory finance and management accounting courses. Therefore, the mechanics of discounting techniques, especially net present value and internal rate of return calculations, should by now be familiar to all readers of this book. With the increased availability of spreadsheets on personal computers, no technical barrier exists to the widespread use of discounting procedures for evaluating proposed investments.

But, despite the extensive experience of many companies with the techniques and the theoretical training students receive in accounting and business programs, many people still believe the technique is too limited. They note that, in practice, discounted cash flow (DCF) techniques have usually been applied only to investments in plant and equipment and to new products. DCF techniques have rarely been applied to R&D, advertising, or employee training, because such investments did not provide simple, quantifiable cash flow benefit streams.

We believe that concerns with the applicability of financial analysis to investments in future capabilities arise from two principal sources:

1. Whether discounted cash flow techniques are consistent with today's technological investments for improvements created not only for efficiency and cost reduction but also for improved quality, reduced cycle times, and enhanced flexibility
2. Whether the analytic discounted cash flow approach can capture all the learning, growth options, and organizational capabilities that can be created from certain product and process investments

In this chapter, we will address both of these extensions to traditional capital budgeting and net present value analysis.

IS A NEW THEORY NEEDED?

Our study of the actual practices used by firms in applying discounting procedures to proposed capital investments reveals many flaws; but these are flaws in application, not in the underlying theory. Therefore, if students wish to apply DCF procedures in practice, they need to understand these flaws and how to overcome them. The flaws occur when managers

1. Require payback over arbitrarily short time periods
2. Use excessively high discount rates
3. Adjust inappropriately for risk
4. Compare new investments with unrealistic status quo alternatives
5. Emphasize incremental rather than global opportunities

6. Fail to recognize all the costs of the new investment
7. Ignore important benefits from the new investment

We will address each of these problems in turn.

Short Time Horizon

Many companies demand that investments, particularly new investments in untested process technologies, be paid back within a short time period, say two or three years. Various reasons have been offered to justify the use of short payback periods, including managerial distrust of the estimates of future cash flow savings and the need to stay liquid and self-financing in order to reduce the financial risk of the company. All of these are ad hoc explanations; none of them arises from the economics of discounted cash flow analysis. Certainly, if companies in the mining or timber industries demanded three-year payback periods, there would be little opportunity for such companies to grow or even survive.

Nothing in the theory of discounted cash flow analysis justifies the use of arbitrarily short evaluation periods. In fact, quite the contrary. DCF analysis permits cash flows received many years in the future to be made comparable with cash flows received now or one year from now. Thus, the critics' complaints of short time horizons must be about the decision horizons of their senior managers, not of the analytic technique itself.

Excessively High Discount Rates

Perhaps the major pitfall to the successful application of DCF occurs when companies use discount rates in excess of 20% and 25% to evaluate proposed new investments. Use of an excessively high discount rate penalizes a long-lived investment just as much as the use of an arbitrarily short evaluation horizon. Because the discount rate compounds geometrically each time period, cash flows received five or more years in the future will be penalized severely in the analysis. For example, compare the difference in discount factors between a 12% rate and a 25% rate for years 5 and 10:

YEAR	DISCOUNT FACTOR AT 12%	DISCOUNT FACTOR AT 25%
5	0.567	0.328
10	0.322	0.107

Clearly, investments in long-lived technologies will be severely penalized by excessively high interest rates.

Discounting future cash flows serves to repay investors for the lost opportunity to invest their cash while waiting for the returns from the investment project. Therefore, the discount rate should reflect the opportunity cost of capital for such investors: what they could otherwise be earning from investments of comparable risk. Extensive empirical and theoretical research in finance and economics during the past three decades have established useful guidelines for determining the opportunity cost of invested funds.

One can estimate the cost of equity capital in either of two ways: Use the historical nominal return on corporate stocks of between 12% and 13% per year, or use the real return (net of inflation) of about 8% to 9% and add the expected future inflation rate over the life of the project. Either method is reasonable and would be a dramatic improvement over the practice of some firms of using rates in excess of 20%.

The erroneous use of interest rates in excess of 20% for discounting future cash flows probably arises from several sources. Some firms derive their cost-of-equity capital from their accounting statements. It would not be unusual for organizations to have accounting returns on shareholder equity that exceeded 20%. But the accounting return-on-equity figure has many defects that make it a poor estimate of the rate of return the firm has been earning on its capital investments. Apart from leverage effects (we will discuss debt financing shortly), the return-on-equity figure is distorted by financial accounting depreciation conventions, by decisions on capitalization and expensing, and by use of leased assets (among other explanations). We have already discussed the impact of accounting conventions on the periodic return-on-investment figure in Chapter 10. We noted there that it would be rare for a firm's return-on-equity ratio to be a good estimate of its rate of return from past investment.

A second error arises when managers use the discount rate to adjust for risk. With estimates of investment cost and future cash benefits already provided in the analysis, the discount rate becomes the only "free" parameter in the net present value analysis. Thus, it frequently serves not only to make future cash flows commensurate with present cash flows (its only real purpose) but also as a crude mechanism to adjust for risk. It is a crude mechanism because the geometric compounding of the interest rate over time implies that project risk must also be compounding geometrically, an assumption that is almost always wrong.

Much of the risk from new investment will probably be resolved early in the project's life. If there is uncertainty as to whether a new piece of equipment or a new technology will work, we will learn about this outcome in the first year or two. If there is uncertainty about demand for a new product, this too will undoubtedly become known relatively early. For example, for a new shopping center or office complex with a 20- to 30-year lease, the major uncertainty will be resolved when the project is built and occupancy and rental rates become established. There might be great risk about both occupancy and rental rates, but this is not a risk that is appropriately quantified by discounting 30-year rentals at an interest rate that has been grossed up by 10 or more percentage points.

As an extreme example, consider visiting a race track, where you make lots of risky investments. The risk is real, but there is no interest rate for the time interval between when you place your bet and when the outcome from that action is revealed several minutes later that will help you decide whether or how much you should invest in each race. Except for a narrow definition of risk (to be discussed shortly), raising discount rates arbitrarily as an ad hoc adjustment for risk is a crude instrument and one that will systematically penalize long-lived investments.

A third error occurs when firms use nominal interest rates (such as the 12%–13% long-term return to equity holders) to discount future cash flows but make no adjustment for inflation in the cash flows themselves. Many firms project future cash flows using today's prices, wage rates, material costs, and energy prices. But if inflation is embedded in the cost of capital estimates, such as by using the historical 13% return that reflects historical inflation experience of between 4% and 5%, then unit prices for output products and input resources should also incorporate expected future price increases. It is inconsistent to reflect expected inflation in the cost of capital used for the discount rate but to ignore price increases when projecting the future benefits from the proposed investment. An alternative possibility would retain the assumption of unchanging future unit prices but then use a real (not nominal) cost of equity capital of between 8% and 9%.

The analysis to this point has focused on the cost of capital for an all-equity-financed firm. Most companies finance some of their assets with long-term debt. The historical evidence from publicly traded high-grade corporate debt reveals that the cost of debt financing is well below the cost of equity capital. Long-term investment-grade corporate debt generally returns between 1% and 3% above the inflation rate. The return from smaller, riskier companies would have to be somewhat higher to compensate creditors for the higher risk that they were bearing.

The nominal interest paid on corporate debt is a tax-deductible expense for the corporation. Therefore, if the nominal cost of long-term debt is I% per year, the after-tax cost of debt capital to the company is $I * (1 - t)$, where t is the marginal corporate tax rate.

The simplest way to incorporate a mixture of equity and debt capital is to calculate a weighted average cost of equity debt capital.[1] The weights should be the fraction of total market value represented by equity and debt capital, respectively. Many companies estimate their debt-equity ratios using book values from their accounting balance sheet; this basis is less desirable than the weights implied by the market values of equity and debt but produces an acceptable approximation if market values, particularly of privately held or off-balance sheet debt, are difficult to estimate.

When the 13% cost of equity capital is averaged with nominal after-tax debt costs in the 5% range, it is clear that the overall cost of capital for many firms will be in the single-digit range. This result makes the use of discount rates in the 20+% range even more indefensible. Thus, many of the concerns with DCF techniques may reflect nothing more than the frustration of attempting to push innovative projects through a corporate financial process that is systematically biased against investments in long-lived assets.

When a company has some debt in its capital structure, still another opportunity for error arises. Interest payments will appear as an expense in a company's income statement. When projecting the cash flows from an investment, companies frequently subtract a pro rata share of corporate interest expense from the cash flows of a project. This calculation is erroneous because the payment of interest (as well as dividends and capital gains to shareholders) is already included in the interest rate used to discount future cash flows. The cost of capital includes the ability to repay both interest and principal on any debt incurred for the project. Subtracting interest expense from a project's future cash flows will cause these payments to be counted twice (once in the numerator and once in the denominator) and will therefore cause the project to appear less attractive than it actually is.

Risk Adjustments

We have already expressed our skepticism about arbitrary escalation of interest rates in a misguided attempt to compensate for project risk. Both theory and evidence provide support for embedding some adjustment for risk into the discount rate. But this risk adjustment arises from risk that is not diversifiable by investors. Pure uncertainty in outcomes does not require a risk adjustment if the uncertainty is not correlated with the uncertainties faced by other companies. The only risk for which investors, holding diversified portfolios, demand compensation is systematic risk—risk that is not diversifiable across firms.

The systematic risk probably arises more from the nature of the firm's product markets than from uncertainties in its production processes. Therefore, this risk would be the same for both existing and proposed investments in process technology. The subject of measuring a company or division's systematic risk is complex and is discussed intensively in finance courses.[2] For our purposes, the contemporary conventional finance thinking leads us to use the division's "beta," as estimated from the capital asset pricing model, to adjust for risk. In practice, the beta adjustment could move the cost of equity capital up or down by several percentage points, depending on the typical business and financial risk of the division.

Adjusting for the systematic risk of shareholders through the use of the CAPM beta controls for one type of risk and avoids the distortions created by arbitrary escalations of the cost of capital. Nevertheless, managers still face risk that is specific to the project, and to their careers, any time they undertake a major capital investment project. We have argued that increasing the discount rate is a poor method for controlling for this type of risk. Much better would be for managers to formulate different scenarios to represent the possible outcomes from a major investment.[3] These simulations can now be performed with standard and widely available spreadsheet languages. Alternatively, managers could formulate most likely, optimistic, and pessimistic scenarios for the investment project. Returning to our example of constructing a shopping center or office complex, the three scenarios could correspond to normal occupancy and rental rates, full occupancy, and low occupancy. Under each alternative, the managers would estimate the investment cost and future cash flows that are consistent with the assumed scenario. The cost of capital would then be used to discount all future cash flows to the present—its intended and defensible purpose—with risk evaluation left to the manager after contemplating the distribution of net present values across the different scenarios.

Alternatives to New Investment

Any new investment is evaluated, either explicitly or implicitly, against an alternative of not undertaking the new investment. The desirability of the new investment depends critically on how this alternative is evaluated. Many companies use the present conditions, the status quo, as the baseline alternative. That is, they assume that present cash flows can be maintained with no investment in new technology. Thus, the proposed investment must be justified by improvements in future cash flows—lower labor, material, or energy costs for example—relative to the present situation. This situation is captured by the diagram in Exhibit 12-1, in which the horizontal line represents the maintenance of present net cash flows into the future, and the small wedge above the line represents the cash flow improvements from undertaking the new investment. With this assumption, the area in the cash flow savings "wedge" may not be large enough to repay the initial investment in the new technology.

But the experience of many industries in Western countries has clearly shown that it is erroneous to assume that a firm could maintain level cash flows after rejecting new technology investment opportunities. For when a new process technology becomes available to one company, it will probably also be available to competitors. Even if existing competitors decide not to adopt the new process technology, a company overseas, such as

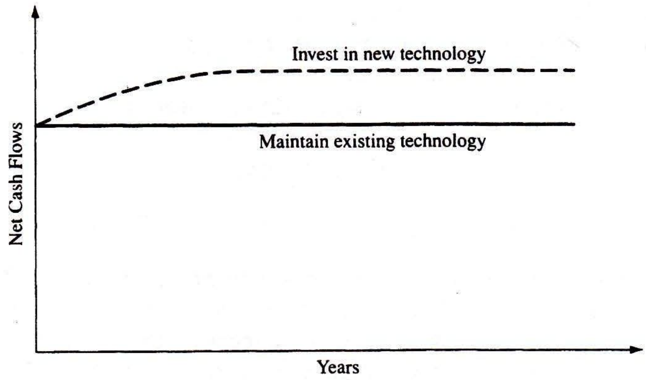


EXHIBIT 12-1 Comparing New with Existing Technology: Extrapolating the Status Quo

in a newly industrializing country, could adopt the new technology when it built a new plant to produce competitive products. Therefore, the most likely alternative to adopting new process technology is to assume a declining cost or quality position relative to a leading-edge competitor. Once a firm has lost technological leadership, it will find it difficult to maintain present market share and gross margins. This difficulty will lead to declining cash flows in future years. It is this pattern of declining cash flows (see Exhibit 12-2) that represents the most likely cash flow pattern for maintaining the status quo in rejecting the new technology option.

Once the process innovation "genie" is out of the bottle, it cannot be captured and corked up; it will flow to current or future competitors who will upset the existing market structure. Thus, the difference in cash flows between the new process investment and the status quo is the much larger area shown in Exhibit 12-2. Unfortunately, unlike our present cash flow position that we can estimate to considerable precision, we may not be sure

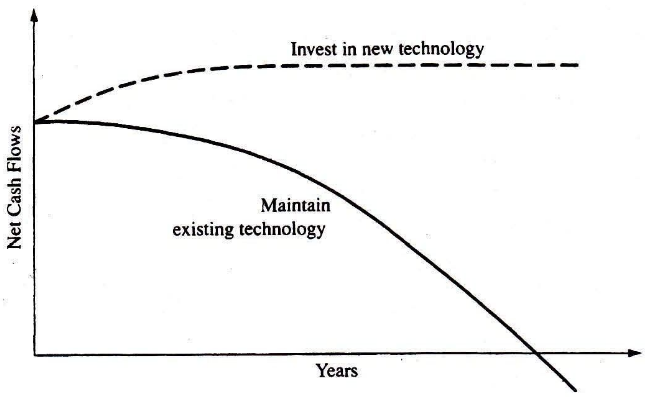


EXHIBIT 12-2 Comparing New with Existing Technology: Recognizing Loss of Technology Leadership

how fast the curve in Exhibit 12-2 will decline in future years. Perhaps the experience of companies in U.S. industries such as consumer electronics, steel, and machine tools can be studied to determine the rate of decline once technological leadership is lost to overseas competitors. It may be 5% per year; it may be 12% per year. Sensitivity analysis can be usefully applied to test how conclusions may vary with different decay rates. But we can be quite sure that assuming a zero rate of decay is precisely wrong.

Incremental versus Global Analysis

An additional problem with current practice is its bias toward incremental rather than revolutionary projects. The capital approval process for many companies specifies different levels of authorization as a function of the size of the request.[4] Small investments, under $100,000 say, may need only the approval of the plant manager, whereas expenditures in excess of several million dollars may require board of directors' approval. This apparently sensible procedure, however, creates an incentive for managers to propose a sequence of small projects that fall just below the cutoff point at which higher-level approval would be needed. Over time, a division may undertake lots of little investments, implementing minor changes in its basic facility, each one of which promises adequate savings in labor, material, or overhead costs or higher revenues by relieving an existing production bottleneck. But, collectively, the factory will become less efficient because of a less-than-optimal pattern of material flow. The factory may even become obsolete because of the outdated technology embedded in its core production equipment.

Each year, a division manager may propose and undertake a series of small improvements in the production process—to alleviate bottlenecks, to add capacity where needed, or to introduce islands of automation based on immediate and easily quantified benefits. Each of these projects, taken by itself, may have a positive net present value. By investing on a piecemeal basis, however, the division never gets the full benefit from a completely redesigned and reequipped plant that can exploit the latest organization and technology of manufacturing operations. At any point in time, there may be many of these annual, incremental projects scattered about from which the investment has yet to be recovered. Were the plant to be scrapped, the incremental investments made during the past several years would be proved incorrect.

One alternative to this piecemeal approach is to forecast the remaining technological life of the plant and then to enforce a policy of accepting no process improvements that will not be repaid within that period. At the end of the specified period, the old facility would be scrapped and replaced with a new one that incorporated the latest technology. Although none of the business-as-usual incremental investments might have been incorrect, the collection of incremental decisions could have a lower net present value than the alternative of deferring most investment during a terminal period, earning interest on the unexpended funds, and then replacing the plant. Again the failure to evaluate such a global investment is not a limitation of discounted cash flow analysis. It is a failure of not applying the analysis to all the relevant alternatives.

Front-End Investment Costs

Most investment proposals seriously underestimate the initial costs associated with installing new equipment, particularly equipment that embodies dramatically new technological features. In general, the hardware costs will be estimated well after obtaining quotes from vendors. But much new equipment requires considerable software development as well. Companies relatively unfamiliar with digital processing technology may overlook the extensive software investment required to make their new equipment operational and effective. Aggravating this tendency is the financial accounting requirement that in-house expenditures on software be expensed as incurred. Numerous instances could be cited in which expensive new machines were never used to their capabilities because the projects were starved for software.

In addition to presenting a more realistic picture about the investment cost in the new technology, a behavioral reason exists for explicitly recognizing front-end software and programming costs. Many companies budget capital funds separately from operating expenditures. If front-end software and programming costs are not provided for in the capital budget, they will eventually have to be supplied from operating funds. As managers are pressed to meet short-term profit goals and budgets, it becomes seductive to reduce funding for "intangibles" such as software for new machines. The temptation exists to force the machines on-line prematurely, without sufficient software support, an action that will virtually guarantee the eventual failure of the new process technology thrust.

A similar mistake is often made when organizations fail to budget funds to retrain and educate workers, supervisors, and managers in the new process technology. We observed one automobile assembly plant where workers had been furloughed for the several months required to install electronically controlled welding, paint spray, and conveyor equipment. After all the hardware had been installed, the workers were called back and were instructed to start production on the new car line. This plant subsequently demonstrated the slowest ramp-up to capacity production in the company's history as workers struggled to learn, under severe production pressure, how to keep the radically new production equipment operating and how to troubleshoot and repair it when it broke down (which was often). As the TV commercial reminds us, "You can pay now (in training and education); or you can pay later (in low production, frequent downtime, low morale, high turnover, and expensive repair costs)." Roger Smith, chairman of General Motors during the 1980s, learned that "spending money on new technology without adequate investment in training and educating our workers merely enables us to produce scrap faster." As with software and programming, the financial accounting requirement that training and education costs be expensed as incurred has prevented many companies from recognizing that such costs are investments, just as much as hardware costs, in the new technology process.

Also, many investments in flexible production technology require complementary investments to create capacity for new product development. Instead of producing a standard mix of products, an organization, with flexible production technology, can now customize its products and services. But to exploit this capability, companies have to transform their salesforce. Previously, salespeople served mainly to take and negotiate orders for existing products. For the new technology, the salesforce must be capable of new market development, of understanding and anticipating customer needs, and of performing customized applications engineering. The salesforce must not only uncover new opportunities, it must translate such opportunities into specifications for new products. If a company does not make complementary investments to enhance salesforce skills, the capabilities of the new, flexible facilities will go untapped. The costs of such skill enhancement must also be considered part of the "investment" in new manufacturing technologies if the full promised benefits from these technologies are to be realized.

Benefits Invisible Using Traditional Cost Systems

Investments in new technology, particularly information-intensive technologies such as flexible manufacturing systems (FMS), computer-aided design (CAD), and computer-aided engineering (CAE) provide companies with the capability for efficient design and production of small volumes of customized products. But these technologies provide little savings in direct labor, actual machining times, or direct materials usage. Before the advent of activity-based costing, the benefits case for investment in new machinery typically came from quantified savings in direct labor and machine times. Such labor and machine time savings could be directly tied to the company's traditional, volume-based costing system, in which operating expenses were allocated to products via direct labor and machine hour burden rates. Flexible design and manufacturing technologies (such as FMS, CAD, and CAE) typically do not provide labor and machine time savings relative to what could be achieved with much less expensive "hard-wired" special-purpose machines that do not contain sophisticated microprocessors, microcontrollers, and extensive automatically controlled materials and tool handling equipment. Therefore, it is difficult to justify the added expense to obtain these flexibility capabilities. In effect, the benefits from rapid introduction of new products and rapid changeover from one product to another are invisible in direct labor and machine hour costing systems.

Activity-based systems make visible the costs of batch and product development and product-sustaining activities (see Chapter 4). ABC systems reveal the high cost of the batch activities required by conventional manufacturing processes to:

- Change over (setup) from one product to another
- Move materials from one special-purpose machine to another
- Inspect items after each production run
- Schedule production runs, prepare materials and tools for production runs

ABC systems also reveal the high cost of producing a broad product line, with extensive customization, including the product-sustaining costs to:

- Design new models and variants for meeting individual customer needs
- Sustain the capabilities to produce a large number of products (such as maintaining engineering drawings, an updated bill of materials, labor and machine routings, and standard cost information)

And applying ABC to a company's entire supply chain reveals the high costs to:

- Order and schedule materials in small lots from many different suppliers
- Process customer orders for small lots of specialized products

Thus, many of the benefits—in real and quantifiable cost reductions and cost avoidance—associated with introducing flexible manufacturing and design technologies and electronic data interchange (EDI) between customers and suppliers were invisible because companies buried the costs of their support activities in overhead pools that were allocated on the basis of labor and machine hours. The advent of activity-based cost systems provides a much more visible basis for understanding the operating cost savings that can be realized from investments in advanced electronic manufacturing, design, and information technology.

MEASURING ALL THE BENEFITS FROM THE NEW PROCESS

Traditional project evaluation procedures estimate future savings in material, labor, and energy because these inputs are generally measured and tracked well by the company's cost accounting system. Innovative process technologies, however, also provide benefits that are not measured by traditional cost accounting and project appraisal systems. These benefits include inventory reductions, reduced floor space requirements, and improved quality.

Reduced Inventory Levels

The process flexibility, more orderly product flow, higher quality, and better scheduling that successful adopters of flexible automation technology have enjoyed will drastically cut both work-in-process (WIP) and finished goods inventory levels. Inventory reductions of 75% to 90% have been reported by many companies.

Reductions in inventory levels represent a large cash inflow at the time when the new equipment becomes operational and the inventory can be reduced. Because the reduction usually occurs early in the project's life, and thus is not discounted heavily, the cash flows from reduced inventory are especially valuable.

Consider a product line for which the anticipated monthly cost of sales is $500,000. Using existing equipment and technology, the producing division carries about three months' of sales in inventory. After investing in flexible automation, the division heads find that reduced waste, scrap, and rework, greater predictability, and faster throughput permit a two-thirds reduction in average inventory levels. Pruning inventory from three months to one month of sales produces a cash inflow of $1 million. If sales increase 10% per year, the company will also enjoy increased cash flows from the inventory reductions in future years; if the cost of sales rises to $550,000 in the next year, a two-month reduction in inventory saves an additional $100,000 that year, $110,000 the year after, and $121,000 the year after that. Furthermore, there will be less obsolescence when new variants and models of products are introduced.

In addition to the obvious reduction in cash demands from holding less inventory, many overhead costs that are largely driven by holding, moving, scheduling, and inspecting inventory can also be reduced when inventory reductions are accomplished. Studies that documented the decrease in productivity when new capital equipment is introduced have found strong increases in productivity as inventory levels are reduced.[5] Thus, the initial productivity decline from introducing new equipment can be offset by the higher productivity arising from operating with much lower inventory levels. Also, with less inventory and with continual flow production of small lots rather than batch production of large lots, the need for forklift trucks and drivers will be reduced, perhaps eliminated.

Less Floor Space

New process technologies frequently enable the same job to be accomplished with far less floor space. Just eliminating inventory, which is stored on or about the floor in most factories, will free up large amounts of productive space. More-efficient grouping of machines through better scheduling and coordination will produce significant floor space reductions. Companies have reported space savings of 50% to 70% after installing flexible manufacturing systems. Such space savings are real but are rarely measured by traditional financial and cost accounting systems. Most organizations have a continually increasing demand for space, if not for production then for engineering, support, and administrative personnel, so any realized space saving represents a real cash benefit to the firm. The savings from reduced space requirements can be estimated either on an annual basis—using the square-foot rental cost for new space—or on a one-time basis, analogous to the computation of inventory reduction savings, based on new space construction cost.

Quality Improvements

Greatly improved quality represents a major source of tangible benefits from new technology investments. Automated process equipment, properly installed and operated, leads directly to more uniform production and, frequently, to an order-of-magnitude decline in scrap, rework, and waste. As production uniformity is increased, fewer inspection stations are required and the number of inspectors is reduced. Automatic gauging can eliminate virtually all manual inspection of parts; out-of-tolerance parts can also be detected immediately rather than waiting for an entire batch of products to be produced before the production problem is detected.

The opportunities for savings in quality can be estimated by first collecting information on how much the organization is currently spending on producing, repairing, and discarding poor-quality items. Some of these costs will appear in categories such as inspection, scrap, waste allowance, and rework cost. These categories will fail to capture all the cost of substandard quality production. Storing substandard items in the factory, moving them around, and rescheduling the production line to accommodate rework of faulty items all impose high costs on the organization. Typically, these costs are buried in overhead accounts and allocated to all production, both good and bad. The analysis should attempt to identify all the costs incurred to produce poor-quality items, including inspection, expediting, and rescheduling costs.

All these expenses provide the pool of current expenses that improved production processes can reduce. Once the size of this pool is known, we can estimate the benefits from new process technologies that offer the potential for 50% or higher reductions in the incidence of substandard-quality production.

More-Accurate, Less-Precise Estimates

Projected savings in inventory, floor space, and quality are frequently estimated from the experience of similar companies or divisions. These savings cannot be estimated to the four or five significant digits that are the customary precision from the firm's financial and cost accounting system. But many analysts err when they conservatively assume that difficult-to-estimate benefits must be zero. For purposes of financial justification, it will be sufficient to get the first and perhaps the second digit about right and to know how many zeros follow the first digit or two. It is better to be vaguely right than precisely wrong.

The Difficult-to-Quantify Benefits

In Joseph Bower's classic study of capital budgeting procedures,[6] managers of a specialty plastics division wanted to build a flexible facility that would facilitate rapid changeovers in response to shifting demand and that could also efficiently produce small batches of new compounds conceived in the R&D laboratory. When corporate financial staff insisted on understanding the base case—what would happen if the flexible facility were not built—the managers had to concede that the products intended for the proposed facility could be built using spare capacity in existing facilities. The managers insisted that the existing facilities did not offer the quality and cost advantages of the proposed facility, but they could not translate their claims into tangible cash benefits. The corporate staff therefore assumed that the current incremental cost of producing the proposed products was essentially zero.

Nor could the managers articulate the flexibility advantages from the proposed facility, which would allow them to produce efficiently a changing volume and mix of products. The company's capital budgeting format insisted on estimating the cash flows for a particular mix of products. The managers were forced to assume a standard mix of products. This constraint prevented the analysis from capturing the benefits of flexibility for difficult-to-predict product mixes and for products not yet formulated. Eventually, the difficulty of communicating the savings and the benefits from the flexible facility caused the project to be abandoned.

New process technologies, especially those that are information-intensive, offer opportunities for radical changes in the way operations are performed. Some of these changes will be reflected in the substantial savings of inventory, space, and quality costs previously described. But even beyond those tangible reductions in costs that are currently being incurred, the new process technologies can provide dramatic improvements in flexibility, faster responses to market shifts, significant reductions in throughput and lead times, and opportunities to learn from and grow with technology advances.

INVESTING IN ORGANIZATIONAL CAPABILITIES[7]

A recent analysis of several field studies identified investments leading to five different types of organizational capabilities:

1. External integration, leading to *quality*
2. Internal integration, leading to *speed* and *efficiency*
3. Flexibility, leading to *responsiveness* and *variety*
4. Experimentation, leading to *continuous improvement*
5. Cannibalization, leading to *radical innovation*

We briefly summarize each of these capabilities.

External Integration: Linking Design to the Customer

Japanese manufacturers create high-quality products by investing in information systems that link customers, engineering teams, suppliers, and manufacturing operations. External integration is the ability to link knowledge of customers with the details of engineering design to create and improve products. The external integration must:

1. Build systems to gather, collate, and analyze information about customers and the ways they use the product. This process can include training the salesforce and service organization to gather in-depth knowledge of customer needs.
2. Link customers' needs to engineering design.

These two aspects of external integration are complementary. The organization must both understand how customers use their products and also communicate this knowledge to the engineers who are designing or redesigning the products that customers will use. If these costly investments are not made, the company is unlikely to be producing products that will work in ways that customers expect.

Internal Integration: Connecting Functions within the Organization

Internal integration exists when problem solving is tightly connected across departmental and functional boundaries. Decisions in one function, such as engineering design, should take into account the knowledge, skills, and concerns of other functions, such as manufacturing, sales, and finance. High degrees of internal integration enable a company to accelerate the time-to-market of new products and greatly reduce the cost of the product development process.

Internal integration in the order fulfillment process—booking and receiving customer orders, scheduling production, producing the order, and distributing the order to the customer—should provide the business unit with a just-in-time capability to meet customer demands with short lead times. Companies offering one- to two-week lead times when competitors are promising 60- to 90-day deliveries should be able to capture premium prices and higher market share. Greatly shortened lead times will also permit companies to respond quickly to changes in market demand. If the marketing department detects a shift in customer preferences, the factory can respond quickly to product mix and design modifications. The company will beat technologically inferior companies to the market and will avoid the obsolescence of in-process and finished goods inventory that its competitors with two- and three-month lead times must absorb.

Internal integration requires the specialists from different parts of the organization to have common vocabularies, concepts, and objectives. The specialists must also have specialized information systems to facilitate interaction, such as shared data bases, computer simulation and testing capabilities, rapid prototyping, and integrated systems from customers through production and distribution. The extensive communication and collaboration across organizational functions require investments in education, training, and career progression and explicit incentives to produce the desired payoffs in efficiency and speed for delivering existing products and launching new ones.

Flexibility: Responsiveness to Change

Flexibility allows a company to change product or process characteristics rapidly and at low cost. It enables a company to respond quickly to changes in customer demands and tastes, market conditions, and competitor initiatives. Flexibility can be measured along several dimensions:

- **Variety:** Capability to turn out a wide range of goods and change the mix quickly as demand shifts
- **Volume:** Capability to vary the rate of output, especially in continuous flow processes
- **Innovation:** Capability to introduce new products into manufacturing rapidly and efficiently

For example, companies with computer-integrated manufacturing (CIM) technologies can change product specifications easily, process engineering change orders rapidly, implement process improvements continually, accommodate schedule changes, both volume and mix, at low cost, and introduce entirely new products and variants on existing equipment with little disruption. Adoption of computer-based production processes has permitted some companies to produce efficiently in batch sizes of one.[8]

In the short run, CIM equipment may be performing the same functions as less-expensive, dedicated automation. In this case, the flexibility of CIM equipment is not being exploited, and it becomes difficult to justify the added expense of linkage to the computer workstations of product designers and engineers, the programmable controls and the flexible materials handling equipment. It is only over time, with CIM's ability to easily accommodate engineering changes, product redesigns, and major product changes and innovations, that the payoffs from CIM flexibility will be realized.

As another example, to achieve product flexibility, companies need to invest in modular designs, whereby common components and subassemblies can be combined in unique ways to meet a wide variety of end applications. Modularity raises the initial cost of design but enables a company to offer a more varied product line, without paying the normal high cost of small-lot customization. Process flexibility requires investments in operating procedures and software that permit rapid changeovers and ability to meet unexpected contingencies. Embedding such contingencies in routine operating procedures requires heavy front-end investments in training and simulation and in designing and testing software. The payoff comes from the capability to alter outputs within minutes rather than the hours or days required in conventional, nonflexible processes.

Experimentation: Achieving Continuous Improvement

Continuous improvement (*kaizen*) requires that organizational participants be constantly involved in experimentation and learning. This process requires skilled operators to conduct systematic investigation on processes, using the scientific method and statistical analysis.

The capacity to experiment requires two complementary types of investments. First, the firm must have research capacity, including extra manufacturing capacity, to allow experimentation in the plant. This capacity includes sensors and tools for collecting data as well as people and systems to organize, analyze, and report the data. Second, the firm must have systems for communicating between scientific and operating personnel and the human and organizational skills to implement rapidly and effectively the insights from the systematic data analysis. These capabilities will allow the organization to modify and improve existing practices by exploiting the knowledge gained through constant experimentation.

Cannibalization: Achieving Radical Improvement

Many companies are reluctant to replace an existing process with a new process whose cost improvements cannot be demonstrated. For example, U.S. steel manufacturers delayed for decades the introduction of continuous casting process technology, despite its cost and quality benefits relative to the companies' traditional batch production process. Missing from the capital budgeting analysis of these companies who wish to preserve the status quo is the recognition that a decision to acquire the new technology also gives the organization the opportunity to participate in future enhancements. Companies that invested in electronically controlled machine tools in the 1970s acquired a technology option, analogous to a stock option, in microprocessor and microcontroller technology advances. As the capabilities of integrated circuit chips improved by several orders of magnitude, these companies increased the machines' productivity by retrofitting the more-advanced electronic products. Companies that stayed with mechanical, manually operated machine tools failed to obtain an option in technology advances and hence could not benefit from the enormous performance-price improvements in electronic chips. Investing in new process technologies also permits the entire organization to learn about the capabilities of leading-edge production processes. Thus, many of the startup costs could ultimately be shared by other projects that use similar technologies. Assigning all the front-end costs to the specific project being authorized will fail to recognize the eventual benefits to future projects.

Despite these benefits, some managers, in the face of rapid technology changes, feel that it is safer to defer investment and wait until the rate of change and technological advance have slowed down. These companies fail to realize how important the learning process is when shifting to an entirely new production technology. By waiting, they delay their learning process and eventually find themselves organizationally and technologically so far behind their competitors that they can never catch up. In effect, they have not acquired an option in technological advances.

Even more common, companies resist or delay the introduction of a new product that will severely cut into the sales of their existing products. The slow reactions of IBM and Digital Equipment to personal computers and powerful workstations can, in part, be attributed to their managers' concerns about cannibalizing the far more profitable sales from their mainframe systems and minicomputers. As these examples show, the introduction of cannibalistic new processes or products have implications well beyond a simple financial comparison between the status quo and the proposed innovation. Sometimes, what appears to be a destructive innovation to existing processes and products will actually provide new organizational capabilities that will yield substantial future returns. But these future returns will be earned only if the introduction of the cannibalistic new product or process is accompanied with investments in procedures, information systems, and new employee skills, in addition to the investment in physical assets.

One type of investment will provide the organization with the capability to experiment with radical new opportunities at low cost and to test them in selected markets without disrupting existing efforts to support and improve existing products, customers, and processes. Another type of capability will be required to follow the new direction, if it proves successful in experiments and market tests. This second type involves excellent capabilities in new product design and process engineering. A complementary capability is to manage the ramp-up of the new product or process while simultaneously managing an orderly and profitable phase-out of the old product or process technology.

SUMMARY ON BUILDING ORGANIZATIONAL CAPABILITIES

Investments in organizational capabilities may be among the most important that business units can make. For example, external integration reduces product risk; internal integration increases the frequency with which opportunities are generated and the speed with which the business unit can respond to customer requests; flexibility increases the range of options associated with a given investment; the capacity to experiment allows systematic improvement and value creation over time; and cannibalization deters entry and increases the value of a business unit's market position.

The benefits from these organizational capabilities are just as important, if not more so, than the cost, inventory, space, and quality savings measured by traditional capital budgeting systems, but they are much harder to quantify. We may not be sure how many zeros should be in our benefits estimates (are they to be measured in thousands or millions?), much less which digit would be first. The difficulty arises in large part because many of the benefits represent revenue enhancements rather than cost savings. It is fairly easy to get a ballpark estimate for percentage reduction in costs already being incurred. For revenue enhancements from features not yet in place, it may be difficult to know which city you are in, much less the size of the ballpark in which you are playing. But, although the benefits may be difficult to quantify, there is no reason to value them at zero when conducting a financial analysis. Zero is no less arbitrary than any other number, and we must avoid the trap of assigning zero value to benefits that we know exist but are difficult to quantify.

Because of the difficulty of quantifying the benefits, investments in organizational capabilities are often neglected. All organizational investments must be justified in an environment in which formal capital budgeting systems demand quantified benefits. Spending on some "intangibles"—such as R&D, advertising, and training—does coexist with formal capital budgeting systems, since such spending can be approved on the basis of the educated judgment of senior executives, or on faith, or perhaps on both. These expenditures can be formally budgeted and the outcomes reviewed periodically to assess whether results are in line with expectations. Investments in organizational skills, systems, and procedures, however, are difficult to segregate, and they affect value indirectly and in nonlinear combinations with each other. One source of nonlinearity, or nonadditivity, arises from threshold effects in which a capability might fail to be achieved because one small but critical element was omitted. Also, the capabilities usually complement each other: The value of two capabilities working together typically exceeds the sum of the values of either working alone.

The Bottom Line

New organizational and accounting systems will need to track, in addition to financial flows, measures of quality, speed, flexibility, innovation, and rates of improvement.[9] New planning and capital budgeting systems must be developed that can measure a project's impact on these critical drivers of a business unit's performance. A capabilities view of investment will, over time, likely evolve to become integrated with the formal, financially based, capital budgeting systems that have been in use since World War II.

But lacking such new approaches for measuring and eventually valuing increments in organizational capabilities, we still need mechanisms for evaluating such investments today. One way to combine difficult-to-measure benefits with those more easily quantified is, first, to estimate the annual cash flows about which we have the greatest confidence. First we should estimate the relatively easily quantified annual cash flows: the cash outflows for new equipment and systems and to introduce the new equipment and processes into the organization. These enabling processes include data bases, systems, software, training, and education. In addition, for computer-based process technologies, we should estimate the tangible benefits from labor, inventory, floor space, and quality savings. We can then perform a discounted cash flow analysis, using a sensible and defensible discount rate, considering relevant and realistic alternatives, and examining possible scenarios. Should the new technology investment show a positive net present value at this point, we can be comfortable with the acquisition decision, since the financial hurdle has been passed even without adding in some of the difficult-to-quantify benefits.

If the net present value, however, is negative, then it becomes necessary to estimate how much the annual cash flows must increase before the investment begins to look favorable. Suppose, for example, that an extra $1,000,000 per year over the life of the investment is sufficient for the project to have the desired return. Then management can decide whether it expects heightened organizational capabilities in external and internal integration, flexibility, and organizational learning and the technology options including spillover effects to future projects to make the investment worth at least $1,000,000 per year. Would the company be willing to pay $1,000,000 annually to enjoy these benefits? If so, the project can be accepted with confidence. If, however, the additional cash flows needed to justify the investment turn out to be quite large—say, $10,000,000 per year—management, while still valuing improvements in organizational capabilities, can decide that they are not worth purchasing at $10,000,000 per year. In this case, it is perfectly sensible to turn a proposed investment down.

Rather than attempt to put a value on benefits that by their very nature are difficult to quantify, managers should reverse the process and estimate first how large these benefits must be in order to justify the proposed investment. Senior executives can be expected to judge that improved flexibility, rapid customer service, market adaptability, and options on new process technology may be worth $1 to $2 million per year but not, say, $10 to $15 million. In this final stage, we may be proceeding on faith, but at least our formal analysis has reduced the price that faith must pay.

ENDNOTES

1. If this were a finance, not a managerial accounting course, we would have to spend much more time on choosing the appropriate cost of capital. Modern financial economics uses an adjusted present value calculation that separately values an asset's real cash flows and the cash flow impacts from financing, including tax shields, bankruptcy risk, options, and hedges; see T. A. Luehrman, "What's It Worth? A General Manager's Guide to Valuation," and Luehrman, "Using APV: A Better Tool for Valuing Operations," *Harvard Business Review* (May–June 1997) pp. 132–54.
2. Good treatments are available in R. Brealey and S. Myers, *Principles of Corporate Finance*, 5th ed. (New York: McGraw-Hill, 1996); and J. Van Horne, *Financial Management and Policy*, 10th ed. (Englewood Cliffs, NJ: Prentice Hall, 1995).
3. See, for example, D. B. Hertz, "Risk Analysis in Capital Budgeting," *Harvard Business Review* (January–February 1964), pp. 95–106; and D. B. Hertz, "Investment Policies That Pay Off," *Harvard Business Review* (January–February 1968), pp. 96–108.
4. Organizational and behavioral issues in the capital budgeting process are documented and discussed in J. L. Bower, *Managing the Resource Allocation Process: A Study of Corporate Planning and Investment* (Boston: Division of Research, Harvard Business School, 1970).
5. R. H. Hayes and K. B. Clark, "Why Some Factories Are More Productive Than Others," *Harvard Business Review* (September–October 1986), pp. 68–69; and "Exploring the Sources of

Productivity at the Factory Level," in *The Uneasy Alliance: Managing the Productivity-Technology Dilemma*, ed. K. B. Clark, R. H. Hayes, and C. Lorenz (Boston: Harvard Business School Press, 1985), pp. 183–84.

6. J. L. Bower, *Managing the Resource Allocation Process* (Boston: Harvard Business School Press, 1986).
7. This section is based on C. Y. Baldwin and K. B. Clark, "Capital-Budgeting Systems and Capabilities Investments in U.S. Companies after the Second World War," *Business History Review* (Spring 1994), 73–109.
8. Economies of scope from computer-integrated manufacturing are discussed in J. D. Goldhar and M. Jelinek, "Plan for Economies of Scope," *Harvard Business Review* (November–December 1983), pp. 141–48; and M. Jelinek and J. D. Goldhar, "The Strategic Implications of the Factory of the Future," *Sloan Management Review* (Summer 1984), pp. 29–37.
9. Recall the linkage of strategy to a combination of financial and nonfinancial measures in the Balanced Scorecard, discussed in Chapter 8.

■ PROBLEMS

12-1 Portsmouth Pottery Company

The Portsmouth Pottery Company (PPC) manufactures a line of pottery that is primarily related to the commemorative and tourist industries. Sam Franklin, the production manager, is considering the possibility of purchasing a new kiln for the number 5 line. This line produces commemorative plaques. The kiln costs $700,000 and has a life of five years. PPC has a marginal tax rate of 35%. The tax depreciation schedule allows the following percentages of the cost of the kiln to be claimed during the kiln's life: year 1, 16%; year 2, 21%; year 3, 21%; year 4, 21%; and year 5, 21%.

The new kiln would be used to replace an existing kiln, which has a useful life of five years. The existing kiln has been fully depreciated and has a salvage value of $25,000.

The new kiln promises annual cost savings of $100,000 in the production of the existing plaques. In addition, the size and operating attributes of the new kiln will allow PPC to begin producing a new line of mugs that could be printed with the customer's promotional message. The net income before taxes expected from this new line of business is $120,000 per year.

The salvage value of the new kiln would be $50,000 in five years. PPC is required to take any salvage value, in excess of the undepreciated historical cost of an asset, into income to be taxed at the normal rate.

PPC's required after-tax return on this type of investment is 14%.

Required

(1) Should the new kiln be purchased?
(2) What is the rate of return on this investment?
(3) What is the minimum level of total annual savings and new net income at which the new kiln is desirable?
(4) What is the maximum purchase price of the new kiln at which this project is desirable?

12-2 Acme Telephone Company (William Cotton)

The Acme Telephone company is a supplier of telephone service to a medium-sized community in the Northeastern United States. Scott White, the chief executive of Acme Telephone company, has just attended a trade exhibition entitled "Automate, Emigrate, or Evaporate." As a result of what he learned at this exhibition, and also from scuttlebutt he has picked up from his peers in other companies, Scott is concerned about Acme's ability to maintain its competitive position in the telecommunications market. Owing to deregulation in the telecommunications industry and the aggressive actions of new competitors in the local area, a significant number of Acme's customers have switched to other suppliers of telephone and related telecommunications service.

White feels that if Acme were to invest fully in new state-of-the-art fiber-optics technology as well as upgrade to the latest computer equipment, the loss of market share may be arrested, and operating efficiency may be improved. He contacted a leading vendor of fiber-optics systems and associated computer equipment to obtain information on operating characteristics and costs. This vendor would provide the necessary fiber-optics equipment, all associated installation costs, computer hardware, and initial software support for a total cost of $30,000,000.

Although powerful and flexible, the new equipment is also compact, requiring much less space than the existing equipment. In addition, the equipment will require fewer people to operate and support it. Thus, additional benefits are realized by savings in occupancy and personnel support costs. The new equipment promises to be highly reliable and easy to maintain, and these attributes will lead to substantial savings in maintenance and repair costs. After White had consulted with his engineering and managerial accounting staff, the staff developed the following estimated annual cost of savings from implementing the new system:

1.	Reduction in occupancy costs due to reduced floor space requirements	$2.0 million
2.	Lower maintenance and repair costs	$4.0 million
3.	Reduced labor costs, fringe benefits, and associated overheads	$7.0 million

The new equipment should also lead to reduced levels of working capital. Because of the vastly improved reliability of the new equipment, inventories of spares and repair equipment will be minimized. And the high-quality customer service will result in far fewer disputed customer accounts, so more customers will pay their bills on time. White expects a $5,000,000 reduction in inventory and accounts receivable, which, for simplicity of analysis, he assumes will occur about the time the new equipment is put into operation.

In addition to the outlay costs for hardware and software, White is aware that there are likely to be substantial in-house expenses related to the installation of the new technology. The engineering and accounting staffs estimated $10,000,000 of one-time internal costs for implementing the new technology. These costs include the retraining of operating and maintenance personnel. For internal reporting purposes, the $10,000,000 internal costs will be capitalized along with the $30,000,000 purchase price when determining the investment required for the new proposal. In addition, the $10,000,000 internal costs will be amortized over the life of the project. For simplicity, it may be assumed that the

$10,000,000 implementation cost is required at the same time as the $30,000,000 equipment purchase is made.

The vendor of the equipment requires an annual maintenance contract of $1,500,000 for the computer equipment, and the annual costs of maintaining and upgrading the software programs are assumed to average about $2,000,000. The vendor is adamant that all the equipment will have at least a 10-year useful life if it is properly maintained. The estimated disposal price of the equipment and software programs is $5,000,000 at the end of five years and $2,000,000 at the end of 10 years. In evaluating capital expenditures, Acme normally uses a discount rate of 16% and a maximum time horizon of five years. Acme does its investment evaluation on a pretax basis.

Scott White has marshaled all these data and wishes to evaluate the proposed investment in the new technology. In addition to the quantifiable data, White knows that some difficult-to-quantify benefits from the new technology are not included in the analysis, and he is unsure how they should be handled.

Required

(1) What is the payback period for the proposal?
(2) Calculate the net present value of the proposal assuming Acme's normal assumptions of a 16% cost of capital and five-year life. Should Acme adopt the new equipment given its existing investment criteria?
(3) Scott White has read an article that argues that many companies are rejecting proposals because either the discount rate is too high or the time period over which the benefits are considered is too short. He believes that Acme should use a 10% discount rate and evaluate benefits over a 10-year period. Prepare some comments for White on the effect of making these changes in the net present value calculations.
(4) What other issues would you recommend that Acme consider in deciding whether to accept the proposal, and how would you factor these into your analysis?

■ *CASES*

OTHELLO CORPORATION (A): CAPITAL EQUIPMENT PLANNING AND CONTROL*

Our future as a business may well depend upon how well we invest in technology today," said Dan Krause, Vice Chairman of Othello Corporation, during a planning review meeting in April 1986. Joining him were Mike Sullivan, Director of Planning and Information Systems, and Mike Anderson, a newly hired MBA. "More than ever before," continued Krause,

> we are experiencing rapid changes in technology. These changes not only shrink our products' life cycles but also impact the methods we use to design and manufacture our products. To add to the challenge, our major customers, aircraft manufacturers and the federal government, are forcing our margins

*This case was prepared by Steve Young, under the direction of Professor Kavasseri V. Ramanathan, University of Washington, Seattle.

down while demanding higher levels of quality and service. To survive and grow profitably in this business we need to invest aggressively. Developing new products and marketing, protecting, and enhancing our current market positions, keeping our design and operating costs down, and assuring quality and service—all these require substantial and judicious commitment of new capital expenditures. Are we making the right investments? Is our capital expenditure planning and control process helping us to identify and decide on the relevant projects and monitor actual payoffs from such investments?

Continuing the review, Sullivan provided a historical perspective and said, "Our capital equipment process may have been adequate in the past, but we are a much larger business now and are shortly going public. This may be a good time to review the general approach and policies that guide our investment planning and decisions and how well they integrate with our strategic plan."

After some further discussion, it was agreed that Anderson would study the Othello capital expenditure decision process and report his findings and recommendations to Krause and Sullivan before their May meeting.

Background

Othello Corporation was founded in 1957 by a group of engineers from Boeing. At first, the corporation manufactured power conversion devices, such as transformers and power supplies, for military and aerospace applications. Since then it has grown in both size and scope to a corporation with 1,500 employees and fixed assets of $27 million. Its three revenue-producing divisions are expected to produce sales approaching $100 million in 1987.

The Power Conversion Division (PCD) retains Othello's original business and is the technology leader for the markets it serves. The Monitor and Control Division (MCD) manufactures instruments for measuring fuel flow in jet engines, while the Aircraft Systems Division (ASD) produces proximity switches and systems and aircraft power conversion equipment for commercial and military aircraft. ASD currently has 95% of the one-piece proximity switch market.

Capital Equipment Planning and Control

Prior to the annual operations planning meeting of Othello executive management in March, department managers are asked to identify items to be considered for the next fiscal year (April 1–March 31) capital budget. Department managers solicit ideas from their staff and then accept items they deem appropriate to support the production, sales, etc., forecast for their department. Ideas for new equipment may be based on the need for increased capacity, capability, productivity, or modernization required to operate effectively in the next year.

A Capital Facilities Plan FY is prepared listing the proposed items and is submitted to the division or support organization officer. One division requires a brief explanation of the reason for each equipment item to accompany the lists. The equipment lists of the various departments are reviewed by the officer, who may reject equipment items he deems as low priority or not appropriate. The equipment lists are then incorporated into the organization's fiscal year operations plan, which is submitted to the president/COO for review, approval, or modification.

At the annual operations planning meeting, the CEO reviews all division and support organization operations plans. The sales and profit plans are approved or directed to be modified. The CEO reviews each unit's capital equipment list and may question the need or reason for specific items. Subsequent to the reviews, capital equipment budgets for

EXHIBIT 1 Othello Capital Equipment Requests, Budgets, and Actual Expenditures ($000)

FISCAL YEAR		MCD	PCD	ASD	ALL OTHER*	TOTAL	ACTUAL EXPENDITURE
1987	Request	$556	$1,981	$1,719	$3,198	$7,454	
	Budget	500	1,200	900	1,800	4,400	$4,319
1986	Request	138	1,385	1,418	1,707	4,648	
	Budget	150	100	100	1,475	3,625	3,307
1985	Request	465	950	800	890	3,105	
	Budget	350	700	600	650	2,300	2,251
1984	Request	218	719	1190	1,818	4,017	
	Budget	220	635	750	1,395	3,000	1,838
1983	Request	334	774	1038	1,646	3,792	
	Budget	330	700	800	1,400	3,230	2,217

**Central Technology, Central Operations, Finance, Central Services, Human Resources.*

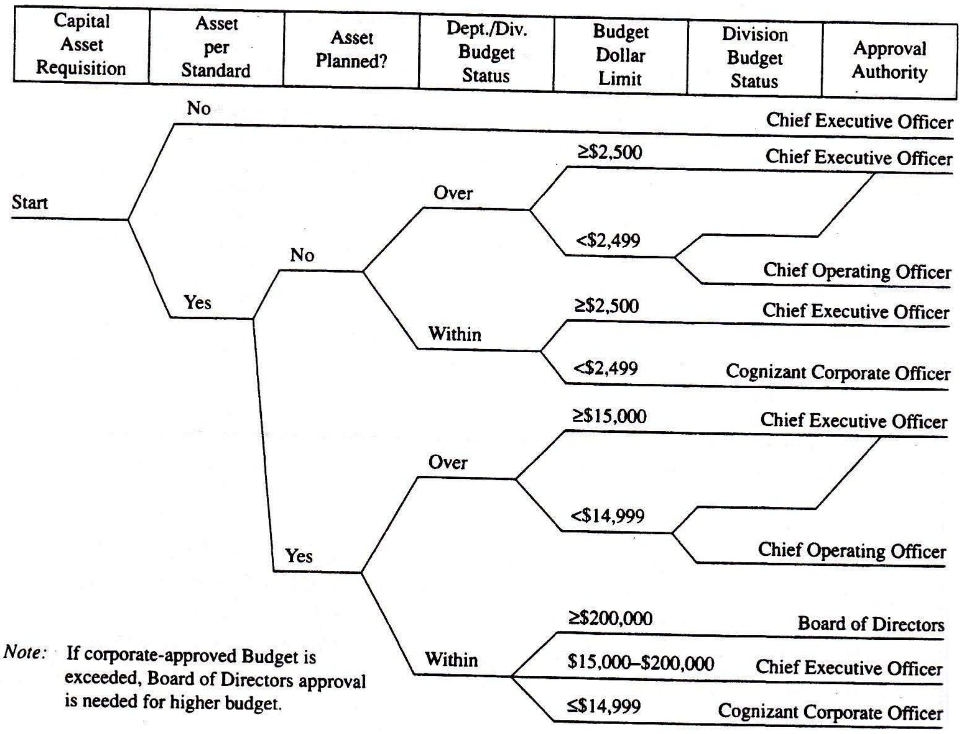
each division and support unit are established by the CEO. These budgets are based on a percent of sales for divisions and perceived need for support units. Subsequent to the meeting, a representative list of capital equipment items and the capital equipment budgets are submitted by the CEO to the Othello board of directors. The board approves the annual capital equipment budget and must also approve any individual capital item over $200,000.

The equipment lists are then communicated back down through the layers of management. The rejected items from the planning process are summarized and returned to the department managers. These are reviewed, and a decision is made on each item to either resubmit it for reconsideration, hold it for the next period, or reject it entirely. Exhibit 1 shows the budget requests, approved budgets, and the amount actually spent for each Othello division for the 1983 through 1987 fiscal years.

Before approved items can be purchased, each must go through a justification process. The requester fills out a Capital Asset Request and Analysis, which specifies the costs and potential savings associated with the acquisition. Bart Stein, CEO, has indicated that capital acquisitions are expected to provide an after-tax return of 15%.

The Capital Asset Request and Analysis form, along with a material requisition, and any supporting written justification, is then sent through an approval cycle. The approval cycle consists of successive levels of management review and approval, starting with the requester's supervision and ending with whichever management level retains final approval authority. Final approval authority is dependent on the asset cost and whether or not the item was part of the operations plan. Exhibit 2 shows the decision tree for final approval.

Having studied Othello policies and procedures concerning capital acquisition, Anderson considered his next step. Although specific information regarding past investments was not available, he concluded that the majority of purchases were under $15,000. To get a better feel for the process, he decided to talk with those involved—the managers responsible for purchasing equipment. He had already heard of some interesting acquisitions, so he knew just who to talk to.



Note: If corporate-approved Budget is exceeded, Board of Directors approval is needed for higher budget.

EXHIBIT 2 Capital Asset Acquisition Approval Decision Tree

PCD Data Acquisition System

Early in 1982, Bob Runner, Production Test Engineering Supervisor, began to recognize the need for more comprehensive monitoring of the inputs and outputs of PCD's power supply products during burn-in. Since burn-in forces failures, monitoring the supplies' inputs and outputs would provide valuable information that could lead to better designs and lower failure rates in the future. As Runner said:

> Right now a major piece of the manufacturing process is invisible. All we know when we remove a supply from the oven is that it did or didn't fail. We don't know exactly when or why it failed. Our present setup just doesn't give us the visibility we need. Also, several of our customers have requested continuous monitoring of the inputs and outputs of the supplies during burn-in. A better test facility would help us meet those requirements and give us the visibility into the process we need.

At that time, PCD was using several different methods of failure detection, ranging from simple periodic visual inspection by a technician for some products to a system employing rented data loggers for the products that require more extensive testing. All of the methods suffered from lack of consistency and an inability to document failure information. All methods proved to be cumbersome and time-consuming to perform.

After researching the problem, Runner concluded that the solution was to acquire a computer-controlled data acquisition system. Such a system would not only sample and store information during burn-in but also control the process itself. That is, it would control cycle times and temperatures as well as digitally program the burn-in loads.

Three data acquisition systems were included in PCD's operations plan for fiscal 1984. But, before the final purchase could take place, the systems had to be justified. Runner assigned Bob Smith, a test engineer, to prepare the formal justification.

Smith, like Runner, believed in the necessity of the data acquisition system and stated:

> We need the data acquisition system for more than just meeting customers' requests for continuous monitoring. At present, no one knows when a supply fails. Heck, no one is even here at night. How are we supposed to know when or under what conditions one failed if it goes overnight? If we can accurately determine the causes of failures we should be able to cut down on the failure rates of our products. But there is no way we can do that with the jerry-rigged setup we have now.

After preparing a material requisition (MR) for the three data acquisition systems, costing $25,000, Smith completed the Capital Assets Request and Analysis form.

> I didn't see any savings at first, so I gave the proposal to Justin [Justin Pearce, Division Controller] justifying the purchase solely on the basis of customer requests for continuous monitoring during burn-in.

The proposal was not approved. The request was returned to Smith with instructions to try and quantify the cost savings to justify the purchase. This instruction forced Smith to rethink the reasons behind the purchase. He came up with four alternatives against which to compare the cost of the data acquisition system:

1. Continue to rent the data loggers
2. Buy the data loggers
3. Hire additional personnel to run the tests
4. Negotiate out of the extra requirements

Alternative number four was ruled out because Smith believed that Othello had a need for the information. Smith resubmitted the request, basing his analysis on what it cost to continue running the tests on the rented data loggers. Discounting the future cash savings at 20%, Smith found that the proposed system would pay back in about five years.

Again, the request was sent back to Smith, unapproved. Justin Pearce explained:

> A five-year payback tells me that this project shows more risk than it should. Something we need as much as this should pay back in around two years. If it does take five years to pay back, maybe we should reevaluate the idea.

Smith gave it one more try. This time, basing his analysis on PCD having to hire six additional personnel (three shifts per day, two people per shift) to perform the tests manually, he achieved a payback in two years. (See Exhibit 3 for the analysis). To ensure a better chance of having the proposal approved, Smith included with the analysis a thorough justification including all the specifications for the equipment. The resulting document was over an inch thick.

The request was approved by both Justin Pearce and PCD's general manager, Mark Price, and sent on for final approval to Stein. Stein sent the request back asking for an analysis of one system instead of three, preferring to let the system prove itself before purchasing the final two. The request was changed (see Exhibit 4 for the cover memo that accompanied the revised request), and the single system was purchased. But, as Bob Runner noted, "By the time we evaluate the first system we will have spent the cost of the other two renting the data loggers for handling what one system can't." Smith added, "We bought our system, but that little notebook [pointing to the data acquisition proposal] probably cost us more than the equipment."

ASD—Automated Circuit Board Stuffing Machine

Art Campbell had just started his summer internship at ASD when Ewing Kendell, Direc-

EXHIBIT 3 Capital Asset Request & Analysis

DESCRIPTION: Data Acquisition and Central System
[ ] JUSTIFIABLE AS COST SAVING (SEE BELOW)

ASSET COST (LINE 5) $ 35,000
[ ] NEEDED FOR

PART NUMBER OR ACTIVITIES		UNIT LABOR COSTS HRS	UNIT LABOR COSTS $	UNIT $/ OH COSTS HRS	UNIT $/ OH COSTS $	UNIT MATERIALS $ * 20%	TOTAL UNIT COST		YEAR 1 '83	YEAR 2 '84	YEAR 3 '85	YEAR 4	YEAR 5
1. SAVINGS FROM ASSET USE	NEW	4,160	$10				41,600	QTY	41,600	41,600	41,600		
	OLD							SAVINGS/YR					
A 48 hrs/day	DIFF $												
	NEW							QTY					
	OLD							SAVINGS/YR					
B	DIFF $												
	NEW							QTY					
	OLD							SAVINGS/YR					
C	DIFF $												
	NEW							QTY					
	OLD							SAVINGS/YR					
D	DIFF $												
	NEW							QTY					
	OLD							SAVINGS/YR					
E	DIFF $												

		YEAR 1 '83	YEAR 2 '84	YEAR 3 '85	YEAR 4	YEAR 5
1. TOTAL SAVINGS APPLICABLE TO PARTS COST (SUM OF 1A THRU 1E)		41,600	41,600	41,600		
2. OTHER COSTS (OR SAVINGS)						
A. MAINTENANCE		2,500	2,500	2,500		
B. SUPPLIES		900	900	900		
C. TOOLING						
D. SPOILAGE						
E. FLOOR SPACE $ 3 / SQ FT (FIGURE ON CHANGE FROM OLD TO NEW, USE ( ) IF LESS)		n/a	n/a	n/a		
F. TAXES & INSURANCE OTHER THAN INCOME TAXES (.025 OF ORIGINAL COST PER YEAR)		570	570	570		
G. INSTALLATION COSTS (ZERO AFTER YR1 UNLESS MOVE IS PLANNED)		6000				
3. SUBTOTAL ADDED COSTS (SUM OF 2A THRU 2G)		9,970	3,970	3,970		
4. CASH SAVINGS (LOSS) (1.) − (3.)		31,630	37,630	37,630		
5. ASSET COST (ENTER IN COL YR1 THRU YR5) (PRICE + SALES TAX + FREIGHT)		25,000	25,000	25,000		
6. DEPRECIATION FACTOR (DEPENDS ON TYPE OF ASSET)		0.15	0.22	0.21		
7. DEPRECIATION EXPENSE (5.) × (6.)		3,750	5,500	5,250		
8. TAXABLE SAVINGS (4.) − (8.)		27,880	32,130	32,380		
9. INCOME TAXES (8.) × 0.48 (CORP. TAX RATE = 48%)		13,382	15,422	15,542		
10. NET CASH SAVINGS (AFTER TAXES) (4.) − (9.)		18,248	22,208	22,088		
11. TAX CREDIT (10% OF ASSET VALUE. LINE 5.) (ENTER COL 1 ONLY)		2,500				
12. TRADE IN OR SALE OF REPLACED ASSET (ENTER COL 1 ONLY)			—	—		
13. SALVAGE VALUE (ENTER COL 3 ONLY)		—	—	—		
14. TOTAL CONTRIBUTION (10.) + (11.) + (12.) + (13.)		20,748	22,208	22,088		
15. PRESENT VALUE FACTOR 20% = DISCOUNT RATE		0.833	0.694	0.578		
16. PRESENT VALUE (14.) × (15.)		17,283	15,412	12,767		
17. CUMULATIVE PV (COLUMN TO COLUMN)		17,283	32,695	45,461		

Exhibit 4

MEMORANDUM

November 6, 1985

JMH85-81

TO: B. Stein 30
FROM: J. Pearce 20

SUBJECT: Data Acquisition and Control System

REFERENCE: Our Prior MR and Justification Submittal

The prior submittal was difficult, if not impossible to follow.

Rather than completely rewrite that document I have abstracted and extracted from that document to create a new one.

The problem that we are attempting to solve is to continuously monitor the output of power supplies during burn-in. Making the task more complex is the requirement to program the temperature setting and cycle the power on and off at certain points during the temperature cycle.

We attempted to solve this problem with an internally designed system based on Fluke 2280 data loggers. This system could not provide the interactive control required, the data logger has proven to be too noise-sensitive and not very reliable, and the nature of recorded data is not very suitable for analysis or customer presentation.

Using the data logger approach, however, did demonstrate that this concept works but more versatile equipment is needed.

Continuous monitoring would be a benefit for the burn-in of all of our products; however, today, on only a few do we have a contractual requirement. Table 1 [not shown] shows the products which have the continuous monitoring requirement which is either contractually imposed or self-imposed because of the complexity of the supply (i.e., potential of intermittent problems during temperature cycling).

We will be needing three systems during the next year; however, this request is for only one system to prove out the specific systems approach.

The cost savings and justification are based on this system's performing the work equivalent to two man-years per year.

This is an abstract concept. The data acquisition system can manage, control, and record data from two ovens at once, with each oven loaded with ten power supplies and each supply with seven outputs. The primary controlling and recording activity occurs on a cyclic basis, therefore the workload may be equivalent to six man-hour per hour loads per day plus one continuous man-day per day.

tor of Manufacturing, approached him with a project:

> Art, I've got a job that I'd like you to do. I've come to the conclusion that our circuit board stuffing could be improved. I know that a fully automated insertion machine is probably more than we can use, but a light-guided insertion machine may be just about right. I would like you to do a study and determine if it is cost-effective for us to purchase one.

Campbell began by researching the current process. He found that most boards were stuffed manually while the rest were stuffed on the slide line. Manual insertion rates ranged from 100 to 300 components per hour. The slide line boosted rates about 21%. The rates varied according to the complexity of the board (see Exhibit 5).

Consolidating data on ASD's product line, such as the number of boards per order, number of components per board, and time currently required to stuff each board, it was possible to define a "typical" board in terms of labor hours required for stuffing, rework, inspection, and test. The results are shown in Exhibit 6.

Given that historical data showed that 62,358 labor hours were required to complete 11,070 boards, a typical board required 5.6 hours to produce. Using the percentage figures from Exhibit 6, the labor hours involved in this typical board as 0.56 hours to stuff, 0.39 hours to rework, 0.08 hours to reinspect, and 0.29 hours to troubleshoot in the first test after stuffing (see Exhibit 7).

The next step was to find out what kind of performance the light-guided stuffing machine could provide. Light-guided insertion machines improve stuffing rates because they present the operator with the component and show the proper location and orientation for the insertion. With this assistance, operators can achieve rates of 300 to 600 components per hour. The vendor's literature also claimed possible reductions in error rates over unaided assembly of 50% to

EXHIBIT 5 Component Insertion Rates for Selected Boards

PART NUMBER	SAMPLE SIZE (BOARDS)	COM-PONENTS BOARDS	STUFFING RATE (HR/BOARD)	INSERTION RATE (COMPONENTS/HR)	NOTES
8-317003-01	138	48	0.30	160	
8-060-02	2,064	56	0.18	311	Slide line
8-341105-01	29	101	0.48	210	
8-336401-01	22	138	0.76	182	
8-355303-01	26	160	0.81	198	
8-336103-01	26	181	0.65	278	
8-336205-01	27	250	0.99	253	
8-336311-01	66	299	0.77	388	
8-356-01	315	413	1.20	344	Unaided
	626		0.99	417	Slide line
	13		0.81	510	Guided (2 boards allowed for training)
8-351-07	249	462	1.68	275	Unaided
	23		1.47	314	Slide line
	14		1.09	426	Guided (2 boards allowed for training)

EXHIBIT 6 Stuffing, Rework, Inspection, and Test for Selected Boards

	PERCENTAGE OF TOTAL HOURS			
PART NUMBER	STUFFING*	REWORK†	INSPECTION‡	TEST§
8-317003-01	6.3	12.3	0.8	2.3
8-060-02	11.5	5.8	2.2	1.3
8-341105-01	8.6	8.5	1.1	16.4
8-336401-01	9.5	6.0	3.0	9.4
8-355303-01	9.9	6.4	1.1	5.2
8-336103-01	12.0	8.3	2.0	5.0
8-336205-01	15.2	4.9	0.5	5.2
8-336311-01	5.2	6.3	0.8	1.0
8-356-01	8.1	4.9	1.1	2.3
8-351-07	14.2	5.8	1.5	3.6
$\overline{X} \pm S$	10.0 ± 3.2%	6.9 ± 2.2%	1.4 ± 0.8%	5.2 ± 4.7%

**Stuffing includes only actual run hours in the "stuff" step of the process flow.*
†*Rework includes only CBA "manufacturing originated" rework hours.*
‡*Inspection includes only "reinspection" hours in the first inspection after stuffing.*
§*Test includes only "trouble-shooting" hours in the first test after stuffing.*

95%. But the extra costs associated with the machine included programming time for each type of board that Campbell estimated would require almost 200 hours per year. He also expected maintenance costs of $500 per year.

As he was analyzing the data he had collected, Campbell discovered that PCD had recently purchased its own light-guided machine. Recognizing a chance to obtain some actual data on machine performance, Campbell called PCD.

PCD personnel were enthusiastic about

EXHIBIT 7 Estimated Stuffing, Rework, Inspection, and Test Labor Hours for a Typical Board

	MANUAL	LIGHT-GUIDED	DIFFERENCE
Stuffing	0.56	0.37	0.19
Rework	0.39	0.16	0.23
Inspection	0.08	0.05	0.03
Test	0.29	0.18	0.11
	1.32	0.76	0.56

Assumptions:

1. Likely order size = 10 boards
2. Guided insertion requires 0.25 hour setup per order
3. Average insertion rates: manual = 280 components guided = 450 components
4. 50% of board failures are due to stuffing errors
5. 75% reduction in unaided error rates with guided insertion

EXHIBIT 8 Capital Asset Request & Analysis

DESCRIPTION: Guided Component Insertion [ ] JUSTIFIABLE AS COST SAVING (SEE BELOW)

ASSET COST (LINE 5) $ [ ] NEEDED FOR

PART NUMBER OR ACTIVITIES		UNIT LABOR COSTS HRS	UNIT LABOR COSTS $	UNIT $/ OH COSTS HRS	UNIT $/ OH COSTS $	UNIT MATERIALS $ * 20%	TOTAL UNIT COST		YEAR 1 80%	YEAR 2 90%	YEAR 3 100%	YEAR 4 100%	YEAR 5 100%
1. SAVINGS FROM ASSET USE	NEW												
	OLD							QTY	3,200	3,600	4,000	4,000	4,000
A CBA STUFFING	DIFF $	0.19		6.46			1.23	SAVINGS/YR	3,928	4,419	4,910	4,910	4,910
	NEW												
	OLD							QTY					
B CBA REWORK	DIFF $	0.23		6.46			1.49	SAVINGS/YR	4,755	5,349	5,943	5,943	5,943
	NEW												
	OLD												
C INSPECTION	DIFF $	0.03		7.34			0.22	QTY	705	793	881	881	881
	NEW							SAVINGS/YR					
	OLD												
D TEST	DIFF $	0.11		8.86			0.97		3,119	3,509	3,898	3,898	3,898
	NEW							QTY					
	OLD							SAVINGS/YR					
E TOTAL	DIFF $	0.56					3.91						

		YEAR 1	YEAR 2	YEAR 3	YEAR 4	YEAR 5
1. TOTAL SAVINGS APPLICABLE TO PARTS COST (SUM OF 1A THRU 1E)		12,506	14,069	15,632	15,632	15,632
2. OTHER COSTS (OR SAVINGS)						
A. MAINTENANCE		500	500	500	500	500
B. SUPPLIES		1,292	1,292	1,292	1,292	1,292
C. TOOLING						
D. SPOILAGE						
E. FLOOR SPACE $ 3 / SQ FT (FIGURE ON CHANGE FROM OLD TO NEW, USE ( ) IF LESS)						
F. TAXES & INSURANCE OTHER THAN INCOME TAXES (.025 OF ORIGINAL COST PER YEAR)		625	625	625	625	625
G. INSTALLATION COSTS (ZERO AFTER YR1 UNLESS MOVE IS PLANNED)						
3. SUBTOTAL ADDED COSTS (SUM OF 2A THRU 2G)		2,417	2,417	2,417	2,417	2,417
4. CASH SAVINGS (LOSS) (1.) − (3.)		10,089	11,652	13,215	13,215	13,215
5. ASSET COST (ENTER IN COL YR1 THRU YR5) (PRICE + SALES TAX + FREIGHT)		25,000	25,000	25,000	25,000	25,000
6. DEPRECIATION FACTOR (DEPENDS ON TYPE OF ASSET)		0.2500	0.1875	0.1406	0.1055	0.0791
7. DEPRECIATION EXPENSE (5.) × (6.)		6,250	4,688	3,515	2,638	1,978
8. TAXABLE SAVINGS (4.) − (9.)		3,839	6,964	9,700	10,578	11,238
9. INCOME TAXES (8.) × 0.48 (CORP. TAX RATE = 48%)		1,843	3,343	4,656	5,077	5,394
10. NET CASH SAVINGS (AFTER TAXES) (4.) − (8.)		8,246	8,309	8,559	8,138	7,821
11. TAX CREDIT (10% OF ASSET VALUE. LINE 5) (ENTER COL 1 ONLY)		2,500	—	—	—	—
12. TRADE IN OR SALE OF REPLACED ASSET (ENTER COL 1 ONLY)		—	—	—	—	—
13. SALVAGE VALUE (ENTER COL 3 ONLY)		—	—	—	—	
14. TOTAL CONTRIBUTION (10.) + (11.) + (12.) + (13.)		10,746	8,309	8,559	8,138	7,821
15. PRESENT VALUE FACTOR 15% = DISCOUNT RATE		0.928	0.807	0.702	0.610	0.531
16. PRESENT VALUE (14.) × (15.)		9,972	6,705	6,006	4,965	4,150
17. CUMULATIVE PV (COLUMN TO COLUMN)		9,972	16,677	22,683	27,648	31,798

their machine. Operators were said to "fight over" the chance to use the machine. Insertion rates had jumped to between 400 and 500 components per hour, while stuffing error rates had been reduced 90%. Also, the department could use lower skill level operators and still increase the level of reliability of the stuffing operation.

Campbell felt that he now had enough data to begin his analysis. Based on the data he had collected, he developed a comparison of labor hours between the current stuffing process and the proposed light-guided insertion machine. Exhibit 7 shows the results of Campbell's comparison.

Assuming the machine would be used at 80% capacity the first year, 90% the second, and finally reaching 100% in the third, payback on the $25,000 insertion machine was 3.5 years. Exhibit 8 is the completed Capital Asset Request and Analysis form.

The investment looked like a good opportunity, and it was approved by senior management, but Campbell was still concerned about his analysis:

> I really don't know how representative my analysis was of the investment. To be safe, I was conservative with my estimates, so if anything, the project is better than my justification shows. But I don't know if I used the correct discount rate for this type of investment. All I used was what was printed on the Capital Asset Request and Analysis form. Also, I had no way to quantify other benefits the machine provides. For example, because it can be operated by less-skilled workers, the more experienced people are freed up to do other things. How can you quantify the flexibility it gives us because of something like that? I'm glad it could be justified on cost savings alone.

TCO—Computer-Aided Design System

Early in 1981, Joe Heefer, Director of Engineering for Technology and Central Operations, was looking for ways to improve the productivity of the Othello printed circuit board (PCB) designers. In researching how other firms were performing the same task, he discovered that many were using computer-aided design (CAD) systems as tools to speed the process and, at the same time, improve the quality of designs. Further research on the concept convinced Heefer that CAD was an important step that Othello should take.

CAD

A CAD system is an integrated package of computers, graphics terminals, plotters, and specialized software aimed at helping the engineer with the design process. Within the CAD system, extensive data bases are developed that allow engineers to try many different designs and test the performance of those designs. This can greatly reduce the time for a product to reach production.

Ultimately, CAD can be extended to engineering analysis, manufacturing, and document control. The data base linking the various areas serves to improve both the speed and accuracy of the product development cycle. CAD software is available to do circuit simulation, thermal analysis, and mechanical design and to track engineering changes and even to program automatic manufacturing equipment.

Feasibility Study

A study that took almost a year was conducted to assess the possibility of implementing an Othello CAD system. PCB design was anticipated to be the major use for the system initially. The analysis focused on determining possible cost savings with a CAD system. Both the historical and projected number of circuit boards designed by each division were determined to gauge potential savings.

A series of meetings with a Corporate Engineering User Committee were held to dis-

EXHIBIT 9 Benchmark Results

	TIME TO COMPLETE	
FUNCTION	SYSTEM X	SYSTEM Y
PCB Design		
(130-hr manual job)		
Schematic entry	5.0 hr	5.5 hr
Reference designation	2.0	1.5
Auto Placement	1.0	0.3
Interactive placement	1.5	0.5
Auto routing	2.0	3.0
Interactive routing	8.0	20.0
Run prints	1.0	1.0
Total	20.5 hr	31.8 hr
Net savings	109.5 hr	98.2 hr
Mechanical Part Design		
(4- to 6-hr manual job)		
Design part	3+ hr	2 hr
Run plots	5 min	5 min
Total	3+ hr	2+ hr
Net savings	3 hr	4 hr

cuss CAD's role in the long-term growth of Othello. Discussions centered on whether CAD was the appropriate step for Othello to take and, if it was, how much capability was required. The committee reached a consensus that Othello needed a full-capability system and identified two possible vendors.

A benchmark design of a representative board was done using each of the two systems (X and Y) under consideration (see Exhibit 9). Exhibits 10 and 12 show the projected costs and savings from the proposed system. From the results of the benchmark design, an estimate of the number of hours saved using CAD was produced (see Exhibit 11).

The initial proposal called for two identical systems (Y) to meet the projected usage levels. Senior management was skeptical at first, preferring either to wait on moving to CAD or to purchase only one system and let it prove itself before expanding to a larger system. They felt that the savings might not be entirely realizable due to the risks involved with implementing such a system. After much discussion, they finally decided to purchase two systems. In approving the systems, Bart Stein required that adequate records be maintained to keep track of the output of the systems and the savings gener-

EXHIBIT 10 Cost and Savings ($000)

Nonrecurring Costs			
Equipment purchase	$568		
Facilities	63		
Startup labor	39		
Training	25		
Initial lower efficiency	70		
Total	$765		
Recurring Savings and Costs			
	FY83	FY84	FY85
PCB & mechanical part design	$491	$550	$615
Maintenance contracts	(71)	(71)	(71)
Photo plotting	(48)	(61)	(71)
Training	(5)	(6)	(7)
System overhead labor and materials	(69)	(76)	(83)
Total	$298	$336	$383

EXHIBIT 11 CAD Presentation Made to Executive Management on December 14, 1981

	CAD HOURS			
	MCD	PCD	SSD	TOTAL
FY 1983				
Manual	8623	33049	20800	62472
Caddable	4623	29049	18800	52472
CAD	1934	9982	5800	17716
FY 1984				
Manual	9485	43841	26500	79826
Caddable	5485	39841	24500	69826
CAD	2294	13691	7500	23485
FY 1985				
Manual	10396	49313	35000	94709
Caddable	6396	43213	33000	82609
CAD	2676	14849	10100	27625
CAD factor				
(caddable/CAD)	2.39	2.91	3.26	

Calculation of Savings Possible

1. CAD factor = CF = Weighted average of division cost improvement

$$CF = \frac{2.91\,(25) + 3.26\,(12.6) + 2.39\,(4.3)}{25 + 12.6 + 4.3^{*}}$$

CF = 2.95

2. Capacity of system in hours
   A. Gross capacity @ 2 shifts
      4 stations × 2080 × 2 = 16640
   B. Factored: 20% for downtime and usage factor
      10% for training

   16640 × 0.7 = 11,648 net hours available

   C. Hour savings = 11648 (CF − 1) = 11,648 (1.95) = 22,713

3. Cost savings:
   Saving = manual hours (1 − 1/CF) × rate =
   CF (CAD hours) (1 − 1/CF) × rate = CAD hours (CF − 1) × rate
   Calculation of FY83 weighted mechanical design rate

$$Rate = \frac{25(12.04^{\dagger})(1.92^{\dagger}) + 12.6(11.95)(1.68) + 4.3(9.86)(1.73)}{25 + 12.6 + 4.3}$$

Rate = \$21.60

Savings = (CAD hours) (CF − 1) (rate)

FY 1983: Savings = (11,648)(1.95)(21.6) = 490,613
FY 1984: Savings = (490,613)($1.12^{\dagger}$) = 549,487
FY 1985: Savings = (549,487)($1.12^{\dagger}$) = 615,425

*Total hours of caddable labor = SSD 25,000; PCD 12,600; MCD 4,300.

†Inflation factor: 12.04 = hourly wage rate; 1.92 = overhead rate.

EXHIBIT 12 Capital Asset Request & Analysis

DESCRIPTION: Computer Aided Design System　　[ ] JUSTIFIABLE AS COST SAVING (SEE BELOW)

ASSET COST (LINE 5) $ 765.00　　[ ] NEEDED FOR

PART NUMBER OR ACTIVITIES		UNIT LABOR COSTS HRS	UNIT LABOR COSTS $	UNIT $/ OH COSTS HRS	UNIT $/ OH COSTS $	UNIT MATERIALS $ * 20%	TOTAL UNIT COST		YEAR 1 '83	YEAR 2 '84	YEAR 3 '85	YEAR 4	YEAR 5
1. SAVINGS FROM ASSET USE	NEW												
	OLD							QTY					
A	DIFF $							SAVINGS/YR					
	NEW												
	OLD							QTY					
B	DIFF $							SAVINGS/YR					
	NEW												
	OLD												
C	DIFF $							QTY					
	NEW							SAVINGS/YR					
	OLD												
D	DIFF $												
	NEW							QTY					
	OLD							SAVINGS/YR					
E	DIFF $												

		YEAR 1 '83	YEAR 2 '84	YEAR 3 '85	YEAR 4	YEAR 5
1. TOTAL SAVINGS APPLICABLE TO PARTS COST (SUM OF 1A THRU 1E)		298,000	336,000	383,000		
2. OTHER COSTS (OR SAVINGS)						
A. MAINTENANCE						
B. SUPPLIES						
C. TOOLING						
D. SPOILAGE						
E. FLOOR SPACE $ 3 / SQ FT (FIGURE ON CHANGE FROM OLD TO NEW, USE ( ) IF LESS)						
F. TAXES & INSURANCE OTHER THAN INCOME TAXES (.025 OF ORIGINAL COST PER YEAR)						
G. INSTALLATION COSTS (ZERO AFTER YR1 UNLESS MOVE IS PLANNED)						
3. SUBTOTAL ADDED COSTS (SUM OF 2A THRU 2G)						
4. CASH SAVINGS (LOSS) (1.) − (3.)		298,000	336,000	383,000		
5. ASSET COST (ENTER IN COL YR1 THRU YR5) (PRICE + SALES TAX + FREIGHT)		765,000	765,000	765,000		
6. DEPRECIATION FACTOR (DEPENDS ON TYPE OF ASSET)		.25	.1875	.1406		
7. DEPRECIATION EXPENSE (5.) × (6.)		191,250	143,438	107,559		
8. TAXABLE SAVINGS (4.) − (8.)		106,750	192,560	275,441		
9. INCOME TAXES (8.) × 0.48 (CORP. TAX RATE = 48%)		51,240	92,428	132,212		
10. NET CASH SAVINGS (AFTER TAXES) (4.) − (8.)		246,760	243,570	250,788		
11. TAX CREDIT (10% OF ASSET VALUE. LINE 5.) (ENTER COL 1 ONLY)			—	—	—	—
12. TRADE IN OR SALE OF REPLACED ASSET (ENTER COL 1 ONLY)			—	—	—	—
13. SALVAGE VALUE (ENTER COL 3 ONLY)		—	—	—	—	
14. TOTAL CONTRIBUTION (10.) + (11.) + (12.) + (13.)		246,760	243,570	250,788	250,788	250,788
15. PRESENT VALUE FACTOR 15% = DISCOUNT RATE		.870	.756	.658	.572	.497
16. PRESENT VALUE (14.) × (15.)		214,680	184,139	165,019	143,451	124,642
17. CUMULATIVE PV (COLUMN TO COLUMN)		214,680	398,819	563,838	707,288	831,930

ated. The time spent designing PCBs on the CAD equipment was monitored and compared against historical figures.

Within a few months after installation, it became apparent that the systems would not generate the savings predicted. They were not able to reduce the time required to design circuit cards. Further analysis showed that the CAD software did not have the capability to handle the complex, tightly packaged PCBs Othello used.

Joe Heefer, however, remained convinced of the necessity of the project:

> It's a shame the only thing we can measure on the CAD system is the one thing it failed at. It does the job expected on mechanical design. Plus, I'm convinced our quality has gone up, but how can you quantify that? Maybe we should have presented a clearer picture of the extent we were justifying the equipment for immediate savings and the extent it was intended to serve long-term strategic goals.

Conclusion

Having reviewed his notes, Mike Anderson considered in what ways Othello's capital equipment acquisition could be improved. Gathering all the information he had collected, he settled down to write his recommendation.

WILMINGTON TAP AND DIE (ABRIDGED)*

Len Green pulled on his coat and walked out the door of the administration building toward the loading dock of the adjacent factory. Four new automated Icahn thread grinding machines used in the production of taps had just been delivered, and Len knew many of the managers would be gathering to see them. As he strolled toward the dock he couldn't help but remember taking this same walk seven months before in May 1978 when the first two Icahns had arrived. It had been his first day as plant manager of Wilmington Tap and Die (WTD).

WTD now had a total of seven Icahns (including this delivery and one prototype purchased in 1974). They had all been ordered by Len's predecessor as part of a manufacturing modernization program. The program called for the purchase of an additional 10 Icahns over a three-year period, but Len had halted further purchases based on a September performance audit of the first three machines. The audit showed that the productivity and expenses associated with the Icahns had been much worse than expected. In addition, sales of WTD taps for the first half of 1978 had been 20% below forecast. Len had to decide whether he should proceed with the purchase of the four Icahns planned for 1979.

Background of Wilmington Tap and Die

Wilmington Tap and Die was incorporated in 1912 after the merger of three machining firms. The three companies were located in the small industrial town of Wilmington and had started up based on an 1871 screw-cutting invention used to produce taps and dies. The company grew through a series of mergers and acquisitions in the 1920s, 1930s, and 1950s and added drill bits to the tools that it produced. Following a 1963 merger with the American Tool Corporation, WTD became one of the world's largest producers of

*This case was prepared by Research Associate Glenn Bingham under the supervision of Professor Robert S. Kaplan.

threading and cutting tools. In 1971, the company was acquired by United Industries, a diversified manufacturer of electronic, aerospace, and industrial products.

United and WTD

WTD was a division in United's Industrial Products Group. WTD had sales of $18.5 million ($6 million from tap sales) in 1977 on total assets of $8.1 million. The division had been profitable even though sales had been stagnant for the past four years (see Exhibit 1). WTD had been acquired as part of United's strategy to purchase and rationalize high-quality manufacturing businesses with high engineering content. The merger with United had not caused many apparent changes in the management of WTD other than modifications made in the budgeting and accounting systems to conform with United's practices. The plant manager prior to Len Green had been with WTD for over 26 years. WTD operated autonomously except that the plant manager could not make any unbudgeted capital expenditures over $10,000 without approval from United superiors. Under United's capital budgeting process, expenditures over $1,000,000 required CEO approval, expenditures above $500,000 required sector approval, and expenditures over $250,000 had to receive group-level approval. United normally applied a 20% ROI hurdle rate when evaluating capital expenditure requests.

Tap Production and Marketing

Taps are used to cut threads into a drilled hole. WTD, with a 9% share of market, was one of the largest producers of taps in the country (see Exhibit 2). It produced a full line

EXHIBIT 1 Income Statement Summary ($ Millions)

	1974	1975	1976	1977
Sales	18.3	17.6	17.6	18.5
Cost of sales—standard	10.2	9.7	10.0	10.2
Gross margin	8.0	7.9	7.6	8.3
Variances	1.0	1.5	1.5	0.7
Actual margin	7.0	6.4	6.1	7.6
SG&A	3.7	3.2	4.8	4.6
Profit before tax	3.4	3.3	1.3	3.0
Tax	1.6	1.5	0.6	1.4
Profit after tax	1.8	1.7	0.7	1.6

Balance Sheet Summary ($ Millions)

	1974	1975	1976	1977
Receivables	2.1	1.8	1.6	2.1
Inventories	4.8	3.7	3.6	4.3
Current liabilities	−1.8	−1.2	−1.5	−1.4
PP&E	1.9	1.9	2.2	3.1
Total	7.0	6.2	5.9	8.1
ROI				
(Net income/net assets)	25.6%	27.9%	11.9%	19.6%

EXHIBIT 2 Market Share of Tap Market

Greenfield	12%
Winter Brothers	10
Wilmington	9
Bendix	8
Cleveland	6
Brubaker	6
Regal Beloit	5
Vermont	4
Jarvis	4
Hanson-Whitney	4
Morse	4
Sossner	3
Reiff & Nestor	3
Bath	2
Hypro	1
Wood & Spencer	1
Detroit Tap	1
New England Tap	1
New York Twist	New
Other	16%

of taps used in the automotive, hydraulic, construction, and machinery manufacturing industries. The company was known for its high-quality products and its sales support for distributors. WTD considered its strong distribution base as one of its principal strengths. WTD was especially strong among distributors that supplied the smaller end users.

WTD was considered one of the "traditional" manufacturers in the industry along with Greenfield, Winter Brothers, Besley, Cleveland, Union Twist, and some smaller operations. The "traditionals" generally represented the older companies (in business 50 years or more). Most were located in the Northeast (many near the Wilmington area), were unionized, and offered a full product line through a network of tool distributors.

The newer tap manufacturers ("independents") were mostly located in the South and generally had lower labor costs than the traditional firms. The independents had carved out part of the tap market by utilizing specialized marketing strategies. Low price was a key factor, and quality was also important because long and consistent tool life expectancy enabled end users to reduce the expense and disruption caused by frequent tap changes. Companies such as Regal Beloit and Vermont competed by providing 24-hour (or less) delivery of taps that had to be custom-produced. They were adept at producing small volumes that required frequent machine setups.

WTD anticipated that lower unit manufacturing costs when using the automated Icahn grinders would allow it to begin competing for the business of the large-volume, price-sensitive end users.

Thread Grinding Machines

Grinding the threads onto a tap blank was the last major step in the production process. It was also the most critical step from a cost and quality standpoint. Thread grinding was the most labor-intensive part of production and required the use of expensive machining equipment and skilled machinists. The quality of the tap was almost exclusively a function of how accurately the threads were ground. WTD used two types of grinding machines prior to purchasing the Icahns.

There were 16 Wilmington Automatic Mechanical Thread Grinders that produced sizes #6 MS to ¼″ inclusive. These machines had been designed and built by Wilmington engineers as hand machines in the 1930s and had been automated in the late 1950s. They operated by a single-rib (grinds one thread at a time), multipass grinding method that had remained essentially the same for 20 years. The age of these machines made it increasingly difficult to ensure quality output. Much of WTD's historical success was due to the high productivity of these machines when first developed and especially after their automation in the 1950s. Now, however, they were no longer as productive as the machines used by competitors.

The company also had eight Jones & Lamson Hydraulic Automatic Thread Grinders that manufactured tap sizes 5⁄16" through 3⁄8". These machines were purchased in the late 1960s, when it became economically impractical to develop entirely new grinding equipment internally. The J&L grinders also operate using the single-rib, multipass grinding method. WTD had made several proprietary improvements to help increase the production efficiency of the J&Ls.

Icahn Grinding Machines

Shortly after the 1971 acquisition, United made a strategic commitment to maintain WTD's quality and leadership position in the industry. Most other tap producers were also using modified J&L grinders, and any perceived quality gap was narrowing. Investment in the most modern equipment to improve manufacturing efficiency was considered an important part of WTD's future success. As a result, WTD formed a manufacturing engineering team in early 1973 to rationalize the manufacturing process and investigate the latest alternative equipment available. The company discovered that no new thread grinding technology had been developed, so WTD began work with Icahn, a Swedish company, to design a fully automated multirib thread grinder. A prototype, known as the "yellow bird" (because it was yellow), was purchased in 1975 and installed on an experimental basis in the Wilmington plant. The production experience with the yellow bird was encouraging. The machine was not only more efficient than other grinders but it produced a much higher quality tap. The principal quality advantage of the taps produced on the Icahn was a much longer life expectancy. This was apparently due to lower grinding temperatures, which produced less metallurgical damage to the hardened steel used for the taps. WTD engineers felt that over time several modifications could be made in-house to the Icahn machines to increase their efficiency and output quality beyond what had been achieved on the yellow bird prototype.

In January 1976, WTD prepared a capital budget request to purchase two Icahns as the initial phase of an overall plan to buy 16 of the machines. The Icahns would enable WTD to phase out the eight J&L grinders by 1979 and would meet the needs for additional capacity based on the sales forecast through 1980. The request called for the expenditure of approximately $217,000 per machine (a total of nearly $3,500,000) and represented the largest equipment expenditure in WTD's history. The original request was sent back to WTD by the group executives, who wanted a more thorough evaluation of the financial return that the investment would provide and a complete examination of alternatives open to WTD. A revised capital expenditure authorization request (known as a CEA) was submitted to United in 1977. Its principal justification was to maintain WTD's market share (see Exhibit 3) through the purchase of additional production equipment. The CEA explored several equipment alternatives. Two of these were:

1. Rebuild 16 WTD and 8 J&L Auto thread grinders. Total cost—$880,000.
2. Retire all thread grinders and purchase 16 Icahn Auto thread grinders. Total cost—$3,472,000.

EXHIBIT 3

TAP MARKET OUTLOOK WITHOUT INVESTMENT ($000)	1976	1977	1978	1979	1980
Total market in units	27,761	29,146	30,553	32,015	33,565
WTD market share	9.00%	9.00%	8.65%	8.31%	7.98%
WTD sales (units)	2,498	2,623	2,643	2,660	2,678
WTD price (average)	$2.51	$2.44	$2.42	$2.41	$2.39
WTD sales	$6,280	$6,404	$6,404	$6,404	$6,404
Major Competitors' Market Shares* (units)					
Greenfield	3,609	3,789	3,972	4,162	4,363
Winter Brothers	2,776	2,769	2,750	2,561	2,350
Bendix	2,221	2,405	2,597	2,881	3,189
Cleveland	1,943	2,113	2,291	2,561	3,021
All other	14,714	15,447	16,300	17,190	17,963

TAP MARKET OUTLOOK WITH INVESTMENT ($000)	1976	1977	1978	1979	1980
Total market in units	27,761	29,146	30,553	32,015	33,565
WTD market share	9.00%	9.00%	9.09%	9.15%	9.24%
WTD sales (units)	2,498	2,623	2,779	2,929	3,102
WTD price (average)	$2.51	$2.44	$2.42	$2.41	$2.39
WTD sales	$6,280	$6,404	$6,724	$7,060	$7,413
Major Competitors' Market Share* (units)					
Greenfield	3,609	3,789	3,972	4,162	4,363
Winter Brothers	2,776	2,769	2,750	2,561	2,350
Bendix	2,221	2,405	2,597	2,881	3,189
Cleveland	1,943	2,113	2,291	2,561	3,021
All other	14,714	15,447	16,165	16,921	17,540

**Assumes that competitors will not have similar new quality machinery.*

The rebuilding or purchase of the various thread grinders would be spread over a five-year period (see Exhibit 4).

WTD estimated the costs under each alternative to determine the net cash flow of the projects (see Appendix A for detailed pro-forma financial projections for the two alternatives). The capital expenditure request evaluated each alternative on the basis of incremental cash flow as shown below:

	ALTERNATIVE 1	ALTERNATIVE 2
Cumulative net cash flow ($000)	12,760	15,736
Present value @ 20% ($000)	5,198	5,656
ROI	42.0%	43.6%

EXHIBIT 4 Production Machinery Schedule

	1977	1978	1979	1980	1981
Alternative 1					
WTD grinders	14	14	14	14	16
J&L grinders	7	7	7	7	8
Total	21	21	21	21	24
Alternative 2					
WTD grinders	12	12	4	—	—
J&L grinders	8	8	8	4	—
Icahn		6	10	14	16
Total	20	26	22	18	16

The CEA recommended that WTD pursue alternative 2 and replace all existing equipment with the Icahn equipment. In late 1977, United approved the program to purchase 16 Icahns and authorized WTD to purchase six machines: two to be delivered immediately and four for delivery in 1978. It was also planned that four Icahns would be purchased each year in 1979 and 1980 and two machines would be added in 1981 to complete the program. Purchase of the final 10 machines would require final approval in each year conditional on the experience with the Icahns previously purchased.

Postaudit of the Icahns

In September 1978, an analyst from the group-level financial staff was sent to the Wilmington plant to audit the initial operating statistics for the Icahn equipment. At the time of the audit, the first two nonprototype Icahns had been operational for three months. The audit was conducted on the three Icahns at Wilmington in anticipation of the request to proceed with the planned purchase of four additional machines to be delivered in 1979 (the four machines to be delivered in December 1978 had already been ordered). The audit revealed three areas in which the actual results differed substantially from the CEA projections as outlined below:

1. The strength of the Swedish kronor in foreign exchange markets had caused the price of an Icahn to rise more than 15% to approximately $250,000.
2. Sales and production of WTD taps were about 20% below the CEA projections in 1977. Unit sales were projected to be about 13% below in 1978 as noted below:

1977		1978	
CEA	ACTUAL	CEA	ACTUAL*
2,623	2,107	2,779	2,415

**6 months actual, 6 months forecast.*

While sales were below the CEA projections in both years, the increase in sales from 1977 to 1978 was expected to be over 13%. This compared favorably with the 5% annual real growth forecast in the CEA.

The higher annual sales growth for alternative 2 (5% versus 2%) for WTD taps in the CEA was based on expected quality improvement in taps produced using the Icahn thread grinders. The postaudit revealed that, although the quality had improved (initial tests showed a 20% increase in tap life), the

WTD marketing group had not been able to capitalize on the improved quality. No effort had been made to publicize the improved Icahn taps because only a fraction of the WTD's total production was produced on the new equipment. This situation would continue for two or three more years until more of the Icahns were put into production.

3. The actual pieces produced per hour on the Icahns averaged about 10% below CEA projections, and the operating costs associated with the machines were significantly higher than planned.

The reduced output of the machine was caused by several problems:

1. The time required to change the grinding wheel had been omitted from the calculations of cycle times used in the CEA.
2. It was necessary to have the Icahn company build new work drivers (a mechanism that loads and aligns the tap into the machine) and install them for the machines to operate properly.
3. Maintenance technicians had difficulty in troubleshooting the machines' programmable controls. The older thread grinders were operated strictly with mechanical controls. The yellow bird prototype incorporated hydraulic controls that were manually adjusted. But the two recently purchased Icahns had been improved with electronic computerized controls, and the skills developed on the old thread grinders were not applicable to the new machines. WTD had decided to retrain its machinists rather than to hire new personnel. A substantial training program using Icahn factory personnel was undertaken to train the operators and maintenance support. Video equipment had been ordered to help develop better training tools.
4. Variations in the flute length of the tap blanks caused machine malfunctions. Unlike the other grinding machines, the Icahn's grinding stroke was a function of flute length as determined by a sensor on the machine.
5. The CEA production figures were based on the production of regulars. In actual practice, the Icahns were being used to produce some specials (custom-sized taps).
6. CEA labor costs were based on the use of one operator per four machines. Because, at the time of the audit, WTD had only three machines, there could be only three machines per operator.

The postaudit report was first sent to the auditor's superior at the group level. The group controller contacted Len Green and recommended that further Icahn purchases be stopped until a new CEA could be prepared using the actual data from the Icahns already in place. Len Green had already decided to halt further purchases of the Icahns when he received the memo from the group controller. He was concerned with the poor operating results of the Icahns, but he was also worried that thread grinding equipment might soon be available from other manufacturers that would be even more efficient than the Icahn machines.

Postaudit Follow-Up

After the audit had been conducted, WTD recalculated the discounted cash flow rate of return of alternative 2 using the actual performance at the time of the audit rather than the projections contained in the CEA. Just the effect of the external factors (lower sales and higher cost of the machines) reduced the return to 9%. The reduced productivity of the Icahns would have lowered the return even further, but the exact level was not calculated because the accounting system was not structured to provide cost data on the Icahn machines alone.

There was considerable concern at WTD with these lower projections. The division had been averaging returns in excess of 20% in normal years, and the compensation plan for the senior managers of WTD included bonuses, based on divisional ROI, which could amount to up to 30% of total compensation. Len Green asked his financial group to look closely at the figures to see whether the return from the Icahn investment could reasonably be expected to exceed the 20% hurdle rate.

Further tests were conducted to determine the actual piecerate output of the Icahns. The

Appendix A: Wilmington Tap and Die (Abridged)

Financial Outlook without Investment—Alternative 1: Rebuild present machines, no increase in production

	($000)									
	1977	1978	1979	1980	1981	1982	1983	1984	1985	1986
Sales	$6,404	$6,404	$6,404	$6,404	$6,404	$6,404	$6,404	$6,404	$6,404	$6,404
Cost of Sales										
Labor	$ 168	$ 168	$ 168	$ 168	$ 168	$ 168	$ 168	$ 168	$ 168	$ 168
Material	312	312	312	312	312	312	312	312	312	312
Overhead (excl. depreciation)	1,557	1,557	1,557	1,557	1,557	1,557	1,557	1,557	1,557	1,557
Interest	0	0	0	0	0	0	0	0	0	0
Depreciation	112	153	175	204	207	96	77	60	43	
Division operating expense	1,473	1,473	1,473	1,473	1,473	1,473	1,473	1,473	1,473	1,473
Staff allocations	218	218	218	218	218	218	218	218	218	218
Allocated finance charge	96	96	96	96	96	96	96	96	96	96
Tax rate	50%	50%	50%	50%	50%	50%	50%	50%	50%	50%
Assets & Liabilities										
Inventory/sales	20%	20%	20%	20%	20%	20%	20%	20%	20%	20%
Other working capital/sales	17%	17%	17%	17%	17%	17%	17%	17%	17%	17%
Gross prop., plant, & eqpmt.	$2,225	—	—	—	—	—	—	—	—	—
Net prop., plant, & eqpmt.	544	—	—	—	—	—	—	—	—	—
Capital expenditures	220	220	220	220	0	0	0	0	0	0
Investment tax credit	22	22	22	22	0	0	0	0	0	0

Financial Outlook with Investment—Alternative 2: Retire present machines, purchase 16 Icahns

	($000)									
	1977	1978	1979	1980	1981	1982	1983	1984	1985	1986
Sales	$6,404	$6,724	$7,060	$7,413	$7,784	$7,784	$7,784	$7,784	$7,784	$7,784
Cost of Sales										
Labor	$ 167	$ 154	$ 148	$ 148	$ 152	$ 152	$ 152	$ 152	$ 152	$ 152
Material	312	328	344	361	380	380	380	380	380	380
Overhead (excl. depreciation)	1,557	1,440	1,390	1,390	1,423	1,423	1,423	1,423	1,423	1,423
Interest	0	0	0	0	0	0	0	0	0	0
Depreciation	134	261	399	518	566	513	409	341	273	204
Division operating expense	1,473	1,547	1,624	1,705	1,790	1,790	1,790	1,790	1,790	1,790
Staff allocations	218	229	240	252	265	265	265	265	265	265
Allocated finance charge	96	101	106	111	117	117	117	117	117	117
Tax rate	50%	50%	50%	50%	50%	50%	50%	50%	50%	50%
Assets & Liabilities										
Inventory/sales	20%	20%	20%	20%	20%	20%	20%	20%	20%	20%
Other working capital/sales	17%	17%	17%	17%	17%	17%	17%	17%	17%	17%
Gross prop., plant, & eqpmt.	$2,439									
Net prop., plant, & eqpmt.	824									
Capital expenditures	434	868	868	868	434	0	0	0	0	0
Investment tax credit	43	87	87	87	43	0	0	0	0	0

original CEA projected an average output of approximately 85 pieces per hour per machine. The actual output of the Icahns averaged 69 pieces per hour. Len Green felt that this would improve over time as WTD went further down the learning curve with the Icahn equipment, but about half of the reduced output rate was due to wheel changing time that had been inadvertently left out of the original projections. Much of the lowered productivity was a result of the difficulty that had been experienced with the programmable controls.

In addition to the operating problems with the Icahns, Len Green had learned that his competitors Bay State and Bendix had ordered new Junker thread grinders and Greenfield was considering new Lindner grinders. He asked his manufacturing engineering manager to review the equipment from these German vendors. Preliminary indications were that the German equipment offered at best only marginal advantages over the Icahns, so the startup costs associated with the alternative machines would not alone justify switching to them in the future. Len, however, was concerned that WTD would be known in the industry for its Icahn equipment because it was the only tap manufacturer that had purchased Icahns. This could be an advantage if the Icahns were acknowledged as *the* thread grinding technology. However, if the Icahn became outmoded, it would be hard to overcome the stigma of being the only firm using Icahns when competitors were purchasing the newer Junker and Lindner grinders.

On a positive note, Len had just received a memorandum from the manager of product engineering, who had been performing extensive tests on a random sample of taps produced by the three types of grinding machines now in use at Wilmington. The conclusions showed the taps produced on the Icahn grinders had longer life and higher resistance to breakage than taps produced on the older grinding equipment.

The most recent sales figures indicated that 1978 sales would be within 2% of original projections, and sales were increasing at a faster rate than previously forecast. Len knew that he would have to proceed with the purchase of additional thread grinding equipment very soon if WTD were to have sufficient capacity to maintain or increase its share of market. He knew that it would be extremely difficult to gain approval for a new Icahn capital budget request based on recent operating data, but he was convinced that the productivity of the Icahns would improve with experience. United's group management, however, had asked that any additional requests to purchase Icahns be based on actual production data of the Icahns already in use.

Required

(1) Evaluate the capital expenditure authorization request for the new machines.
(2) How should Len Green evaluate the post-audit report?
(3) What should Len Green do?

Basis of Study The financial study was based upon the comparison of the production of high-speed ground threaded taps, sizes #6-32 through ⅜″-24, under five different machine combinations involving three sales forecasts. Sales, production costs, and all other sales and production-oriented costs were determined on the basis of their relationship to production and sales levels for high-speed ground threaded taps as specified in the Wilmington marketing study.

Sales

Sales dollars (at net less returns and allowances, cash discounts, and freight-out) and sales/production in units are per the Wilmington Tap & Die (WTD) Marketing Department marketing study.

Material

Material dollar costs were developed using 1977 WTD standard material costs per 100 pieces and applying those costs against production levels as specified in the WTD marketing study.

Labor

Labor costs encompass all direct labor operations for the 12 sizes specified in the range of #6-32 through ⅜″-24 at 1977 standard piece rates, adjusted for production levels per the WTD marketing study.

For direct labor operations other than thread grinding, a direct labor standard piecerate cost per 100 pieces for each of the 12 sizes of taps was applied against production for each size per the WTD marketing study to obtain piecerate direct labor for each size and for total production.

For the thread grinding operation, piecerate direct labor dollars per 100 pieces and direct labor man-hours per 100 pieces were obtained for each of the 12 sizes of taps from George Penrose, WTD standards department. Dollars per 100 pieces were divided by man-hours per 100 pieces to obtain direct labor piecerate dollars per hour for each of the 12 tap sizes. These 12 direct labor piecerate dollars per hour were then weighted by the percentage of units produced per each tap size to total units produced. A weighted average cost of $2.69 per man-hour was derived. This cost was then applied against direct labor hours for each alternative per the engineering hours loading schedule (see engineering summary) to obtain piecerate direct labor dollars for the thread grinding operation for each alternative.

Overhead

Overhead was developed as a function of overhead rates and direct labor dollars. Overhead rates were developed on a plantwide basis taking into effect those changes in the overhead base caused by increased production of the 12 sizes of high-speed ground threaded taps. The overhead rates were then applied against direct labor piecerate dollars (see III. Labor) to derive the overhead applicable to the production of these taps. Overhead was computed *net* of depreciation (see Property, Plant, & Equipment—Depreciation).

Property, Plant, & Equipment

Gross and net property, plant, and equipment are composed of the cost of new or rebuilt machinery, depending upon the production alternative, and a portion of other WTD plant, property, and equipment applicable to the production of the 12 tap sizes.

1. The cost of sales applicable to the production of the 12 tap sizes represents 19.9% of total WTD cost of sales. This percentage was applied against the gross and net property, plant, and equipment (GPPE and NPPE, respectively) balances of WTD at December 31, 1977, to obtain property balances applicable to the specified 12 tap sizes. The cost of capital additions (rebuilding and/or purchase costs) was added to this other WTD plant GPPE and NPPE to obtain the total balances of GPPE and NPPE for each of the two alternatives.
2. Depreciation for the other WTD plant, property, and equipment was obtained by applying the 19.9% rate against depreciation for 1977. The portion of depreciation obtained was applied on a straight-line basis until net book value for the related other property, plant, and equipment reached zero. Depreciation for the cost of rebuilding or purchasing of equipment was calculated on a double-declining balance–sum-of-the-year digits method over 9.5 years, as specified in Tax Bulletin No. 15, dated November 11, 1974.

Capital Expenditures

Capital expenditures were obtained for the two alternatives from the engineering study. Alternative 2, the purchase of 16 Icahns, makes an allowance for the disposal of the Model Fs in the form of offsetting the net book value of the Model Fs against the cost of the Icahns in the year of disposal, obtaining a "net" capital expenditure.

Investment Tax Credit

Represents 10% of gross capital expenditures.

Other

The following expense ratios are based on historical data and were obtained from K. W. Stinger, controller, WTD.

Percentage of Sales	
Division operating expense	23.0%
Staff allocations	3.4
Allocated finance charge	1.5
Tax Rate	50.0%
Other Ratios	
Inventory/sales	20.0%
Other working capital/sales	17.0

STERMON MILLS INCORPORATED*[1]

As he sat at his desk, waiting for the improvement team to arrive, Stan Kiefner, President and CEO of Stermon Mills stared blankly at the letter in front of him. The letter was from Pete Cushing of the Renfield Consulting Group:

> 10/1/92
>
> Dear Stan:
>
> I have given a lot of thought to our conversation of last Friday. Having looked at the latest price figures and the projections for the next five years, I would say that I have to agree with you: Stermon is unlikely to be competitive on the basis of cost without an investment in a new, state-of-the-art paper machine. Given the over-capacity projected for the industry, and the $500M cost—I'd say you have to find an alternative! Stermon just can't keep chiselling on price. In my opinion, the only way to maintain and grow your customer base is to offer something the bigger companies can't—you have to become more flexible than the competition.

The letter confirmed what Kiefner already knew. It was no longer possible for Stermon to match the price being offered by the large mills for commodity grade paper (see Exhibit 1). With the huge economic rewards available to large-scale technology in papermaking, Stermon's small machines simply cost too much to run for the output they produced. Since he left Boise Cascade in 1990, Kiefner had known Stermon was headed for trouble without some dramatic changes. But it was only recently, as the real price of Xerox grade paper hit a 20-year low, that the urgency of the situation had become clear.

If it was to continue to be viable, in both the short-term and the long-term, Stermon had to become more flexible. Kiefner had put together a team of his best managers to look at the problem. He had asked the head of the team, Bill Saugoe, to put together a two-year flexibility improvement plan, which would specifically address the competitive problems facing Stermon, and detail the steps which

*This case was prepared by Professor David Upton.

[1]Names and data have been disguised.

EXHIBIT 1 Monthly Statement of Income for Machine 4: September 1992

ITEM	$ PER TON
Gross sales: paper	769
Freight and other	(79)
Net sales: paper	690
Variable Costs	
Wood	58
Purchased pulp	125
Chemicals and additives	94
Electricity	28
Fuel	54
Other materials	29
Total Variable Cost	390
Variable contribution	300
Fixed Costs	
Mill operating labor	99
Mill maintenance labor	36
Contractor maintenance	22
Maintenance materials	27
Operating supplies	19
Mill supervision	17
Mill G&A: Salaries	6
Mill G&A: Other	16
Depreciation/amortization	78
Insurance and taxes	12
Total Fixed Cost	332
Total cost of goods sold	722
Income: Paper operations	(32)
Nonoperating income (expense)	(2)
Net Income	(34)

needed to be taken in order to make Stermon flexible.

Kiefner was unsure about the whole business. It was a lot easier to work on costs, he thought. You could count dollars after all. But flexibility was a different matter. How could they improve something if they weren't really clear what it was? How could they measure their competitors' performance? How would they even know if they had improved? This was not going to be easy.

Kiefner sat back and waited for Saugoe's knock at the door.

The Stermon Story

Stermon Mills Incorporated was a small, independent fine-paper producer. It was founded by Tom Brasker, a second-generation Scot, in 1910. Located in the town of Fond du Lac, in Northern Minnesota, Stermon's (single) paper mill was a collection of some 20 buildings, housing one pulping plant and four paper machines of varying vintages. The oldest (no. 1) was the original machine installed when the company was founded. Though a giant in its time, it was now the smallest machine in the plant and was affectionately known as "Little Jack."

Stermon had added two additional machines in the 1950s—no. 2 and no. 3 machines were also the giants of their day. The no. 4 machine had been added in 1976 and was the largest machine on site: 186 inches wide, it ran at a speed of 1,700 feet per minute (about 20 miles per hour). Total output from the site was 570 tons of paper a day, with 280 tons of that being produced on machine 4.

The company's major products had always been uncoated wood-free papers (see Exhibit 2). This market was dominated by the demand for xerographic paper, although many other papers were produced in the general category of uncoated fine paper. For example, Stermon also made book paper and paper for writing tablets. Coated papers required extensive additional coating equipment, while mechanical papers could not be produced in Stermon's pulping plant. For this reason, Stermon restricted itself to the production of uncoated fine papers.

Uncoated fine paper was differentiated from other types of papers by both its end uses and its manufacturing process. The primary end uses were printing and writing, and included, for example, the paper on which this case was printed. The end uses could be categorized into four segments: publishing

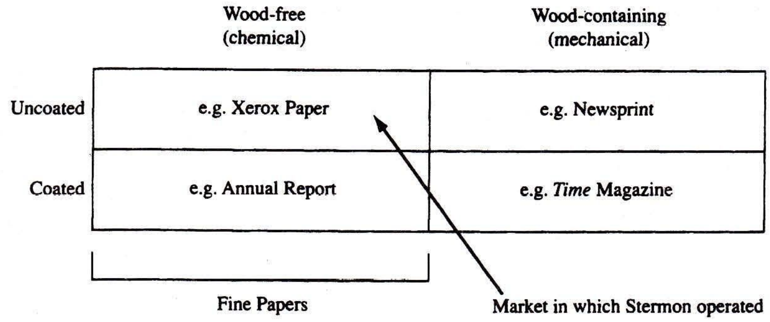


EXHIBIT 2 Types of Paper and Pulping Processes

(books), commercial printing, office/business (computer printers and copiers), and writing. Such papers varied from each other in a number of ways. First, and most important, was the basis weight of the paper. Paper could vary in area density from 15 pounds per unit area to 100 pounds per unit area in Stermon's plant. Xerox paper weighed 20 pounds per unit area. Second, paper could include different proportions of chemicals in the pulp that was used. This was called the furnish. Third, paper could be dyed in order to produce different colors of paper. Colored paper was made only on the smaller machines. The machines required a lengthy washdown after each run of paper, and few companies could afford to keep their larger machines idle for this task—Stermon was no exception.

Making Paper

The first step in making paper and paperboard, after the wood was cut, involved "pulping." This process refined the wood so that only the cellulose, the substance required in paper, remained. Wood consisted of approximately 50% fiber, 30% lignin, a tough, resinous adhesive that gave structural support to the tree, and 20% extractable oils and carbohydrates. During pulping, the cellulose fiber was separated from the other components so it could be processed further; pulping could be done either mechanically, by grinding the wood, or chemically, by boiling the wood with chemicals. Although newsprint manufacturers relied on mechanical pulping, the grinding process broke the cellulose into shorter fibers when tearing them apart and left some lignin in the resulting pulp. This created a weaker paper that turned yellow more quickly. Only products with less rigid quality requirements—newspapers and telephone books, for example—used mechanical pulp. Unlike mechanical pulping, which used 90%–95% of the wood harvested, chemical pulping used 45%–50%. Chemical pulp yielded 1.25 tons of paper per ton of pulp because inert "fillers" were added in the process.

When transformed into fine paper—the bright white type used in business and printing—chemical pulp went through an intermediate step: bleaching. Bleached pulp allowed producers to make a strong, bright paper that did not discolor during storage or when exposed to sunlight. It thereby satisfied the needs of paper products with high demands for purity, brightness, and permanence. Once the pulp was bleached, it was processed into "stock": a suspension of fibers and additives in water. Individual fibers of pulp were suspended in water and then "beaten" and refined to produce fibers with the proper characteristics of length, flexibility, surface area, and density. Chemicals could then be added to the stock: rosin, aluminum sulphate, or synthetics to reduce absorbency for writing papers; starch to add strength; dyes for colored paper. At the end of this process, stock could be made into a sheet of paper.

To produce a finished sheet of paper, a paper machine had to remove water from the stock—between 100 and 500 tons of water for every ton of pulp. Water was removed by three methods in sequence: first by gravity, second by squeezing, and finally by heating. In the "wet" end of the paper machine, the stock was deposited on a "wire"—a continuous belt of mesh material—with inclined blades of metal or plastic ("foils") underneath it, the wire drained the water from the stock. From the end of the wire, what was now a fragile paper web moved into the presses. Protected from above and below by continuous belts of felt, the paper moved through rollers, which pressed the sheet and drained water into catch basins (so the water could be used again). The paper web then travelled to the "dry" end of the paper machine. There the paper crossed double rows of steam-heated, cast-iron cylinders, again held by felt belts.

In the calender section, the paper was pressed further, as a set of hardened cast-iron rollers improved the surface-finish of the paper. From there the paper was wound onto a steel spool. In the final step of making paper, broadly called "finishing," large reels of paper were rewound into smaller reels, some were made into stacks of sheets (reams), and the paper was inspected. Fine paper, once inspected and packaged, was sold to merchants, who supplied end-users, or directly to the users themselves.

The North American Fine Paper Industry

Land of the Giants The North American market was the world's largest consumer and producer of uncoated fine paper. In 1989, the North American market accounted for an estimated 45% of the world's uncoated fine paper capacity, and 44% of the world's consumption. Almost all of the demand for uncoated fine paper in North America was met by domestic (United States and Canada) production. Exports and imports were not significant (around 5%) but had been growing spasmodically in recent years in top-end (high quality coated) and bottom-end (commodity uncoated) fine papers.

Despite industry fears to the contrary in the late 1970s, growth in demand for uncoated fine paper increased (rather than abated) because of information processing in the office/business segment. Since 1982, U.S. uncoated fine paper shipments had increased at 4.7% per year compared with 3.8% per year for the other three paper classifications. However, the strong growth in demand for uncoated fine paper during the 1980s had contributed to the industry's reduced profitability in the early 1990s. Significant capacity expansions to meet projected long-term demand, combined with the softening of demand during the 1989–1992 recession, had led to excess capacity and depressed prices. It was generally agreed that real prices for fine paper were currently the worst the industry had seen for many years.

International Paper was the world's largest paper company with sales totalling $12.96 billion in 1990. Uncoated fine paper accounted for about 18% of International Paper's total sales. The company was a full line producer of uncoated fine paper, possessing well known brands such as Hammermill and Springhill reprographic, printing, envelope and tablet papers. A survey among users of laser paper showed that Hammermill had a 30% brand preference compared to 12% for the next leading competitive brand. Georgia-Pacific was the world's second largest paper company after its acquisition of Great Northern Nekoosa (GNN) for $3.7 billion in

March, 1990. In 1990, Georgia-Pacific had sales totalling $12.67 billion. The GNN acquisition not only strengthened Georgia-Pacific's full line of uncoated fine papers, but also added paper distribution and envelope converting businesses. With the mid-1991 start up of a new 290,000 metric tons per year machine at Ashdown, Arkansas, Georgia-Pacific matched International Paper's uncoated fine paper capacity of 1,905,000 metric tons per year.

For the other top 10 producers of uncoated fine paper, the production and distribution of printing and writing papers (including uncoated fine paper) accounted for a significant percentage of their total sales. For example, the proportions for Champion International and Boise Cascade in 1990 were 40% and 53% respectively. The other producers competed primarily on the basis of having focused product lines, providing product and service flexibility, and/or owning channels of distribution. For example, Domtar, Canada's leading producer of fine papers, had its own distribution company and was developing a niche in the recycling and brokerage of waste paper. Paper companies that had a distribution company often needed to complement their limited product lines by carrying products made by other paper manufacturers.

Recycling The most important change in the market for fine papers had been the growing emphasis on recycling. The very visible problem of the disposal of solid waste, of which, in the United States, 41% is paper and paperboard, had spurred businesses and governments to demand fine papers that contained significant amounts of recycled fiber. Unfortunately, the demand for recycled fine papers was not being adequately met because of a limited supply of suitable waste paper. The traditional sources of suitable, or high grade de-inking waste paper, such as printing and converting waste, were already being heavily exploited. The current North American recovery rate for these preconsumer waste sources was about 85%. The largest untapped source of high grade de-inking waste paper was office/business waste. However, this source was limited due to logistical and technical difficulties. The logistical challenge involved the setting up of efficient and low cost collection programs for offices and businesses. The technical challenge was twofold. The first was controlling the variety of contaminants in the office waste. The second difficulty was the inability of current de-inking technology to remove key contaminants such as xerox and laser print.

These challenges had major implications for both consumers and paper companies. Consumers would assume a critical role in shaping not only the demand, but also the supply for recycled fine papers, since they would be generating and sorting the raw material to be used in the manufacture of the product. For paper companies, it was clear that the distribution of fine papers to businesses might become increasingly tied to the collection of high-grade de-inking waste from those businesses.

Stermon's Integrated Mill

Plants in the industry were either "integrated" or "paper only." Integrated mills, like the one in Fond du Lac, had a pulp plant on site, while "paper only" mills had to ship in dried pulp from outside. Because of the cost of drying and transporting pulp, modern mills tended to be integrated, and only a few specialty mills now ran without pulping capacity on site. Larger pulp facilities were very much more efficient than smaller ones and the output of even a modest modern pulping plant exceeded the requirements of the world's largest machines. Because of the disparity in minimum efficient scale between pulp plants and paper machines, integrated mills usually included a central pulp plant feeding three to six paper machines on the same site. Plants were almost always located near a plentiful supply of both water and trees. Two types of tree were used to make fine paper. Pine trees supplied long-fiber pulp for strength, while deciduous trees supplied short fiber pulp for smoothness and consistency. For this reason, there were paper plants in both the North and South of the United States. Plants in the North shipped in short fiber pulp, while southern plants shipped in the faster-growing long-fiber. The ideal recipe for paper was around 50% of each type of pulp.

Plants within Plants The four paper machines at Fond du Lac were like factories within factories. Each was housed in its own building, and was supplied with pulp through pipelines from the pulping plant. The huge buildings were old and splattered with dried pulp, particularly those housing the older machines. Each machine operated three shifts a day, seven days a week, with a two-week shutdown in the summer for maintenance. About 30% of the hourly workers in the plant worked in maintenance. The remaining direct operators worked in the pulping, papermaking, reeling/winding, and shipping areas.

Each machine required between four and six operators to run. Operators' tasks were ranked: from machine tender (the highest rank) to spare hand (the lowest). Movement through the ranks was strictly by seniority, and a bright young addition to the shop floor staff at Stermon could look forward to being a machine tender after about 15 years of service. The average length of service of the machine tenders in the plant was 24 years. While there were often disagreements within a shift on any machine, a shift formed a tight cluster of people who knew each other well, and had to solve problems arising on their machine, day and night. In keeping with the tradition of the paper industry, the key measure by which operators were judged was the utilization of the machines. Lew Frowe was a backtender on machine 4:

> There has been a big push recently on improving safety in the plant. A few weeks ago, a guy got caught in a storage tank when it filled with pulp: he died. We have far too many accidents. We've also had management pushing us on quality. Seems like whatever we do it isn't good enough. When all's said and done though, there's only one thing that really counts: "Tons is King" is what everyone knows in the paper industry. You try to get lots of other things right, but if you don't make your tons, your neck is on the block.

Stermon's hourly workers belonged to the United Papermakers Union (UPU). Disputes were frequent (274 recorded in 1991 alone), and two-thirds of cases centered around overtime allocation. Senior union members were supposed to take precedence for being allocated overtime, though management would often try to circumvent this rule. However, the most troubling disagreement for the plant's management concerned the demarcation of functions. Dave Yarrow, the pulp plant manager commented:

> Let's take unloading as an example. Pumping chemicals off a tanker coming into the rail yard is a pretty straightforward job. Here, it needs two people. You need a pipefitter to connect up the coupling, but you need a material's handler to actually turn the valve! It sounds ridiculous and it is, but it's true! The two of them have to sit there like twenty buck an hour hatstands while they watch the tanker empty.

Employee turnover was low in the plant—Stermon was by far the highest-paying employer in the area, and the union protected its employees well. There was a long waiting list for jobs at the plant. "You've got to wait till someone dies!" commented Frowe.

Machine operations had been dramatically altered in the 1980s when digital control was added. Rather than running around the plant altering the speed of drives manually, the operator of the machine used computer control, operated from a central cab midway down its length. A graphical display showed the condition of almost any motor or valve on the equipment. Stermon had found that computer control greatly improved utilization as the computer was able to adapt quickly to slight changes in input materials without production problems. While the computer system on machines 3 and 4 allowed grade changes to be carried out automatically, operators on machine 3 claimed that the computer was far too slow and changed grades manually by altering valves and drive speeds. The most common type of grade change was a simple change in basis weight—the most important way in which one type of fine paper differed from another.

> The computer never quite does it right—but it never messes up too bad either. We just let it take the reins in the middle of a run. For grade changes though, we prefer to do it on our own. (Back-tender, machine 3)

The smaller machines carried out four or five grade changes within a day, but machine 4 averaged one grade change a day, because of the high cost of having it not producing paper. Each machine ran on a two week cycle, and progressed up and then down the basis weight range for the machine, changing furnishes as it went. The order was important, since gradual grade changes kept the paper-making process more stable than large shifts. The machines stayed on each grade for a varying length of time depending on the orders for that particular grade.

Selling the Sheet

Sylvia Tannar had worked in the sales department at Stermon for almost 15 years. "We've seen slumps before," said Tannar, "but never one as bad as this. We've got guys in this plant who say their fathers don't even remember it being this tough. Paper prices are through the floor. 20-lb Xerox paper has been selling as low as 650 bucks a ton. We can't even get close to that!"

In 1991, three new uncoated fine paper machines came on line in the United States. Georgia Pacific, Union Camp, and Boise Cascade all introduced state-of-the-art machines running at 4000 fpm, producing 850 tons per machine each day. All three were focused on 20-lb Xerox paper, with occasional runs of 18 lb or 24 lb. These gargantuan new machines took advantage of the tremendous economies of scale in the technology. Paper machines had consistently grown in size and speed since the early twenties. With each new machine introduced into the industry, its owner hoped to grab greater economies than competitors, and win out on price or margins. Each of the 1991 machines cost $500m. Historically, the big companies had often invested in new capacity at about the same time, each seeing the same window of opportunity. This magnified the already cyclical nature of the paper industry and 1991 saw the biggest capacity glut the world had ever seen. Fine paper prices fell from $950 per ton in 1988 to $650 per ton for comparable grades of paper in October 1992.

While such prices were hurting Georgia-Pacific, Boise Cascade, and Union Camp, they were devastating to a small company like Stermon, that lacked the scale economies of the bigger machines. "We've had to find new ways to win orders," noted Tannar. One way Stermon had kept machine 4 busy was to begin making grades which were lighter and heavier than were usually made on the machine. "We might not be able to run flat out on one grade," said Tannar "but we can try to keep busy by selling some cats and dogs at the ends of the range. People can come to us for stuff they can't buy elsewhere."

Forty-two percent of Stermon's paper went to paper merchants, who sold their paper to converters. Converters turned the paper into envelopes and forms. In the last two years, merchants and other customers alike had shown an increasing reluctance to carry inventory, pushing the inventory back into the struggling paper plants. "They want it Just-in-Time or not at all," complained Tannar. "I never thought I'd see the day when this JIT business would hit a process industry, but it's here. If we don't deliver in bits and pieces, we lose the business. It either ends up with us carrying the inventory, or pushing really short runs onto the machines. The manufacturing guys hate it—but what can we do?"

Are We a Cessna or a 747?

Together with the other five members of his crew, Charley Jonn was responsible for keeping machine 4 running. John had worked the night shift tending machine 4 for 21 years.

> There's been a lot of pressure around here lately. I usually get in around 10ish, and deal with whatever problems the late shift has left me with. I set the machine back in trim: Hank on the last shift never does set it on its sweet-spot. Then, I start to take a look at any changes coming up in the schedule.

The paper machine operator's job was essentially one of monitoring the machine, keeping an eye open for equipment problems and making changes in paper grade from the control booth at the center of the machine. Operators generally liked to keep a machine stable, running on one grade. This gave the process stability and avoided a common but catastrophic source of failure—a paper break. As the name suggested, a paper break occurred when an instability in the process or some impurity in the web caused the paper running in the machine to tear. Paper tangled everywhere and the machine would shut down while the web was rethreaded. This meant having the whole crew clamber over the machine, tearing out paper. One intrepid member would throw the leading edge of a new web into the machine while precariously balanced between two rollers. It took anything from 10 minutes to 8 hours to repair a break, during which time production was at a standstill. Breaks were much more likely with thin papers and unfamiliar grades. Curiously, they seemed to occur much more often at the beginning of a shift than at any other time.

Jonn threw his hands up in despair at the increasing frequency of grade changes the crew was being asked to make.

> A big paper machine is like an airliner. It takes time to get up in the air and time to come down. If you want to do small hops, you go in a Cessna not in a 747. This paper machine was made to stay in one spot. We lose 30 minutes of production time every time we change grades. That might be OK on machines 1, 2, and 3 but this is a high-output machine and we lose a lot of output in 30 minutes. I know that times are hard, but if you're always changing over, you never have time to make paper.
>
> We're all measured on output. The bottom line is and always has been tons per day. You don't make your tons—you've got problems, so we're really careful when we change grade. We're careful and we try to get it right.

Even so, time lost due to grade changes had almost doubled, from 6% in the early 1970s to 10% in 1992. On average, machine 4 was making twice as many changes as it had in 1990, and productivity was suffering. "It's bad enough as it is, without losing all this time and making all this broke[1] changing grades."

Quality "We've always prided ourselves on making a real quality product," noted Lars Robikoff, superintendent of machine 4,

[1]*Broke* was the term used for off-standard paper. Between runs, the off-specification paper made was repulped and cycled back through the plant.

"but some of the problems we've been having recently have really taken us by surprise." A large piece of holed paper pinned to the wall was testament to this. "This hole cost us $5,981.28" said the felt-penned inscription.

> It's only in the newer grades—we're so used to making 20 lb, that we make a mistake here and there on the heavy stuff and the light stuff. Customers are coming back screaming at us—you can't blame a printer for crying out when he's got a web with holes the size of lumberjack's thumbs breaking in his press.

Stermon relied heavily on sampling inspection to ensure the quality of the product shipped. Inspectors would check for moisture content, ash content, color, and a host of other features. Any discrepancies would be reported back to machine operators, who would take the appropriate action. Product quality was also monitored continuously by computer on machine 4—even so, the occasional problem slipped through the net.

Robikoff attributed the quality problems to the instability in the papermaking process, due to the higher frequency of changes and the "odd" papers that were becoming more common. He was nevertheless optimistic.

"All of these changes have to end soon. Once business picks up again we'll be back making one or two grades, I'm sure. It'll be the same as it was before."

No Paper Tiger

"I don't think it's ever going to be the same as it was before," said Kiefner. "No matter what happens, we can't compete with the likes of Boise Cascade and Union Camp. We just can't hit those kind of costs in this plant. We'll always be marginal. But you know we're small—and we can do one thing those guys can't—we can be flexible." It was the only way to continue to compete. "Even if things pick up," he said "we'll still need something we can be really good at; we need to become excellent at being flexible."

Kiefner had charged Saugoe with the job of developing an improvement program to set Stermon on a path that would make it once again, a world-class plant. But now it would be world-class in terms of its flexibility rather than its cost. The improvement scheme would begin on November 10, 1992, and was to set clear goals and milestones. The initial focus of the plan would be machine 4, the largest machine in the plant, and the one considered the most important and the least flexible.

Saugoe had been included in a number of improvement schemes in the past. In August, 1977, he had set up a real-time cost analysis system in the plant. In March 1983, he had led the Total Quality Initiative (TQI), with the specific aim of reducing defects in the paper. Saugoe had looked at a number of Quality Improvement Programs in the process industry before the team finally agreed on a scheme developed by Manzax Chemical in the UK, based on Philip Crosby's methods. Both schemes had been considered a success by management. But flexibility seemed different. What did it mean to "get flexible?" Saugoe didn't know, so he pulled together a team to find out.

Flexibility in Manufacturing On September 12, Saugoe's team of manufacturing specialists discussed the flexibility improvement scheme. A handful of worried people crowded into his office. He had asked each of them to come up with ideas on how to improve flexibility.

Davie Pemthrall was superintendent on machine 3.

> We should figure out how to push this machine a little more. If we improved some of the process control systems, and put in higher powered dryers on machine 4, we'd really be flexible. We'd be able to dry real heavy papers,

> but still be able to control the process well enough to make light papers. We'd be able to make almost anything if we did that, then we'd really be flexible.

Peter Lohresich (machine 2 superintendent) differed:

> I don't know Pem, I saw it a little differently. I think we need to improve the changeover times so we can switch between the grades a little more easily. Grade change time and paper breaks are really starting to eat into the efficiency on machine 4. Some of the guys on 3 have got together a fire-brigade. They figured out a way to beat the computer every time on grade changes. They run around like crazy when it comes to changing the machine. The computer does it in ten minutes. These guys are incredible! They do it in two or three.
>
> "Yes Pete, but number 3 is a little machine, you can play around with that kind of thing there. Machine 4 is making almost 300 tons a day. You need to be safe when you change grades."
>
> "I still think we should work on speeding up grade changes on 4. I don't see any reason why it can't start getting really flexible, just like number 3."

Lars Robikoff (Superintendent, machine 4) disagreed:

> No, I don't think either of these things really makes us flexible. It's all very well saying we should work on getting machine 4 to make a large range of weights or to changeover quickly, but you'll never be really flexible until you fix the fundamental problem: the machine was built for 20-lb Xerox paper. It likes to run there—that's where it's most efficient. You should forget about getting it to do real heavy, light and all those other weird papers. Let's get it to be efficient across the range of papers we make *now*—on 15-lb, 18-lb, and 24-lb—get the yields up there. Then we won't care which we produce—we'll really start to be flexible.

Pemthrall agreed:

> We have really patchy quality across the grades we make now on 4. Customers shouldn't have to put up with holes in the web just because we're making stuff our machine doesn't like. As well as that, there are folks out there who've got machines that *are* set up specifically for 15-lb or 24-lb. We better learn to be as good as them, or they'll win every time.

Flexibility in Sales "It means doing what the customer wants," said Elly Ryesham in the sales department. "Flexibility means being all things to all people—of course, you can never do it; but you do your best. It means giving the customer exactly what they want, when they want it, I suppose."

Saugoe wasn't sure that helped. What kinds of things did the customers want, and what exactly did they mean by flexibility? Saugoe set Ryesham a task. "Go back to your salespeople, and see if you can put together a list of things we need to do to be what our customers call "being flexible." Break them into categories, and see which kind of request comes up the most."

Two days later, Ryesham returned.

> Well, it wasn't real clear, but I guess we came up with three things. The first need is for customized paper—one-offs and specials—that kind of thing. Some of our customers would really like us to be able to make paper tailored to their specific needs, even real lights and heavies. Second, customers want us to deliver just-in-time frequently rather than pushing a whole run onto them. Finally, I guess they like the fact they can do one stop shopping here; we've got a lot of product lines. I have my own opinions about which of these is most important, but I also asked the salespeople.

Ryesham had taken a straw poll of the sales force, asking which of these were most important. "They all are!" replied one saleswoman. Eventually the committee ended up with a list, grading each type of flexibility from A (important) to E (unimportant) (see Exhibit 3). Unfortunately, some salespeople had added more "flexibility" items to the list.

EXHIBIT 3 Survey of Sales Force

REQUIREMENT	ANDY NEWLAND	LIZ FOXELL	JIMMY MELLOR	TRACY SHAW	NICK WALKER
Customization	A−	A−	B−	D	B−
Responsiveness in delivery/JIT	A	A+	A+	B+	A
Having a broad product line	B	A	B	B	B−
Having flexible, helpful salespeople	B	A	C	C	B
Bring in new products frequently	D	E	B	E	C

Note: A, important, to E, unimportant.

"There are all types of flexibility," said Saugoe, "but now we have a better idea of what's really important to the customer." Saugoe still wasn't sure how this translated into a flexibility plan for the plant. One complicating problem was that there was already a flexibility improvement program in operation. For the past two years, HRM people had been negotiating a flexibility scheme with the union. Union officials had agreed to begin to relax the traditional constraints on workers taking each others' jobs. Aidan Waine, UPU representative in the pulp plant commented on the rumors he had heard: "We've been negotiating this deal for three years and now they're saying we've got to be even more flexible! Sounds to me like another way of getting something for nothing."

Flexing the Factory

Saugoe sat in his office putting together his presentation on overhead foils for Kiefner. He felt that Kiefner had been losing some patience with the team recently. It took them two weeks just to work out what a flexibility improvement program meant! Kiefner was a man with cold, steely heart for warm, fuzzy ideas. Two weeks ago, the team had come up with some comparatively vague suggestions for an improvement program. Kiefner had insisted that nothing would ever happen if the results could not be measured. Besides, he was concerned that Saugoe had no idea how to rank the various schemes in terms of their importance. Saugoe had remade a list of the flexibility improvement options, and was now working on which of these should be carried out.

First, Stermon could upgrade machine 4 with computer control, extra dryer capacity, and better training, so that it could make a much broader range of basic weights. With better control, the number of "recipes" the machine could make would also be increased. This would clearly improve the flexibility of the machine. If the machine were able to make heavier weights as well as slightly lighter weights than it could now, Stermon could make money by tailoring paper to customers' specific requirementsboth within the existing range of the machine, and outside it. Marketing estimated that a 7% premium (before freight) could be charged for such a service on these grades, though the machine would only produce such specialty jobs for 30% of the time. The capital cost of improving the flexibility of the machine in this way was $3.1 million.

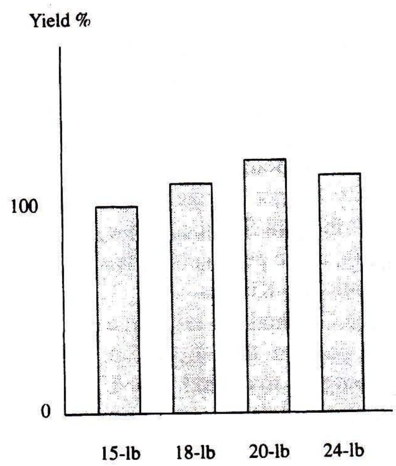
The second option relied much more on the people in the plant being able to adopt new ways of working. It would mean completely breaking with paper industry tradition. Machine 4 could be taken to a one week cycle, and run through the existing grades every week instead of every two weeks. This would certainly save on inventory costs—but even if inventory stayed the same, marketing estimated that Stermon could charge a 3% prefreight premium for the ability to make weekly "JIT" production runs. This was not at all straightforward though. If changeover times remained the same, it would mean a lot more time lost due to grade changes on machine 4. Ten percent of available machine time was currently lost due to changeovers. Would the machine operators be able to learn to change over faster? Perhaps some of the machine tenders from machine 3 could help the crew on 4 to become more flexible among the grades.

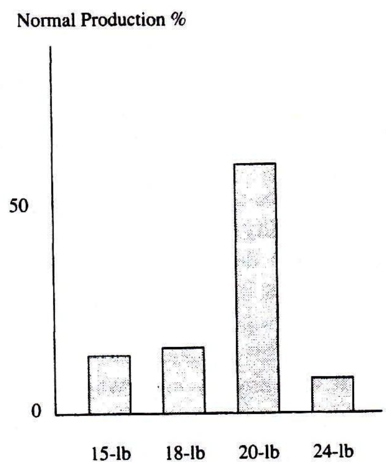
The third option was to improve the yield on machine 4 on the less frequently produced grades. In general, paper produced on the machine split into four categories, as shown in Exhibit 4. Machine 4 was strongly focused on 20-lb Xerox paper. Over the past year however, demand had been very soft for this paper because of the new capacity in the industry. For 28% of the past year's two-week machine cycles, there had been no demand for 20-lb paper (see Exhibit 5), and the capacity of the machine was shared among the other grades in their "normal" proportions to each other. This situation was expected to continue for at least two more years. These abnormal weeks were very unpopular on the floor, since it meant spending two weeks without running the machine on its sweet spot. The machine was not sufficiently flexible to produce all grades well.

EXHIBIT 4 Yields and Proportions of Output on Machine 4

GRADE	<15-LB	18-LB	20-LB	24-LB+
Yield*	78%	86%	95%	89%
Usual proportion of production	14%	16%	62%	8%
Proportion when no 20-lb demand	37%	42%	—	21%

**Yield figures are net of grade changes. These are the yields once the machine is running the grade.*





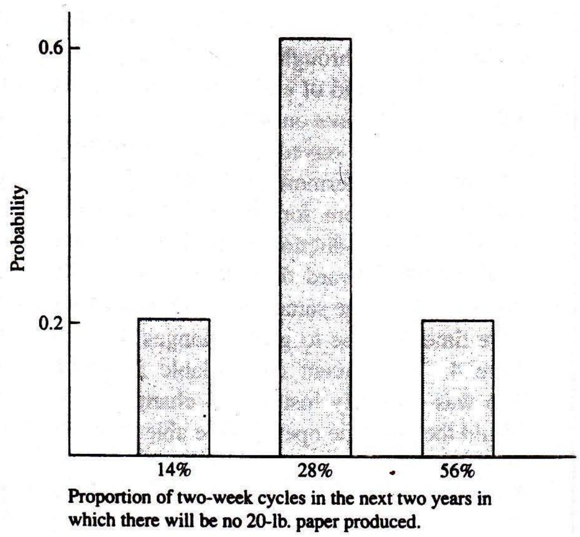


EXHIBIT 5 Marketing Projections—Best/Worst/Expected for 20-lb Xerox

To improve this flexibility among the grades, a new expert system for process control could be installed. This system promised to raise the yields for 15-lb to 24-lb paper made on the machine so that they would be comparable to that for 20-lb, providing the machine with much more flexibility across its grade range. The machine would then be much more tolerant of a lack of demand for its "favorite" grade. In addition, quality would become more consistent across the grade range. The cost of this system and the associated actuator network was $5.05 million.

Finally, Saugoe could recommend accelerating the flexibility program that was being worked out with the union. There had been other fires to fight in recent months, and a lot of the original impetus in the program had drained away. This program had the advantage that it was already underway, and was important in improving the effectiveness of the labor in the plant. Seeing people sitting around waiting for the "right" job to show up was getting to be really demoralizing for everyone in the plant.

While Stermon could go ahead with all four plans, Saugoe knew from his experiences with other improvement schemes that it would be much better to focus attention on one or two. In addition, he was concerned that some combinations of the flexibility improvement plans would conflict. He sketched out some notes to himself on how the plans might interact (see Exhibit 6). Saugoe wondered if there might be another way out. "Maybe we should work on having enough flexibility to get out of this business altogether!" thought Saugoe, half-cynically, half-seriously, as he put together the slides for his presentation to Kiefner.

As he checked his recommendation in indelible pen on the slide, Saugoe thought, "No changing my mind now I guess." With no flexibility left, he knocked on Kiefner's door.

EXHIBIT 6 Combinations of Improvement Plans

	INCREASE RANGE	ONE-WEEK CYCLE	UNIFORM YIELDS
One week-cycle	Might be difficult just to make new grades *without* trying to change between them quickly. Combination of unfamiliar grades and process instability might cause paper breaks and/or quality problems.		
Uniform yields	Would be too difficult to improve yields at the same time as stretching the machine. With the new grades being anticipated, would not expect any yield improvement on existing grades.	In order to improve yields, would probably need to stay on grades for at least as long as current run lengths. Unlikely to get process stable enough to improve yields if more changes. Could do it—but results would be to raise non-20-lb yields only about 3%.	
Labor multiskilling	Could use existing skill base and use this as an opportunity to cut across functional lines. People generally enthusiastic about "difficult" papers. Would need to relax "output" pressure.	Might cause a lot of discontent if people were being asked to change over faster/more often, as well as performing multiple functions. Not likely to work well.	This would already be seen as a way of improving output rather than improving flexibility. Hard to combine with a push on multitasking.

Burlington Northern: The ARES Decision (A)*

ARES will give Operations better control over its assets. We will schedule locomotives and cars more precisely, and get more efficiency and utilization of locomotives and tracks. ARES will also enable us to service our customers better by offering more reliable and predictable deliveries.

Joe Galassi, Executive Vice President, Operations

In July 1990, Burlington Northern's senior executives were deciding whether to invest in ARES (Advanced Railroad Electronics System), an automated railroad control system. ARES, expected to cost $350 million, would radically change how railroad operations were planned and controlled. The potential implications of this investment were so extensive that they affected virtually all parts of the BN organization. Nine years had passed since BN managers had begun to consider whether automated control technology could

*Professors Julie H. Hertenstein and Robert S. Kaplan prepared this case as the basis for class discussion.

EXHIBIT 1 Recent Financial Data

INCOME STATEMENTS ($000)	YEAR ENDED DECEMBER 31 1989	1988 RESTATED
Revenues		
Railroad	$4,606,286	$4,541,001
Corporate and nonrail operations		158,516
Total revenues	$4,606,286	$4,699,517
Costs and Expenses		
Compensation and benefits	1,701,146	1,630,283
Fuel	327,606	288,477
Material	319,497	341,126
Equipment rents	343,436	320,900
Purchased services	524,845	531,555
Depreciation	309,206	350,948
Other	410,266	406,459
Corporate and nonrail operations	13,748	150,869
Total costs and expenses	$3,949,750	$4,020,617
Operating income	656,536	678,900
Interest expense on long-term debt	270,272	292,050
Litigation settlement		(175,000)
Other income (expense)—net	4,397	(32,655)
Income from continuing operations before income taxes	390,661	179,195
Provision for income taxes	147,670	80,493
Income from continuing operations	$ 242,991	$ 98,702
Income from discontinued operations Net of income taxes		57,048
Net income	$ 242,991	$ 155,750

BALANCE SHEETS ($000)	YEAR ENDED DECEMBER 31 1989	1988 RESTATED
Assets		
Current Assets		
Cash and cash equivalents	$ 82,627	$ 83,620
Accounts receivable—net	430,355	685,018
Material and supplies	133,286	157,954
Current portion of deferred income taxes	119,589	98,339
Other current assets	31,137	39,740
Total current assets	$ 796,994	$1,064,671
Property and equipment—net	5,154,532	5,078,262
Other assets	196,254	187,401
Total assets	$6,147,780	$6,330,334
Liabilities and Stockholders' Equity		
Total current liabilities	$1,287,966	$1,218,757
Long-term debt	2,219,619	2,722,625

continued

	YEAR ENDED DECEMBER 31	
BALANCE SHEETS ($000)	1989	1988 RESTATED
Other liabilities	268,721	270,702
Deferred income taxes	1,277,715	1,186,124
Total liabilities	$5,054,021	$4,398,208
Preferred stock—redeemable	13,512	14,101
Common Stockholders' Equity		
Common stock	967,528	992,405
Retained earnings (deficit)	131,544	(20,624)
Subtotal Equity	$1,009,072	$ 971,781
Cost of Treasury stock	(18,825)	(53,756)
Total common stockholders' equity	$1,080,247	$ 918,025
Total liabilities and stockholders' equity	$6,147,780	$6,330,334

	YEAR ENDED DECEMBER 31	
CAPITAL EXPENDITURES ($000,000)	1989	1988 RESTATED
Roadway	$297	$305
Equipment	154	155
Other	14	14
Total	$465	$474

Source: 1989 Annual Report.

be applied to the railroad. Yet managers were still divided about whether the ARES project should be continued.

Company Background

Burlington Northern Railroad was formed in 1970, by the merger of four different railroads. In addition to a vast rail system, the merged company owned substantial natural resources including extensive land grant holdings containing minerals, timber, and oil and gas. In 1989, up to 800 trains per day ran on BN routes generating revenues of $4,606 million and net income of $242 million (see Exhibit 1 for financial data).

BN's diverse operations and staffs were headquartered in three cities. The firm's CEO, COO, and corporate functions such as finance, strategic planning, marketing, and labor relations were located in Fort Worth, Texas. The Operations Department, headquartered in Overland Park, Kansas, was the largest department in BN. It oversaw operating divisions comprising train dispatchers, operators, and their supervisors, and it managed support functions such as research and development, engineering, and maintenance. Additional corporate staff functions, such as Information System Services, were located in St. Paul, Minnesota.

Products, Markets, Competitors, and the Effects of Deregulation

BN's revenues came from seven primary segments: coal, agricultural commodities, industrial products, intermodal, forest products, food and consumer products, and automotive products.

Coal was BN's largest source of revenue, representing about one-third of total revenue. Over 90% of the coal carried by BN originated in the Powder River Basin of Montana and Wyoming. BN had invested heavily in the 1970s to build lines to serve the Powder River Basin. If the U.S. government enacted the anticipated acid rain legislation, demand for the Powder River Basin's low-sulphur coal was expected to increase substantially. Managers also believed that Powder River coal had promising export potential to Japan and other Pacific Rim nations from the west coast ports served by BN.

Coal was carried in unit trains or "sets" (108 cars, each holding 102 tons of coal, powered by three to six engines). Virtually all of the unit coal traffic was under long-term contract with fewer than two dozen customers. To insure good asset utilization, cycle time was important. A reduction in the average cycle time reduced the number of sets required to carry a given amount of coal, and hence, reduced the capital investment in coal cars, most of which were owned by customers. Thus, unit coal trains never stopped, and the coal business was almost totally predictable. Although sensitive to cycle time, the coal business was not sensitive to arrival time precision as coal could be dumped on the ground without waiting for special unloading facilities or warehouse space. Even electric utilities, however, were becoming aware of just-in-time delivery benefits.

BN's major competition in coal were other railroads, especially the Union Pacific (UP). UP had made substantial investments in heavy duty double track and in new technology, fuel efficient engines for carrying coal. BN management believed UP had excess capacity, whereas BN, with its single track lines, was running close to capacity on its coal lines.

Agricultural commodities, primarily grain, was BN's second largest segment. Strategically located to serve the Midwest and Great Plains grain-producing regions, BN was the number one hauler of spring wheat, and the number two hauler of corn. Although grain and coal were both bulk commodity businesses with little competition from trucks, the grain business differed substantially from coal. Demand for grain deliveries was more random since the time of harvest varied from year to year, and export demand for grain also fluctuated with the highly variable market price of grain. Grain traders dealt for the best prices, and long-term arrangements were uncommon. BN managers expected that with the change in economic policies in Eastern Europe (and possibly the Soviet Union), the standard of living in these countries would rise, leading to an increased demand for grain. With its ability to serve both the grain producing regions and west coast and Gulf ports, BN expected this segment of its business to grow significantly in future years.

During the late 1980s, BN changed the marketing of grain transportation through its Certificates of Transportation (COT) program. Under this program, BN sold contracts containing commitments to move carloads of grain within a three-day interval, six months in the future. The COT was helping to eliminate some of the randomness in grain shipments and pricing. BN, though, now had to have cars available reliably for the contracted shipment, or else incur a large penalty for failure to perform. The COT program had been a successful innovation but it put a premium on BN to coordinate and plan its grain operations.

John Anderson, Executive Vice President for Marketing and Sales, believed that BN's five other commodity businesses had many similarities:

> Although the customers differ, these five businesses all have significant flat or boxcar

movements. They have random movement and demand, and are strongly service sensitive. Customers make tradeoffs between price and quality and these businesses all put us into severe competition with trucks.

Think of a continuum of commodities. At one end of the continuum are commodities that should go by train such as coal or grain. These commodities are heavy and low cost, have low time sensitivity, and come in large lots. At the other end are commodities that should go by truck, such as strawberries, electronics, and garments. These are light and high cost, have extremely high time sensitivity, and come in small lots. In between these two extremes are many commodities where trucks and trains compete vigorously on price and service.

Historically, trucks had taken over the transportation of more and more of the contested commodities. At the end of World War II, about 70% of intercity freight had been shipped by rail. In the post–WW II era, rail's share of intercity shipments was lost, primarily to trucking, and especially in the service sensitive segments. Ed Butt, ARES project director, highlighted the reasons for trucking's inroads: "Trucks charge as much as two to three times what it would cost for rail service. But trucks go door-to-door, and people will pay for that level of service."

Recent trends in manufacturing, such as just-in-time production systems and cycle time reduction were making trucking's service time advantages even more valuable. Railroads were using their intermodal trailer/container-on-flatcar service to offer door-to-door delivery but still could not offer the reliability of delivery that trucks could obtain on a highway system where drivers could often make up for unexpected delays. As Butt explained:

We may have peaked at 75% on-time delivery for our general merchandise, and 80% for intermodal. But 75%–80% is not good enough for just-in-time service. Trucks are 90%–95% and we need to get into that range to attract the just-in-time customers, who are enormously sensitive to consistent reliable deliveries.

Effects of Deregulation The deregulation of both the trucking and railroad industries in 1980 had changed both the railroads' and the truckers' competitive environment. The Motor Carrier Act of 1980 gave truckers much greater freedom in setting rates and entering markets. The Staggers Rail Act of 1980 gave railroads similar freedom in setting their own rates; it also included provisions allowing railroads to own other forms of transportation.

Following deregulation, BN modernized its railroad operations. Richard Bressler, the chairman in 1980, established a research and development department in Operations and hired Steve Ditmeyer to head the group. Numerous new technologies and innovations were considered and, where appropriate, were applied to railroad operations. During the 1980s, railroad productivity increased dramatically: the number of employees declined by 50% while revenue ton miles increased by over two-thirds.

But trucking rates fell significantly after deregulation, putting pressure on the railroads' chief advantage: the low-cost transportation of freight. In 1990, additional regulatory changes permitting trucks to be longer and heavier were under consideration. These changes would enable trucks to further reduce their costs. Dick Lewis, Vice President of Strategic Planning, however, recognized:

In our recent analysis we've been surprised to find that railroads and not trucks are some of our major competition. Since deregulation, intrarailroad competition is increasing and driving down prices at a fearsome rate. Trucks have carved off their own segments fairly solidly. Railroads want to compete in these segments, but they don't, and trucks are pretty secure in them.

Existing Operations

In 1990 each day up to 800 trains traveled approximately 200,000 train-miles on the 23,356 miles of track on BN routes. The

5,000 junctions created 25 million possible distinct routings, or origin-destination pairs, for the cars that comprised BN trains. Meets and passes—two trains "meeting" on a single track with one of them directed off to a siding so that the other can "pass"—were carefully managed by the railroad's dispatchers. BN managers believed that thousands of meets and passes occurred each day but were unsure about the precise number; some believed the actual number was as high as 10,000 per day.

A train running off schedule could potentially affect many other trains due to the limited number of tracks—often only one—and sidings in any area. Thus, controlling train operations meant controlling an extensive, complex network of dynamic, interdependent train and car movements.

Trains were controlled by dispatchers, each responsible for a distinct territory. Dispatchers still utilized technology developed around 1920 and little changed since then. A dispatcher was responsible for the 20 or 30 trains operating on his shift in his territory. Operations personnel, however, estimated that a good dispatcher could really only focus on and expedite five to seven trains. The remainder were inevitably treated with less attention and lower priority. At present, dispatcher priority went to scheduling competitive segments like intermodal and merchandise traffic; unit trains carrying coal and grain were not scheduled. Dispatchers had little basis for trading off delaying an intermodal train versus reducing the cycle time for a coal train.

Dispatchers saw information only about their own territories, and not others. Thus, if a delayed train entered a dispatcher's territory, he would be unaware that enough slack existed farther down the line to make up all the lost time, and that he should not jeopardize the schedules of his other trains by trying to catch the delayed train up to its schedule. Typically, trains were directed to run as fast as they could and then halted to wait at sidings.

Dispatchers also scheduled maintenance-of-way (MOW) crews. MOW crews would travel to a section of track that needed maintenance and repair. But the crews were not allowed to initiate work on the track until the dispatcher was confident that no train would run down the track during the crew's work period. At present, train arrivals at MOW work sites could be predicted within a 30- to 45-minute window, but for safety reasons, the work crews were cleared off the track much sooner than the beginning of this window.

Dispatchers spent considerable time establishing communications with trains and MOW vehicles. Dispatchers had to search various radio frequencies to establish contact with trains; MOW vehicles often reported long waits until they were able to get through to the dispatcher for permission to get onto the track. In fact, on some occasions, the MOW crew traveled to the maintenance site but were unable to get through to the dispatcher before the maintenance window closed and another train was scheduled to arrive, hence wasting the trip.

Current information about railroad operations was difficult to obtain. For example, to know how much fuel was available, an engineer had to stop the train, get out, and look at the gauge on the tank at the back of the locomotive. Trains refueled nearly every time they passed a fueling station, even if the added fuel was not necessary for the next part of the trip. Further, despite daily maintenance checks of critical components such as brakes, lights, and bells, and scheduled periodic maintenance every 92 days, the only evidence of a locomotive performing poorly came from reports filed by the crew about observable failures or breakdowns. Except for the newest locomotives, no gauges or recording systems monitored conditions that could foreshadow failures such as oil pressure or temperature changes.

Information about the location of cars and trains was also subject to delay and error. Conductors were given instructions about which cars to set out and pick up at each location. Following completion of a set-out or pick-up, the conductor made a written notation. When the train arrived at the next terminal (conceivably hours later), the paper was given to a clerk who entered the data via keyboard to update management data files. Arrivals of trains at stations were recorded by clerks who, if busy, might not observe the actual arrival, thus recording a 12:00 train as 12:15, and then entering this fact at 1:00 to the management data files.

Some executives were exploring the application of modern management science philosophy to improve railroad scheduling. According to Mark Cane, Vice President, Service Design:

> There are many potentially useful operations research and artificial intelligence techniques that are not yet being used by the railroad. Decision support technology has made a quantum leap forward, and we are trying to take advantage of it.

Dick Lewis illustrated the contrast between the BN and another highly scheduled transportation company:

> A benchmark company in this area is UPS. UPS has 1200 industrial engineers working for them; BN has only half a dozen.

One view, integrated network management, was being discussed among BN's senior managers. Under this approach, scientifically designed schedules would be generated, broken down into "standards" for each task, plus the appropriate education and incentives would be provided for local operations personnel to cause them to run the railroad to schedule. One operating manager voiced the concerns of many about this approach to railroad train scheduling:

> BN has talked a lot about running a scheduled railroad. However, the real challenge is how to manage the unscheduled, for example, a broken air hose or a broken rail. The problem is that problems do not happen on schedule.

By mid-1990, BN's service design organization had begun to institute a reporting system called the service measurement system. Bands of acceptable performance were established for scheduled trains and compared with actual results. On-time scheduled performance measures became part of the bonus incentive system for nonunion operating personnel. Following the institution of the reporting scheme, service showed definite and steady improvement. The percentage of scheduled cars arriving within targeted performance bands jumped from 25% in January 1990 to 58% in June. This suggested to BN managers that service performance could be improved simply by better collection and reporting of performance measures.

Strategic View of Operations

In late 1989, BN executives undertook a major strategic review to help shape the future. Gerald Grinstein, the chief executive officer of BN, focused the review on answering questions like, "What kind of railroad should we be?" Executives formed eight teams to examine in depth the following areas: operating strategies, customer behavior, information technology, labor, business economics, organizational performance, industry restructuring, and competitive analysis.

Dick Lewis explained the conclusions reached by this strategic directions project:

> This company, and the railroad industry, face two major challenges: service and capital intensity. We must improve our ability to deliver service. We must reform and reconstitute our service

> offerings, especially in highly service-sensitive segments. Since World War II, railroads have retrenched from service sensitive segments. For example, they have stopped carrying passengers and less-than-carload shipments.
>
> If we improve service, the first opportunity created is to increase volume, at the expense of other rail carriers. The second opportunity is to raise prices, but this is more questionable. To be able to raise price requires a *radical* service change, not a marginal one. The change must be radical enough to be perceived by a customer who says, "Wow! That's different!" For example, in our chemical business we recently made such a change. We reduced the average delivery time by more than half, and we also reduced the variability of the delivery time. The shipper found he could get rid of 100 rail cars. That had a measurable value significant enough for the customer to perceive the service improvement. We have subsequently been able to structure an agreement with the shipper to provide financial incentives to BN to further improve the service.
>
> The other side of this equation is that BN must improve utilization of assets. We have high capital intensity, poor utilization of rolling stock, and low asset turnover ratios. Actually, BN is good for the industry, but the industry itself has very poor ratios. Not only are the ratios poor, but the capital requirements for the 1990s are daunting. Just the traditional investments in locomotives, freight cars, and track replacements are daunting. If we can improve utilization of these assets, then we can reduce the capital investment required during the 1990s.

The ARES Project: The Origins

Steve Ditmeyer, Chief Engineer–Research, Communications and Control Systems, reached deep into his desk and withdrew a slip of paper with a handwritten note: "Any application to locomotives?" BN's chairman Bressler had written that note in 1981 shortly after Ditmeyer had joined the company and attached the note to an article on new aircraft instrumentation that promised lowered costs by improving fuel and other operating efficiencies. The note and article eventually filtered down to numerous railroad staffs.

In 1982, BN's R&D department contacted the Collins Air Transport Division of Rockwell International to learn whether aircraft technology could be applied to the rail industry. The two companies agreed to work together to identify workable solutions. By the end of 1983 they discovered that the technology existed to integrate control, communications, and information. An electronics unit, placed in each locomotive, could receive signals from the Department of Defense's Global Positioning System (GPS) satellites, and calculate the train's position to within ± 100 feet, a significant improvement over the existing ±10–15 mile resolution from existing systems. By calculating its location every second, the train's speed could also be estimated accurately. A communications network could then be developed to carry information back and forth between the train and a control center.

The R&D department managed the early stages of the ARES project, with oversight by the R&D Steering Committee comprised of senior officers of Transportation, Engineering, Mechanical, Operations Services, Marketing and Information Systems. The Board of Directors in July 1985 viewed a demonstration of the proposed technology installed on two locomotives. In August 1985 BN's senior executives agreed to fund a prototype system: equipping 17 locomotives on BN's Minnesota Iron Range, putting the data segment in place in the Iron Range, and building those elements of the control segment that would permit BN to communicate with and control the locomotives from the Minneapolis control center. The Iron Range was chosen because it was a closed-loop segment of BN's network, with a variety of train control systems, and was served only by a limited set of equipment.

By 1986 the ARES project had grown too large to be carried out by the small R&D staff, and Don Henderson was chosen to oversee the formation of a separate ARES team to manage the project's development. Henderson ensured that team members represented various Operations departments that would potentially be affected by ARES: dispatching, mechanical, maintenance-of-way, control systems and communications, freight car management and information system services. The team members worked with their respective departments and with others such as general managers and operating vice presidents to ensure a system that met operational needs and worked in the railroad environment. Operations managers saw ARES as a means to accomplish key goals of service improvements, operating efficiencies, and improved capital utilization. Operations incorporated ARES into the strategic plans it prepared and presented to corporate.

The ARES prototype was installed on the Iron Range in 1987. The ARES team, BN field personnel, and system developer Rockwell spent the next several years testing, evaluating, and improving the ARES system.

Under Henderson's guidance, the ARES concept evolved to a full command, control, communications and information system that would enable BN to gain additional control over its operations. ARES, using high-speed computing, digital communications, and state-of-the-art electronics, could generate efficient traffic plans, convert those plans into movement instructions for individual trains and MOW units and display those instructions to engine crews. By knowing the position and speed of trains and other equipment on the tracks, ARES could automatically detect deviations from plan or potential problems and communicate these exceptions to control center dispatchers. Dispatchers could determine the corrective action required and use ARES to send and confirm new movement instructions to trains. In many ways, ARES could be considered analogous to the Air Traffic Control system that controlled the aviation industry. ARES eventually came to consist of three segments: Control, Data, and Vehicle.

The Control segment received information on train position and speed to produce schedules and to check that vehicles followed proper operating procedures. It warned dispatchers of violations to limits of authority and speed and produced authorities and checked them for conflict. The Control segment also helped to schedule the MOW crews to get much higher utilization of MOW equipment and labor time. The Control segment displayed for dispatchers the activity in their territories and supplied information about consists, crews, and work orders for any train.

The Data segment communicated data back and forth between the Control segment and locomotives, MOW vehicles, and track monitoring and control equipment. It made use of BN's existing microwave and VHF radio network.

The Vehicle segment on board each locomotive or MOW vehicle included a display (CRT) to provide information from the Control segment, a keypad to communicate back to the dispatcher, an on-board computer to monitor various aspects of locomotive performance, and a throttle-brake interface that the dispatcher or the on-board computer could activate to stop the train if the crew became disabled, if the train violated its movement authorities, or communication was lost with the ARES system. This segment included a receiver for satellite signals to calculate train position and speed, which were then communicated to the Control segment.

The Vehicle segment incorporated an Energy Management System that received information on track profile and conditions, speed limits, power, and car weight to determine a recommended train speed that met service requirements, while minimizing fuel consumption and providing good train-handling characteristics.

The Vehicle segment also included the Locomotive Analysis and Reporting System (LARS). LARS used a number of sensors and discrete signals to monitor the health and efficiency of locomotives and provide early warning signals about potential failures. LARS was expected to permit problematic locomotives to be pulled out of service for maintenance before they failed unexpectedly in a remote region and to provide a data base that maintenance people could analyze to prevent future malfunctions.

The ARES Project: Current Status

By 1989, BN had spent approximately $15 million, cumulatively, on the ARES project. BN managers estimated that Rockwell had spent three times this amount. "Concept validation" had been accomplished through the Iron Range test, which had proved that the technology could locate trains under real operating conditions and could communicate back and forth between the control center and the locomotive. Rolling stock hardware had been tested for robustness and reliability. The Iron Range prototype system was demonstrated not only to numerous groups of BN executives and operating personnel but also to customers, representatives of other railroads, and numerous industry and governmental groups. By late 1989, testing of the prototype was completed.

The ARES team had seen enough from the Iron Range testing to believe that it would enable BN to provide better service, improve asset utilization, and reduce costs. The ARES project that senior executives were evaluating and deciding whether to authorize in 1990 was an integrated command, control, communication and information (C^3-I) system for controlling train movements with, according to the ARES staff, "unprecedented safety, precision, and efficiency." According to a document prepared by R&D and project staff members:

> ARES will allow BN to run a scheduled railroad with smaller staffs and more modest [capital] investments than current signaling systems. It will maintain accurate, timely information about train consists and locations. The results will be improved service, with higher revenue potential, and cost reductions. Another important benefit will be the elimination of train accidents caused by violations of movement authority.

The ARES team now requested authorization for the expenditures needed to complete the development of the full operational system and to roll out implementation through the railroad. The ARES team, and its sponsors Don Henderson, Vice President–Technology, Engineering and Maintenance, and Joe Galassi, Executive Vice President–Operations, faced several important considerations as they prepared to present this investment for authorization.

First, corporate management was significantly changed from the management that had authorized earlier phases. Four CEOs, including the current executive, Gerald Grinstein, had held office since the 1981 inception of the project. None of the vice presidents who were on the R&D steering committee in 1982 and 1983 was still with the railroad. Of the board members who saw the ARES demonstration in July 1985, only one, the current chairman, remained. Thus, although ARES had undergone a lengthy development process within BN, many who must now support and authorize it were unfamiliar with the choices that had guided its development.

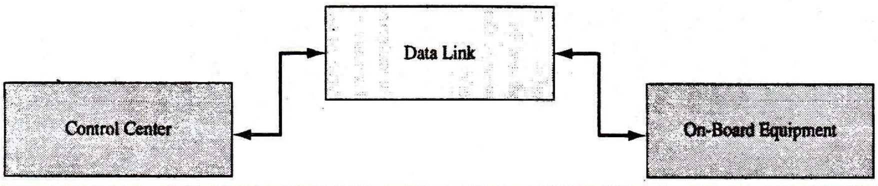
Second, there was a question of whether to propose a full-blown implementation of the ARES project or just an initial phase or two. Presenting the full-blown project would inform top management of the potential range of ARES features and would give them the bottom line for fully installing ARES for the entire railroad: about $350 million (see Exhibit 2 for cost breakdown). Even for a company of the size of BN, this investment was a large amount. And ARES was a complex project, different from typical railroad investments in modern locomotives, cars, track and ties. According to Henderson:

> We may not do the entire railroad; early implementation at least would inevitably be limited to specific geographic areas. Further, we may or may not implement all of the ARES

EXHIBIT 2 ARES Cost Breakdown

MAJOR COST CATEGORIES	COST	COMMENTS
Control Center	≅$80 million	Software development is a major component of this cost.
Data Link (Wayside Communications)	≅$80 million	BN planned to replace much of its existing pole line communication network with an ARES-compatible data link regardless of the decision on ARES. However, this conversion had barely begun.
On-Board Equipment	≅$200 million	Roughly $100,000 per road locomotive; less for switch locomotives and MOW vehicles. Of this, LARS = $16,000/ locomotive with total costs (including software development) expected to be less than $35 million. Although not expected to exceed LARS, Energy Management System costs had not been estimated in detail.

LARS and the Energy Management System were generally considered modules separable from the rest of ARES. Beyond these two, however, it was difficult to identify ARES modules that could be implemented independently. For example, sending a movement authority to a train required the control segment to check conflicts with other vehicles' authorities, the data link to communicate the authority to the train, and the on-board equipment to enable the engineer to receive and confirm the authority. Thus, each of these three segments had to be implemented for ARES to operate in any given region. Although not every locomotive had to be equipped, as fewer locomotives in a region were equipped the overall system became less effective since ARES could no longer confirm the location of—and spacing between—all trains. Limiting ARES to a geographic region within BN reduced Data Link and On-Board equipment costs commensurate with track and vehicle reductions, and reduced Control costs somewhat.



> features; the LARS system and the energy management system are clearly very separable pieces.

Galassi explained the rationale for proposing the entire project:

> We figured that top management would want to have a picture of the total project, rather than being fed a piece at a time for incremental decisions and wondering where the end of the line was.

Finally, there was the issue of how to communicate the ARES benefits and credibly measure their value. Some of the benefits that the ARES team had identified were either difficult to measure because the values were unknown—how much more would a customer be willing to pay for a 1% improvement in service?—or because the railroad did not record and track certain data—how much time was lost by trains waiting for meets and passes? The team firmly believed that if they implemented this innovative technology, they would experience benefits they had not yet even anticipated.

EXHIBIT 3 Consultants' Studies of ARES Benefits

CONSULTANT	PURPOSE	APPROACH	RESULTS
A & L Associates	Measure effect of ARES improvements in terminal and line-haul performance on carload service.	Service improvements were modeled for a representative BN section using the Service Planning Model with inputs on existing conditions and expected changes in performance supplied by C.D. Martland, Wharton, and Zeta-Tech.	Reductions in line-haul times and increased terminal performance will decrease total trip times by 7–8% even if scheduled connections and blocking strategies are unchanged.
John Morton Company	Measure the increase in traffic expected with an increase in the level of service offered customers in given market/commodity areas.	Questionnaires were distributed to decisionmakers who routinely select modes/carriers for shipping commodities in or across BN territories. A demand elasticity model was constructed using conjoint analysis. The model was calibrated, tested, and sensitivity analyses were conducted to generate demand elasticities for each service attribute.	Perceived performance differences between truck and rail are most dramatic with respect to transit time, reliability, equipment usability, and level of effort. Improving reliability offers greatest leverage for increasing BN's revenues. A 1% improvement in reliabilty, if, and only if, fully implemented and perceived in the market place could yield a 5% increase in revenues; a 5% improvement in reliability could yield a 20% increase in prices.
Bongarten Associates	Evaluate the Locomotive Analysis and Reporting System (LARS).	A simulation using actual BN data on train information, trouble reports and repairs tested LARS in four modes: 1) inspection of units committed to shops; 2) examining component status during on-road failures; 3) using prospective diagnostics to schedule additional repairs when locomotive is already committed to the shop; 4) using prospective diagnostics to bring the unit into the shop before a failure occurs.	The two LARS modes which offer the greatest promise are modes 2 and 3; mode 3 offers higher savings but requires development of a prospective diagnostics system. Savings of 3% to 5% were calculated in five areas: departure delay, on-line delay, time off-line, maintenance manhours, and reduced severity of repair due to early detection.
Charles Stark Draper Laboratory	Analyze how safe ARES would be, compared to BN's existing train control systems.	Modeling using Markov analysis.	The probability of a train control system-related accident would be reduced by a factor of 100 when ARES is in place. The primary reason for this improvement is that ARES' integrated system architecture provides highly reliable checks and balances that limit the impact and propagation of human errors.

Zeta-Tech Associates	Measure gains in line-haul efficiency from Energy Management System (EMS) module and Meet/Pass Planning module.	Recorded actual operating data on 846 trains (55 were selected for detailed analysis) from 16 "lanes" chosen to represent BN's full range of operating conditions, control systems, traffic volumes and mixes. Modeled actual operation to establish baseline fuel consumption and running time; then modeled fuel consumption and running time using (1) EMS module and (2) Meet/Pass Planner.	EMS module produced only 2% net fuel savings and large increases in running times for some trains. Z-T argued this was due to software flaws in algorithm and priorities. Meet/Pass Planner reduced running time for all 846 trains by an average of 21%. For the 55 selected trains, travel time decreased 17% and fuel consumption decreased 2.5%. Reliability increased; the travel time standard deviation also decreased.
Wharton	Measure Meet/Pass efficiency and feasibility.	Modeled fuel consumption and running time using various Meet/Pass dispatching algorithms on selected study trains in the 16 lanes evaluated.	ARES can produce meet/pass plans consistent with operating policies which yield travel time and fuel savings in 30 seconds or less; a pacing algorithm produces further fuel savings.
C.D. Martland (MIT)	Measure of yard productivity.	Collected detailed data from several BN yards. Modeled effect of improved reliability of train operations on (1) yard efficiency through improved interface between line-haul, terminal operations, and crew assignments and enhanced capabilities for communications with and supervision of crews; (2) on yard processing times; and (3) on train connection reliability.	Train performance was variable enough to allow considerable room for increased reliability, reducing average yard times about one hour. Modest improvements in terminal efficiency and train connection performance could be achieved through better utilization of terminal crews. Overall ARES could reduce average yard time .5 to 2 hours at major terminals and reduce missed connections by 15 to 17%.

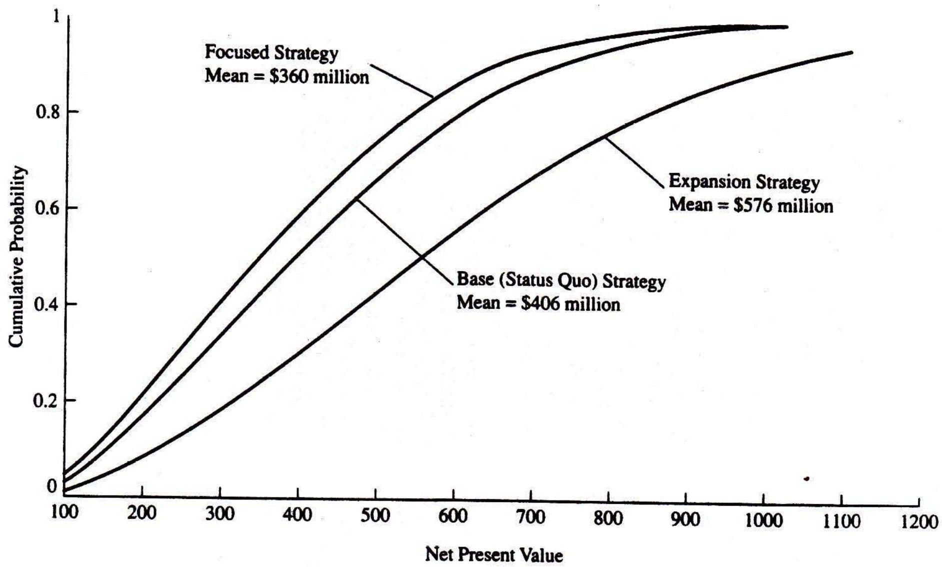


EXHIBIT 4 Cumulative Probability Distribution of ARES Benefits under Three Scenarios

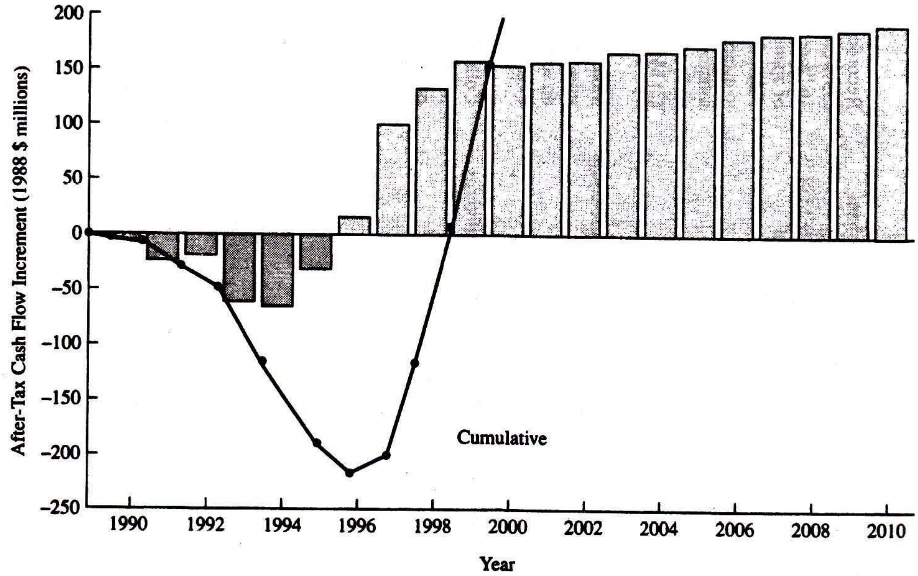


EXHIBIT 5 ARES Projected Annual and Cumulative After-Tax Cash Flow

EXHIBIT 6 Primary ARES Benefits

ARES offer many benefits that enable BN to reach its goals of safe and profitable rail operations. Following is a summary of those benefits.

- Increased rail operations safety results from constant monitoring of wayside signal and detector equipment, train movement, and locomotive health.
- Greater operating efficiency and improved customer service come from operating trains to schedule and handling trains that deviate from schedule, the results of improved traffic planning.
- Improved safety and increased customer service come from real-time position, speed and ETAs for all trains computed continuously and automatically provided to MOW crews and other BN users through existing BN computer systems.
- Improved dispatcher productivity results from automating routine dispatching activities such as threat monitoring, warrant generation, traffic planning, and train sheet documentation.
- Higher effective line capacity is provided by accurate vehicle position information and automatic train movement authorization.
- Improved MOW productivity results from improved traffic planning.
- Improved business management is possible with accurate, current information about the status and performance of operations and equipment.

KEY POINTS

- The study examined benefits in the following areas and estimates the present value of those benefits:

• Fuel	\$ 52 million
• Equipment	\$ 81 million
• Labor	\$190 million
• Trackside equipment and damage prevention	\$ 96 million
• Enhanced revenues	\$199 million
Total	\$618 million

- To account for uncertainty in these estimates, the study calculated ranges of values for them and probabilities of achieving values within the ranges.
- The factors with the largest potential for delivering benefits are also the most uncertain:
  - ARES' ability to improve transit time
  - The amount customers are willing to pay for better service
- Accounting for ranges and probabilities, ARES will make the following mean contribution to net present value for each corporate strategy:

• Focused strategy	\$360 million
• Base strategy	\$406 million
• Expansion strategy	\$576 million

- The probability of ARES' earning less than 9% real after-tax rate of return is extremely small.

To help measure the variety of benefits from a full-blown implementation of ARES, the team economist, Michael Smith, contracted with a half-dozen outside consultants, each of whom focused on a specific area such as measurement of market elasticity, measurement of LARS effects, measurement of meet/pass efficiency, and improved safety (see Exhibit 3 for a summary of each benefit study). Some benefits could be measured only partially in financial terms; for example, improved safety would reduce damaged equipment and freight by perhaps \$20 million per year, although its value in human and political terms was even more significant. According to Steve Ditmeyer:

> ARES reduces the probability of a collision by two orders of magnitude because, in contrast with our existing railroad control system where

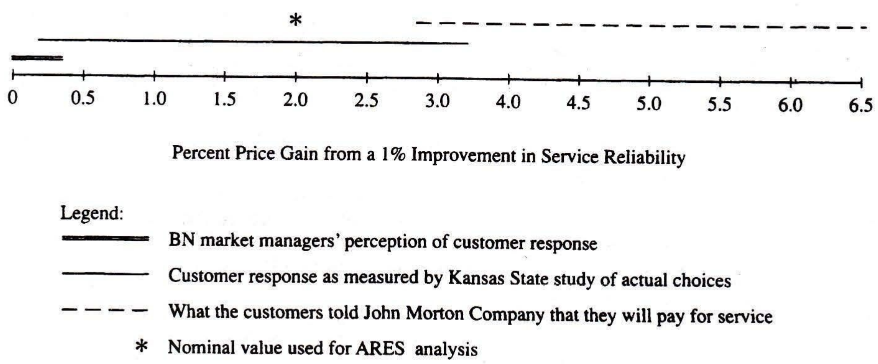


EXHIBIT 7 Price Gain versus Increased Service Reliability

> one failure or a mistake by one person can cause an accident, with ARES no single person or piece of equipment can cause an accident; two must fail simultaneously.

The Strategic Decisions Group (SDG) was hired to help the ARES team integrate the results of the individual consulting studies with other BN data into a single, coherent analysis of benefits. The analysis was conducted using three strategic scenarios supplied by BN's planning and evaluation department: base, focused, and expansion. Using probability distributions of key uncertainties supplied by BN managers, a set of computer models were built to calculate the probability distributions of the net present value of ARES under each of the strategic scenarios. (The cumulative probability distributions of the net present value of ARES benefits under each of the strategic scenarios are shown in Exhibit 4.) Exhibit 5 illustrates a representative annual and cumulative after-tax cash flow for the ARES project. The SDG report concluded:

> The potential benefit of ARES is large but highly uncertain. Using the best information currently available, we estimated the gross benefit in the range of $400 million to $900 million, with an expected present value of about $600 million. This benefit should be weighed against a cost of approximately $220 million (present value). . . . The benefits depend greatly on implementation success: The system design must be sound, a strong implementation plan must be developed, and functional groups across the BN system must be committed to using it to full advantage.

The ARES team concluded that the primary known benefits of ARES (see Exhibit 6) were to be measured in reduced expenditures on fuel, equipment, labor, and trackside equipment; damage prevention; and enhanced revenues. The largest component, revenue enhancements, however, had the most uncertain estimates (see Exhibit 7).

BURLINGTON NORTHERN: THE ARES DECISION (B)*

ARES seems to be a technology in search of a problem. The projected benefits from ARES have been derived from a bottom-up approach, not from a top level strategic planning process.

Dick Lewis, Vice President of Strategic Planning

ARES has the aura of an R&D-driven project. It was never subjected to the company's long-term resource allocation financing process or to a ranking among strategic priorities.

Jack Bell, Chief Financial Officer

Ed Butt, ARES project director, and Don Henderson, Vice President–Technology, Engineering and Maintenance, had presented ARES benefits to senior executives. While the executives found the benefits "fairly convincing," according to CEO Grinstein, they still had questions: "Do we need those benefits? Will there be a return on the $350 million? Is there a cheaper way to get them?" Senior executives had a nagging feeling that BN might be able to obtain 80% of the benefits for only 20% of the costs. Jack Bell articulated these concerns:

> ARES is a very large, complex project. It has many bells and whistles. We need to figure out what is the most important aspect of the project. If it is meet and pass planning, then we should assess the most cost effective way of doing meet and pass planning. "Unbundling," however, is not the favorite activity of project teams, especially late in the development process.

Managers were also worried that the ARES team had become overcommitted to their project and had lost their objectivity for analysis. Some referred to ARES team members as "zealots." It seemed that whenever senior managers identified a problem, ARES was offered as the solution; this confused some executives about exactly what ARES benefits were.

Executives also did not fully believe all aspects of the ARES benefits analysis, particularly the service-price elasticities. The marketing department considered the estimates overstated (see Exhibit 7 of (A) case), and wondered why its people had not been more involved in developing this analysis beyond providing suggestions on market research firms, research sites, and questionnaire content.

Others worried about the magnitude of the investment itself. A $350 million investment was not the largest BN had made, especially considering that the investment would be made over a several-year period. However, some were concerned that the actual investment would turn out to be much larger. According to Bill Greenwood, chief operating officer:

> Many things may be incomplete in the ARES system. Therefore, I don't know if the $350 million represents a bottom line price tag, or if the actual cost to design, program, implement and debug ARES will be a considerably larger number. The technology—vehicle identification, radio and satellite communication, and locomotive monitoring—is almost the least of our concerns. The technology alone does not deliver the benefits. We need to change our underlying business processes which are not only large in number, but intensely interrelated. And the roles and responsibilities of many of our operating positions must be redesigned in order to achieve the objectives and benefits of ARES. This kind of planning process was not

*Professors Julie H. Hertenstein and Robert S. Kaplan prepared this case.

> undertaken in the piloting of ARES, but it will be vital to successful, widespread adoption.

The significance of the required organizational changes concerned other managers as well. Observers noted that this investment would catapult the organization from the Iron Age into the Electronic Age. According to Dick Lewis:

> We wanted to increase our confidence in how the railroad's traditional, hierarchical organization with its deeply rooted, hundred-year-old history would handle the major organization changes that would be necessary.

Financial Operations and Restructuring

Even if ARES were justified, did BN have adequate funds to undertake it? During the late 1970s railroad industry financial performance had been generally poor. The industry was capital intensive, return on assets was low, and some railroads had been forced into bankruptcy.

Concurrently, concerns developed among some of BN's most senior managers that the firm was not doing enough to exploit its extensive land grant and natural resource holdings. They also believed that BN's stock price did not adequately reflect the value of its railroad operations and its natural resource holdings. This belief was made more tangible when T. Boone Pickens started to purchase Burlington Northern shares in 1987. BN management decided to restructure the company. Burlington Resources Inc. (BR) was created in May 1988 as a holding company for BN's natural resource operations. In July 1988, BR completed an initial public offering of its stock and in December, BN distributed its shares of BR common stock to BN's common stock holders thus spinning BR off from BN, and leaving BN with one principal subsidiary: Burlington Northern Railroad Company. To effect this spin-off, BN issued large amounts of debt, leaving the firm with a debt-to-total-capital ratio of 76%, a level considered high for the industry.

In his 1988 letter to shareholders, CEO Gerald Grinstein stated:

> We must manage the substantial debt load remaining after the spin-off of Burlington Resources Inc. This will require a clear strategic focus so that we can maximize the cash flows available for capital improvements while reducing the outstanding debt.

Jack Bell soon noticed the investment community's enthusiasm for debt repayment.

> Following the recapitalization, the investment community estimated BN's earnings per share at $3.20 and its share price at $22, a 7× P/E multiple. We queried analysts about why the multiple was so low and they told us about their concern with the level of debt for a company in a cyclical industry. To convince the investment community that BN had a viable program to pay down the debt and still invest in the railroad, we announced an accelerated debt repayment program that would repay more than the amount required in the debt covenants. Subsequently, we supported this program with progress reports of BN's cash flows and debt paydown in 1989 ($500 million as of year end) and a projection of 1990 cash flows (excluding net income). [See Exhibit 1.] BN's stock price rose significantly in the months following this report.

BN planned to continue to accelerate paydown. Grinstein's 1989 letter to shareholders said:

> One of our top priorities has been to improve our financial structure. We have undertaken a major improvement program and made significant first-year progress, retiring over $500 million in debt [debt-to-total-capital ratio: 68%]. . . . Our goal is to achieve a total debt level of 50% of total capitalization by 1994, paying down debt at an average rate of $200 million per year.

To emphasize the urgency of debt repayment, BN instituted a bonus plan in 1989 for all 3,000 of its salaried employees. The average percent bonus in any year depended on

EXHIBIT 1

($ MILLIONS)

1989 Cashflow			
Sources of Cash			
Net income		$ 243	
Depreciation		310	
Deferred taxes		69	
Lease financing		100	
Cash balance drawdown		1	
Accounts receivable sale		250	
Working capital change		124	
Asset sales net		19	
Total		$1,116	
Uses of Cash			
Capital expenditures		$ 473	
Dividends		109	
Debt service		505	
Required	112		
Optional	393		
ETSI		25	
Other		4	
Total		$1,116	
1990 Cash Flow Planning Assumptions			
Sources of Cash			
Net income		$?	
Depreciation		350	
Deferred taxes		30	
Lease financing		100	
Cash balance drawdown		40	
Other		50	
Total		$ 570	+ Net income
Uses of Cash			
Capital expenditures		$ 537	
Dividends		92	
Required debt service		115	
ETSI		25	
Other		1	
Total		$ 770	+ Discretionary debt paydown

the company's earnings per share, net income, and debt paid down. Individual performance could make individual bonuses somewhat higher or lower than average. Salaried employees below the level of vice president were divided into three groups whose bonuses could range up to 10%, 20%, or 40% of their annual salary respectively. Bonuses for employees at or above vice president level were administered separately.

In a era of accelerated debt paydown, funds for investment were tight, and there were many competing demands for available funds. Normal aging of equipment would require heavy expenditures to replace locomotives, freight cars and track. Recently acquired concrete ties had already demonstrated benefits beyond those originally projected, leading to proposals to make further investments in them as well. The growth in export potential caused some BN managers to consider whether additional railroad acquisitions with good access to west coast ports should be sought. Brock Strom, Vice President–Information System Services, believed that the new strategies resulting from the firm's strategic review would require additional MIS investments to support them. The strategies were still emerging so no specific demands were defined, though his "unsubstantiated guess" was that $100–200 million would be required. Jim Dagnon, Senior Vice President–Labor Relations, suggested that if the current round of labor negotiations produced an agreement that train crew sizes could be reduced, an investment of $100–200 million to "buy out" the excess crew would have an 18-month payback.

Technology Concerns

Apart from financial considerations, some managers were concerned that BN was considering adopting an automated train control technology that differed from the Advanced Train Control System (ATCS) being developed by members of the Association of American Railroads (AAR). ATCS controlled trains; ARES controlled the entire railroad operation. By 1990, when BN had already tested the ARES prototype, the AAR was still developing specifications for ATCS. Some believed that the ARES system was as many as five years ahead of ATCS in development. Other comparisons between the two systems are shown in Exhibit 2.

Other managers pondered whether BN should be first in the industry with an automated train control technology. According to Joe Galassi:

> If the investment is unique for some period and represents a competitive advantage, then BN should be the first mover and get the additional business. However, if the technology does not offer a big marketplace advantage, then it is not best to be first. If other competitors implement it first, BN has the advantage of watching them and avoiding their mistakes.

EXHIBIT 2 ATCS and ARES Comparisons

FEATURE	ATCS	ARES
Accuracy (feet)	+100	+100
On-board equipment (per unit)	$20,000–$80,000	$20,000–$80,000
Wayside communications	UHF radio $146 million	VHF radio $78 million
Equipment maintenance	5%*	5%
On-board signaling	Yes	Yes
Train control	Yes	Yes
On-line locomotive condition	Yes	Yes
Set-out and pick-up instructions to train crews and confirmation from them	Yes	Yes
Full safety benefits	No†	Yes
Positioning system	Transponders between rails; plus dead-reckoning on locomotives	GPS satellites; plus dead-reckoning on locomotives

**Add $0–$2,000/locomotive/year.*

†ATCS cannot effectively monitor the location of maintenance-of-way vehicles due to the substantial time they spend between widely spaced transponders.

Many believed that the development of the control center represented another notable risk. Software development was a key element of the $80 million control center cost. Much of the complex set of control center software had yet to be developed and integrated although some algorithms had already been tested. Forecasts of development costs, or of development time, might be exceeded. Brock Strom suggested that some prior computer applications had not always gone exactly as planned. For example, the computerized track warrant system that one division got from the Canadian Pacific Railroad was supposed to take one year to implement; it actually took four. However, the remaining ARES software resembled existing software applications such as the FAA's air traffic control system. According to Brock Strom:

> The technology risks are not that significant. The hardware technologies have been used in other industries; therefore the issue is not developing a brand new technology but transitioning an existing technology to the railroad. ARES is a major software development effort with all the normal problems, but the programming effort is quite feasible and should be able to be implemented.

Gerald Grinstein believed:

> For the industry to succeed, it will inevitably have to get into some kind of new technology. I don't want BN to be the sole ARES advocate. I've invited other railroads to come and observe the prototype system in the Iron Range. If BN goes with ARES, it will probably drive the rest of the industry this way. The others have to stay competitive, and ATCS is not realistically available now, so ARES is the only operating solution at the current time.
>
> The ARES decision is caught up in another process, shaping BN's future. Major questions to be answered are, "What kind of railroad should we be?" If we deliver a much greater, more reliable level of service, can we profit from that?

Joe Galassi stated:

> There are really two reasons to do ARES. The first is better service. The second is that we will be better able to control assets by scheduling locomotives and cars more precisely and getting better productivity out of the assets. However, the real heart of the matter is service to the customer.

Mark Cane, Vice President–Service Design, concurred:

> ARES could bring higher reliability to the railroad. It could improve the mechanical quality of the railroad, through fewer engine breakdowns. It could improve reliability in terms of consistent arrival time through dispatching and schedule discipline. It could also increase the capacity of the physical plant by tightening the spacing between trains thus allowing more trains to travel on the existing track. If ARES cost $50 million, we might have already begun it, but $350 million is a problem in light of competing demands for capital.

Jim Dagnon also found that ARES offered significant advantages from his perspective:

> The union leadership had toured the ARES prototype facilities. They loved it. The work force is as ready to adopt ARES as any workforce I've ever seen. A significant aspect of ARES for all labor is safety; safety is extremely important, and they see ARES as increasing safety. They see ARES as making their job easier and more important, especially the engineers. Conductors are a little less enthusiastic; it may reduce their job responsibilities. Ultimately, ARES has the potential to schedule the crews' work; this would lead to a higher quality of life compared with today's unscheduled, on-call environment in which crews don't know whether or when they will be called to work.

As BN's executives pondered whether to proceed with ARES, they still were not fully comfortable with whether the assessment of ARES benefits was realistic or optimistic. They also struggled with whether the benefits, or many of them, could be attained at a lower cost: Were technologies cheaper than the one prototyped with Rockwell available to support the ARES project? Could the benefits be unbundled? For example, the recent experience with the service measurement system suggested to some executives that improved discipline and reporting could enhance service without the large capital investment required by ARES. Yet, in contrast to JIT experiences, which had taught manufacturing firms to fix their manufacturing processes before automating them, at BN, without automation—that is, ARES—managers lacked information on operations needed to fix the process. Could BN have the cake without the icing?

Before proceeding with a decision, BN's senior executives decided to conduct an outside audit of the ARES proposal. SRI International (formerly Stanford Research Institute) was engaged to audit the benefits analysis, to investigate the possibility of unbundling the benefits, and to study whether alternative, less-expensive technologies were feasible.