Advanced Process Control, Optimization and Information Technology in the Hydrocarbon Processing Industries—The Past, Present and Future

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**FOREWORD**

I write this perspective, not as a practitioner, but from the point of view of a business researcher who has tried to benchmark progress, levels of application, critical success factors and the impact on business profitability. Perspectives will differ by company, by discipline and by individual. By no means, do I claim to have the absolutely correct perspective. However I would like to share my perspective in the hope of learning more from other points of view. A historical perspective does heighten respect for the true practitioners and their ongoing saga to master a rapidly advancing technological wave for the economic benefit of their companies and all stakeholders.

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The history of automation in the hydrocarbon process industry combines the experiences of many. Process operators saw the computer as a source of better information and operational advice. Instrument engineers saw the potential for better control loop performance. Process engineers realized that the computer might be able to deal with the complexities of economic optimization and concurrently push against multiple constraints.

As the knowledge and applications expanded, specialists emerged. Process control application engineers focused on more sophisticated algorithms, simulation models and software application packages. Systems hardware engineers concentrated on the computers, operating systems, and interconnected networks. All the while, mathematicians throughout academia, military and aerospace, computer vendors, and the hydrocarbon process industries made steady progress in resolving the enormous mathematical complexities.

While almost everything has changed dramatically, one constant lesson never changes. That lesson is that successful application and sustainable on-going performance improvement depends on a team effort of the people with all the critical skills and knowledge. True collaboration must start at the very beginning and last as long as the application remains in use.

From the early pioneering to the present, “disuse” caused by lack of unified support or lack of technical competence, is the big risk for this complex technology. Unfortunately, too often this is not a “lesson learned”. Rather, it is a lesson that seems to be learned over and over again. Since management’s job is all about managing risk, the risk of disuse is the risk that management must manage and be accountable for.

Another constant within this sea of change is that the gains from better knowledge of the process, the equipment, and the improved technical support may match the savings attributed directly to computer control. It takes a “learning organization” that sees the true potential as well as the challenges to capture the full value of this technology.

The Early Years

The refining industry has been a pioneer in automating its processing operations. Many technical milestones have been attained to bring the industry to the state of control that exists today, especially among the process control leaders. Changes brought about by modern process control have also had profound effects on the plant operating culture, from management and technical staffs to shift operators.

Process control has always been a necessary part of refining. As the early industry moved from batch stills to continuous processing operations, control houses were already an integral part of the process unit. These early control houses often contained “look boxes” as major elements of control. These “boxes” were simply wide spots in the product rundown lines, located near the control room and fitted with glass covers. The operator could judge the volume of his product, see its color, take its temperature or just feel the pipe. He could even open the boxes and feel or smell the product if he wanted. The operators could react to obvious change, but had limited ability to actually control the process. From these simple beginnings, process sensors and controls progressed rapidly.

Instrumentation Improves

By the mid-1950’s, fluid flow and other process sensors, pneumatic transmission of process data, pneumatic controllers and valve actuators had become highly developed forms of automated control. Most instrumentation was located in a unit control house, with significant savings in operating personnel achieved through these early process automation steps.

The industry went through several phases of presenting the data to the operator. The most elaborate one was full graphic panel boards displaying the process pictorially in the control room with process indicators and controllers mounted at their appropriate locations on the display. During this period, process analyzers for on-stream analysis became available, providing operators with more specific and
timely information than just process flows, temperatures, pressures and levels. The classical control theory began to be developed by academic institutes and the major control companies.

From the late 1950's to the early 1960's, electronic instrumentation became more prevalent, as many refiners experimented with electronic transmission and control. The instrument industry held heated debates on the relative merits of electronics versus pneumatics. Some standardization was achieved, while instrument vendors championed their own systems.

Data logging was introduced into the control room, usually with limited success as little use was made of the reams of raw process data collected. Some experimentation with digital control computers was initiated on select process units, also with limited success.

The first on-line process computer control project in this industry was described in a cover photograph and four-page story in the April 4, 1959 issue of Business Week. The application was at the Texaco Port Arthur catalytic polymerization unit using a TRW computer.

**Computer Control Spreads**

The appearance of low-cost digital mini-computers in the early 1960's brought about a significant milestone—the use of digital computers to control refineries and chemical plants. Joint development efforts between major users, and instrument and computer companies were undertaken. This collaboration culminated in pilot demonstrations of set point supervisory control and direct digital control (DDC) in the mid-1960's. Through these joint efforts and through internal developments in large industrial organizations, computer control systems software began to evolve rapidly.

The industry grappled with new technology and concepts. Some advocated basic process unit stability, concentrating on obtaining stability with closed loop control, using DDC to set the position of the control valves directly. Others felt they could achieve maximum benefits with supervisory control, manipulating the set points of their conventional instrumentation, without a major upgrade of existing control hardware.

Industry workshops addressing numerous technological issues abounded. Reliability and the need for back-up control capability in case of computer failure were key concerns. Despite the technical turmoil, computer control projects were implemented at a rapid rate from the mid-1960's to the mid-1970's. Their forms took many variations, from mini-computers to mainframes, and covered a variety of process units. Some applications focused on supervisory functions and others on DDC, and some on a combination of both.

Typically, the early projects were costly and delivered late, as the effort for the complex software that needed to be written was often underestimated. Control house consolidations, which combined many smaller unit control houses into a major control center, were frequent. Operating manpower reductions and replacement of obsolete instrumentation helped justify some of these earlier projects.

Hardware needed to be adapted to the control house environment and meet the high reliability, response time, emergency and safety requirements demanded by the industry. Electronic analog instrumentation became prevalent, due to its ability to meet industry requirements and provide reliable computer backup or interface to the process. But the shift from analog to digital was already underway. Visionaries saw that DCS (Distributed Control System) could place multiple loops under one computer chip and implement operator communications through an electronic data highway rather than dedicated panel instruments.

While the hardware, as well as operating system software, for implementing process control was of primary importance to the success of projects, it was applications and process control strategies that reaped the major economic benefits. However, modern control theories, which were researched and developed largely in the military and aerospace industries, did not always have the substantial early impact on the control of refinery processes as some predicted. For example, the issue of deadtime compensation made it difficult to take control theory from the aviation world and apply it to hydrocarbon processes.

Process control practitioners in the refinery and chemical industry recognized that the control concepts
of the period greatly outpaced the practical implementation and that much of the theory was difficult to apply to real processes. The most prevalent reasons for lack of practical implementation were:

- lack of understanding of the process
- strong interactions among variables
- process non-linearity
- few accurate mathematical models

However, as practitioners in the industry gained experience with computer control of commercial plants, the incentives were recognized and realized. These incentives derived from:

- improved regulatory and advanced control
- better understanding of process dynamics and unit operations
- operating closer to constraints
- finding the most profitable operating conditions

Computer control benefits gained recognition, and computer control became an established technology in many organizations. As computer controls and control room consolidation projects increased in popularity, they also had a substantial impact on the organizations in which they were implemented. The process operators' sphere of responsibility was greatly increased. Management and union issues were raised: should the chief operator remain a member of the union or become a member of management?

More fundamentally, the relationship between the operator and his process clearly changed. With feedforward and interactive controls, the operator could no longer make a change in one variable and make acute observations on how other variables respond to this change. The relationships had become much more complex and far less apparent. In some successful installations, the chief operator had the backup and assistance of a professional control engineer right in the control center.

Computer hardware, software and instrument engineers had their turf battles, as did the control and process engineers. The importance of a close, harmonious relationship between operating and staff groups was recognized as a key to successful computer control projects. Significant organizational realignments in operating, technical, and mechanical areas were often necessary to take full advantage of computer control opportunities.

The Microprocessor Era

The early 1970's saw significant improvements in computer control, as the second generation of control computers was launched with increased capability. The computing power of general-purpose computers expanded enormously and monitor displays gained in popularity. This era saw improvements in electronic instrumentation. More importantly, it ushered in digital instrument systems. The advent of low-cost microprocessors spurred instrument companies to incorporate them into their products, thereby providing considerably improved functionality and flexibility.

This development was made possible by the integrated circuit chip, which by 1978 already made it possible to put over 64,000 transistors on a single chip of silicon. Chip technology has evolved to the point that today's chips contain the equivalent of millions of transistors. This era gave birth to the architecture of the modern control system, consisting of several major building blocks. These were the microprocessor-based digital controllers, the operator workstation, the host process control computer and a communication link that connects them all together.

The organization of these building blocks was hierarchical. The microcomputers at the bottom performing repetitive, simple operations, and the host computer at the top doing the complex calculations requiring a lot of number crunching power. This architecture became the backbone of most subsequent computer control installations.
Advances in the 1980’s and 1990’s

Taking advantage of the control system architecture that evolved in the 1970’s, and the high degree of equipment reliability that had been obtained, control panel boards in the central control rooms slowly disappeared. The operator’s “looking glass” into the process became the CRT at his workstation, with many improvements made to the man-machine interface. The integration of instrumentation and control computers into a cohesive control system was rapidly progressing.

The architecture also permitted extending the processing of information from many other systems, located in other parts of the plant. Integrated information systems were installed that extracted and archived data, permitted technical calculations and reporting on process units, as well as oil movements, utilities, machinery monitoring and laboratory systems.

While the decade saw significant advances in plant computer systems, applications technology continued to grow, but at a slower pace. As evidenced from the technical literature, a wealth of applications technology was available within many refinery organizations, or from vendors. This applications technology has spread throughout the industry and has been extended by leading practitioners to the higher levels of control and optimization.

Today, new applications software can be installed concurrently with new hardware as part of a state-of-the-art package. This does not mean that the organizational learning curve to achieve maximum benefits has been eliminated. It does mean that the learning and training process can be accelerated. Many refinery organizations consider advanced process control as one of the best current opportunities for improving their profitability.

In the 60’s and 70’s, distributed control systems enabled PID (Proportional, Integral, Derivative) control of single loops in a consistent manner. By the late 80’s, multivariable model-based predictive controllers enabled control in a single program. With predictive capability, a controller can make the moves necessary to prevent any constraint violation before it occurs, rather than reacting after the fact, as PID controllers are forced to do. Increasingly, plant testing of process response dynamics to develop and improve the multivariable controller models became a strong priority.

By the mid-1990’s, essentially every refiner was using LP (Linear Programming) or other simulation models for off-line business optimization and to provide volumetric signals or guidance for raw material selection, operating throughputs and intensities, and desired product slates. However, most companies still did not have the level of company wide economic training or sophistication to call signals in economic terms.

Most refineries had some advanced process controls, although the actual industry level of application was no more than 25 to 30% of the economic potential. The large volume processes such as crude distillation, fluid catalytic cracking, and gasoline blending attracted the greatest attention. Leaders in the technology were substantially ahead of the rest. Leaders typically had installed 50 to 75% of the technology as measured by potential economic value.

But, what about on-line factors and that old nemesis, disuse? Clearly, dramatic improvement had occurred. In the late 1980’s, few refiners even had accurate measures on the on-line factors, that is, the percent of the time that the application is in use and doing its intended job. In fact, some users in that period indicated that they were too embarrassed about their numbers to discuss them publicly. Sometime there seemed to be disconnects between the achievements and advances being touted at the trade conventions and the actual realities at the typical refinery.

But, by 1995 the technology was working better, confidence was higher, and there was less concern about marshalling all the critical skills. What caused this improvement? Undoubtedly, there are multiple contributors, but many observers point to the emergence of the larger model-based multivariable predictive controllers that use actual plant test data to simulate plant dynamics.

In fact, many companies were switching to these multivariable controllers and deactivating some of their
single-loop advanced controllers. These larger model-based controllers could just manage the dynamic complexities and interactions much better and with some synergy. And the operators liked them. The predictive controllers were installed on an outboard computer to the DCS and deactivated many loops in the DCS. But the old vigorous debates about direct versus supervisory control, and computer reliability and redundancy, had lost their fire due to improvement in all aspects of the technology.

**On-stream Analyzers**

One critical point is much more than a footnote. When asked, “What is the major limitation or problem in achieving the full benefits of advanced process control?”, the most frequent answer over the decade was reliability of the on-stream analyzers. A typical refinery has about 250 on-stream analyzers that may be classified into about fifty-five types. Over twenty percent are used for closed-loop control. Few experts expect that the use of analyzers will decline even with more inferential models to augment or replace the analyzer. Confirming this perspective, one finds that new olefin plants are loaded with on-stream analyzers, providing compositional analysis on all feedstocks, immediate streams, and final products.

Analyzers calibrated with standard samples are often more accurate that the laboratory, plus they provide essential results around-the-clock for process and quality control, safety and environmental protection. With proper design of sampling systems and expert maintenance, on-line factors of at least nine-five percent for critical process control analyzers are quite attainable without undue expense. The integration of analyzer and control technology remains one of the key success factors. On-stream analyzer results are now increasingly accepted for final certification of product quality for customer shipments.

**What is “Advanced” Control Now?**

With advances in control, the issue arises of what defines a truly “advanced” control. Advanced control involves distributed and supervisory control above the basic level of regulatory control. Closed loop PID controllers provide basic regulatory control. Also, simple cascades of a process variable to flow control, such as temperature setting to flow control, are regulatory controls.

Also, there now exist a category of controls that were previously known as “advanced” that are now generally described as augmented regulatory controls. These include nonlinear level controllers, dead time compensators, pressure-compensated temperature controllers, and cascades to a non-flow secondary control variable.

Today’s advanced process controls usually involve composition and constraint control. They can be implemented as a number of individual controllers or as part of a large multivariable model-based predictive controller. The recent trend has been towards larger controllers and away from numerous smaller controllers. By integrating controls into a single controller, interactions across an entire unit or plant can be better managed. These large model-based controllers might be built in a modular fashion with use of sub-models that can be deactivated if problems with sensor data occur.

In the early 1990’s, the typical multivariable predictive controller handled about 12 controlled or constraint variables using about 6 manipulated variables or control valves. Recently, successful applications have been reported that look at 400 variables and move 200 valves.

In the future, neural network models and expert systems will be gradually integrated into both advanced control and optimization applications.

**Optimization**

As the ability to precisely control the plant improves, interest naturally shifts to making sure that one has the right control objective. Exact control to the wrong target does not satisfy any process control engineer. Optimization involves any method to determine the feedstock selection or process operating characteristics that obtain maximum profit and/or minimum cost. The interaction of linear program
models used for off-line plant-wide optimization with on-line optimization and advanced control has a fascinating history.

The refining industry's relationship with linear programming began over fifty years ago. When I started my career at the Esso Baton Rouge Refinery in 1958, sophisticated LP models were widely used for many purposes. The motor gasoline blending model in particular was widely acclaimed. One of my first assignments was to implement LP optimized blending of aviation gasoline, a very large volume business in those days. In the 1960's many companies developed large, complex simulation models that initially required the capabilities of mainframe computer systems.

The ability to apply rigorous optimization techniques and carefully select the optimum solution from among the multiplicity of feasible alternatives can provide the vital ingredient for excelling in highly competitive environments. The problem is that such systems require a great deal of upkeep, analysis and interpretation. Special skills are required to properly use system tools and effectively implement the results.

Due to their complexities, there has long been a tendency to misuse LP techniques and under-utilize their real strengths as a decision-making tool. Now, companies have converted to state-of-the-art models specifically designed to run on the latest microcomputers and still provide essentially all of the needed computing capabilities.

Overall plant optimization may be accomplished using several process or blending models. Mathematically, optimization presents quite a complex problem. Given a desired product slate with various points of delivery for products, viable optimization should be able to determine the following:

- Type and quantity of raw materials to secure, given their price and delivery cost
- Allocation of raw materials to appropriate refineries and chemical plants
- Scheduling of process units for processing the various raw materials to make blending components, and both oil and basic chemical products
- Best shutdown schedules for process unit planned turnarounds with appropriate contingency planning for possible unplanned downtimes
- Optimum operating conditions for the process units, recognizing relationship with catalyst deactivation and equipment coking or fouling rates
- Optimum blending of components to produce finished products
- Product shipping schedules to primary terminals by pipeline, vessels, and barge
- Inventory management for raw materials, intermediates, and products that recognizes seasonal demand patterns and contingency for changed circumstances

In addition, this optimization system should generate marginal costs for supplying more or less of each product to assist in setting sales targets and strategy for the next planning period. In turn, market analysis may provide marginal “revenue factors” which are the predicted market price dynamics of aggressive selling into adequately supplied markets.

Only fundamentally sound economic models can properly address many major optimization tasks such as the following:

**Crude Oil Evaluation**

A volatile raw material market has become a way of life for the industry throughout the world. Although the price of crude oils is readily available instantly from the marketplace, the value of an individual crude oil is a function of the specific features of the refinery under consideration. And it is not a static value. The essence of raw material selection may vary with seasonal changes in product qualities, the condition of major process units and the composition of the remainder of the raw material slate that is scheduled for processing.
In short, raw material purchase decisions profit from frequent reviews of the value of incremental raw materials as generated by validated models. Economic evaluations under “total and average” industry conditions are also useful to evaluate the reasonableness of the price.

**Product Blending**

The development of economic gasoline blending recipes demands a mathematical system. The complicated synergistic and antagonistic interactions between components and the necessity to satisfy a myriad of quality constraints simply exceed the mental capacity of even the most experienced blending operator. Well-structured blending models often generate blend compositions that are outside of the range expected from personal experience. But, it is the unique optimized recipe for each blend that meets all stated goals and maximizes the value of available components that provides the competitive edge in today’s environment.

**Operational Plans**

One of the more vital plant operational decisions is the selection of the most economic utilization of process facilities. The most profitable operators are those who uniquely combine the most cost effective raw materials with the highest plant utilization level, producing a slate of products that command a premium value in the prevailing market. The availability of a highly credible simulation model enables analysts to explore the possibilities and incentives for implementing innovative operating schemes. There is often much to gain in the consideration of changes in cut-points, diversion of component streams, or incentives to process intermediate or recycle feedstocks.

Also, increased emphasis is being placed upon on-line optimization built on models that are typically described as rigorous, fundamental, based-on-first-principles, or engineering type models. By 1995, refinery leaders in advanced process control were installing on-line real time optimizers on selected processes focusing on the large crude distillation, FCC (Fluid Catalytic Cracking), and gasoline blending operations where advanced process controls were successful and well accepted.

These models varied widely in terms of number of inputs updated, calculated set points, equations, steady state detection points, optimization solutions run per day, and time to recalculate and implement optimum set points. Wide variability was also reported concerning the percent of time the model performed in a closed loop mode where the calculated set points are automatically downloaded into the advanced controller.

Perhaps, the most interesting spot for observing this technology in recent years has been olefin plants. Demand growth has been vigorous—stimulating expansion of existing plants and construction of many new plants using state-of-the-art technology. The promised process control deliverables of throughput maximization and better plant reliability have been of great value and in high demand in the expanding olefins business.

With olefin plants, we have seen strong interrelationships among the various control technology applications. Increasing levels of advanced control applications are accompanied by increasing; numbers of multi-variable predictive controllers; on-line factors; real-time optimization; and closed-loop downloading of the optimum setpoints into the advanced controllers. The new trend is that all of these applications increase together in a highly interrelated pattern. Also, the boundaries between process control and optimization are blurring. For example, small LP optimizers may now be imbedded into the controllers.

Business optimization using off-line models is a continuous activity for planners. Business operational plans are updated as soon as they are finalized and approved by management. The distinctions between off-line and on-line optimization seem to have diminished. It is all becoming “seamless” to the casual observer although the reality is still one of many distinct technology software packages, occasional turf battles among the players, and unresolved issues about the best future paths to take.
Evolution of Information Systems

A topic of high current interest is the economic level of integration between the business optimization systems and the information systems in the ERP (Enterprise Resource Planning) or accounting and financial categories. The systematic use of information to guide commercial and industrial decision making is as old as commerce itself. When written records became available in China, India, Persia, and the Middle East many millennia ago, they were used to track and inform on sales, production, inventories, accounts receivable and logistics. Using these records, people made decisions on how to manage their affairs—to gain advantage and to minimize undesirable outcomes.

Over the centuries the sophistication and dependency on information systems may have increased…but nothing as extensive as the dramatic changes that have taken place since the introduction of the computer. People begin to think more in terms of systems as a network of related data, information, and procedures that are organized to help accomplish the organization’s tasks. Many paper-based systems became well structured and systematized using predefined forms and records. Highly organized paper-based systems are often the first attempt in the evolution of systematizing and organizing a function and they often improve performance substantially. Many early computer systems were the direct automation of good paper systems with little additional systematization or sophistication. In fact, paper systems had some advantages in terms of flexibility, understanding of the workflow and simple analysis of information.

In the 1950’s, the computer began to automate many routine operations, particularly high volume, labor-intensive transaction processes in the financial and administrative areas. Payroll accounting and credit card transactions are good examples. Many of these operations had been partially automated over the previous decades using early computing equipment and were well defined and systematized to become prime candidates for further automation. These early efforts at automation emphasized the processing of data and the generation of reports that only summarized the transactions. But management reports needed for making non-routine decisions were still compiled manually.

As the power of computers became larger, the sophistication of their use increased. In the 1960’s, more systems were designed to provide management information. Systems were implemented to directly support operations in areas such as inventory control, production planning and optimization, and preventive maintenance. Many of these information systems started to address particular programmed decisions that were routinely addressed by managers.

During the 1960’s, however, the timeliness of the available decision information was usually not very good. Most computer systems were operated in batch modes and management reports were generated on a weekly or monthly basis with considerable time delays from input data to reported information. In addition, individual systems were operated with separate data files. As a result, integrating management information from one application to another tended to be problematic, time consuming, error prone, and quite often not worth the effort.

Towards the end of the 1960’s, the concept of common data files emerged and that concept—in the form of company-wide shared databases—became available in the 1970’s on large mainframe installations. This concept of “data warehousing” with a single entry of data is still a fundamental organizing principle for many modern information systems.

Most companies, however, still continued to generate much of their decision information manually—even for highly routine decisions. The reasons for this were twofold. First, although computing technology had undergone large advances in cost effectiveness of data processing and storage capabilities, most companies used separate computers for different purposes such as accounting and administration, operations, engineering and maintenance. These systems could not easily share data. Some vendors fought “open” systems to protect profitable proprietary positions. Hence, integration of decision information usually had to be performed external to the systems and that meant that this was done with a high component of manual but cerebral effort.

Second, managers and systems specialists did not adequately know how to systematize or
mathematically describe highly useful decision information applications. The information system profession lacked understanding of managerial decision making processes, and there was little tradition to fall back on. The managers themselves also could offer little help in defining their needs except for highly routine decision situations.

During the mid-1970's, however, the concept of decision support systems (DSS) became increasingly accepted and a number of specialized systems were developed to provide decisions information for management at different levels and for different functions. Since more systems were integrated, the timeliness of the information was also improved which allowed management teams to change the way business was being performed. With timely information, less errors, and more comprehensive decision information, managers were able to increase the efficiency of their operations, improve their service levels to customers, and reduce reaction time to competitors' actions.

These developments also led to other changes. Many staff and middle management functions that previously had prepared decision information reports were no longer needed and organization flattening became possible. The way companies dealt with suppliers and serviced customers improved and movements towards “Just-In-Time” and similar concepts started to emerge.

Other notions such as participative management and Total Quality also became more viable options as a result of the improved availability and quality of information. These approaches often required changes in management practices that were not easy to implement.

The proliferation of the personal computer (PC) and broad integration of systems over networks allowed some companies to increase their efficiency and customer responsiveness during the last two decades. These changes greatly increased competitive and customer pressures, which forced many companies to modify their organizational structure and management practices.

In retrospect, one perceives the computing cycles that have been driven by technology, organizational pressures, and competition. This evolutionary pattern is illustrated as follows:

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Machine Accounting
↓
Data Processing
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Mainframe Data Centers
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Information Services
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Minicomputers
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Microcomputers
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Client Servers
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Internet/Intranets
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The Rise of ERP

By 1990 the typical refiner or chemical plant was using over thirty information systems to help manage process planning and operations, maintenance, custody transfers and quality control, financial and accounting, and administrative and regulatory functions. These systems varied greatly in their level of computerization, functionality, and use. Many were largely data storage and retrieval systems lacking in knowledge-based functionality.

Studies showed little relationship between the level of information system spending and business performance. However, a high level of use for problem solving or decision making did correlate with performance. These important uses in turn required support from the right embedded knowledge-based functionality such as advanced statistical analysis, complex information transformation, simulation, optimization, or automated evaluations.

Basically, it appears that the key to sustainable performance improvement is better decisions. Making the same old decisions the same old ways gives the same old performance, even if you have brand new information systems and the finest hardware all networked and connected seamlessly. Mere data logging, monitoring, or reporting does not equate profitability.

In the early 1990’s, ERP systems coupled with file server size computers began to spread rapidly in global corporations. Modularized software packages became standardized for the essential business functions of financial accounting, payroll, materials management, purchasing, assets accounting, order handling, and customer billing and accounts clearing. Decisions were required on which systems to convert to these standardized offerings from vendors and which legacy systems with unique capabilities to keep.

Companies learned that corporate implementation of ERP systems was not easy. They learned by experience that a high level of corporate readiness was required to conserve money, time and resources. Readiness to engage in ERP implementation may be measured in the following aspects.

- Commitment and engagement of senior management
- Clear critical success factors and business goals
- Educated and open-minded end-user community
- Sufficient funding
- Supportive project environment
- Strong, proven project management methodology
- Technical expertise
- Effective business change management
- Understanding of current business practices and future trends

Project success can be assessed by both useability and functionality. Without sufficient practical useability, a system will fall into disuse or certainly limited use that falls far short of the systems’ potential. Useability requires the right interface capabilities and the right scope of upgrading. Functionality means having the right knowledge codified into the software, and making the best decisions on all the configuration options for subgroupings and consolidations of information.

The decision information scene still continues its rapid evolution. Organizations are struggling to implement integrated information systems that span all relevant applications regardless of the software and hardware platforms. Users continue to demand automatic data entry, on-line access to information, user-friendly features, high flexibility to quickly create ad hoc or customized reports upon demand, and electronic interchange of important business documents.

Continuous business performance monitoring methods are evolving. Performance benchmarks, metrics, balanced scorecards, and performance grids are integrated into systems in ways that provide drill-down analysis as well as providing hierarchical summaries. Performance metrics may be financial and non-
Companies have also become more discriminating concerning the actual benefits of systems integration. Integration of some systems makes a lot of sense, while integration of others does not make sense at all.

More sophisticated analytical and modeling techniques are being incorporated as a knowledge-based functionality of the information systems. Experiments with automation of less routine decisions using embedded expert systems and other kinds of knowledge-based systems are also expanding.

Despite enormous progress, aligning information systems to corporate goals remains one of the top concerns of senior management. In the broadest sense, alignment means the delivery of the required results.

**Outsourcing**

Business process outsourcing is emerging as an alternative to internal investment and upgrading of information systems in certain functions. Designing, developing and implementing information technology solutions for individual businesses has become increasingly complex. Many businesses do not have the time, resources, or expertise to keep pace with industry and the technological changes or to efficiently build information technology solutions.

Globally, businesses are increasingly focusing on their core business competencies and are turning to outside sources to provide information technology services and skills tailored to create timely solutions and change business processes to meet specific business objectives. External firms that specialize in services such as real estate management, payroll, benefits management, auditing, procurement, accounting, and even human resources may provide more expertise and service at lower cost than internal operations.

**Convergence of Technologies**

What ERP vendors seem to lack is a viable dynamic business planning and simulation model. A balanced scorecard seems like a rudimentary optimization tool. The hydrocarbon processing industry seems unique because advanced process control, optimization and simulation modeling, and information systems have all developed along independent but complementary paths. Now we have reached the point where these paths clearly seem to converge and intersect. But the optimum means of convergence is not so clear.

In many cases the expected financial benefits of ERP implementations have not been achieved. Some of these benefits would likely be realized by integrating ERP applications with the production scheduling, optimization and control systems. But information technology always offers the allure of the “pot of gold at the end of the rainbow”, where everything is integrated seamlessly and all the information is of good quality and highly credible. There is great appeal in the idea of total enterprise optimization and even cross-firm optimization through collaborative alliances. But how much faster and how much better would integrated optimization and decision-making really be than many local optimizations in decentralized modes?

The reality is that optimization or decision support modeling and information systems in many firms are a “patchwork” of many independent or loosely connected systems. Older modeling systems may be well validated with many users even as better models are becoming practical due to dynamic technology. Translating business needs into new technology requirements is an ongoing challenge. Managing the transition of a patchwork of older but well used systems to modern systems with high user credibility is even more challenging. The practical transition could temporarily create even more of a patchwork.

Some experts argue that the workflows must be effectively integrated before the technology can be effectively integrated. The real issue is how will the new tools be used? Capital and technology make things possible; but people make things happen.
**Sustainable Competitive Advantage**

The desire of every businessman is to have a sustainable competitive advantage. Information technology when effectively used can provide a competitive advantage. But where is the sustainable advantage when your competitors also have the technology? The ultimate answer must be the people, and what the people do when they are empowered, and enabled. How people use and sustain the technology and tools will be the key success differentiator for the foreseeable future. The ability to marshall the talents, knowledge, and creativity of the human resources is still the logical source of sustainable competitive advantage even in a technological, interconnected world. This truth should be a vital consideration in mapping all fundamental technology paths.

**The Future**

The obvious question raised by a historical perspective is, “What does it tell us about the future?” We are all interested in identifying the fundamental trends. But, separating the few long lasting trends from the many likely fads is a tricky business, as we have all learned. Nevertheless, several powerful developments fascinate most of us.

E-commerce is the new paradigm in the software implementation landscape. The Internet evangelists speak of incorporating the Internet into everything we do to connect with customers or suppliers and to gain speed and mobility. The Internet holds a wide spectrum of promises from achieving sustainable competitive advantages to humanizing work by enabling people to interact globally.

Old and new IT companies are rapidly providing e-commerce solutions to make the new electronic world accessible to companies of all sizes. No doubt business-to-business and retail e-commerce will grow rapidly but ultimate profitability remains uncertain. Studies indicate that the computing for e-commerce will have a major component of transactional type accounting for order handling, billing, and settlement of transactions while the technology glamour will be in the design of the Web sites, the “mining” of customer databases, or implementation of collaborative planning methodologies.

Business to business (B2B) e-commerce may ultimately change the rules on how business is done. Buy-side and sell-side hubs will likely displace Electronic Data Interchange over private networks. E-business systems are rapidly being organized with standardized product codes, customer account and billing information, and shipping data. Substantial reductions in transactional costs are likely along with greater choice and ease of transaction evaluation.

Several on-line chemicals trading exchanges have already been organized. It is noteworthy that before an active natural gas market emerged in the United States only about ten percent of industrial purchases were made in the spot market, but active trading has increased that to about half of all purchases. Economists debate the sustainability of the “New Economy” powered by productivity producing information technology that permits faster growth with lower inflation than previously thought possible. How long this holds up is anyone’s guess, but one fact is clear. Massive amounts of capital have been pumped into the information technology sector of our economy. The technology share of the American stock market capitalization rose from ten percent in the early 1990’s to about thirty percent before the NASDAQ peaked in early 2000.

For awhile, even small new information technology companies were able to obtain risk capital to pursue aggressive growth strategies seemingly without the constraint of immediate profitability concerns. Many older firms also have moved to reshape their image in the e-commerce mode.

A major reallocation of resources from traditional industries to new high potential growth sectors linked to information technology and the Internet has occurred with incredible speed. The level of R&D spending has picked up a bit as a result. Will this research lead to surprising new technology developments? Closer to our traditional business is the current interest in supply chain management. A substantial portion of the supply chain is covered by traditional optimization technology previously discussed in this paper. Downstream petroleum marketers have long worked hard to optimize their truck deliveries and terminating or warehousing operations to manage their customer inventories. Service station network
volume prediction models help optimize site selection and offerings. Are there substantial economics to link the supply chain from the wellhead to the service station in one large integrated system? Or have the smaller, independent optimization modules already captured much of the potential? Managers should ask the tough questions, and expect hard answers on the economics of information technology. The answers may differ for commodity products that can be accurately managed through statistical forecasting of demand patterns, and specialty products where specific customer orders dominate supply chain operations.

The people that have brought about and applied advanced process control and optimization technology in the hydrocarbon processing industries have a proud tradition of accomplishment. Perhaps information technology has largely achieved the dramatic computing and data delivery revolution, although much applications work and more evolutionary development remains. However, much useful and profitable work remains to fully deploy available technology to achieve true potential. There are also far-reaching new developments to challenge us.

My projection is that the future focus will shift towards the delivery of knowledge relative to the delivery of data. Computer systems that merely deliver and format data will lose out to those with knowledge-based functionality. For example, in the past and even today some touted “planning and scheduling” systems do not produce viable plans or schedules; they produce information for the planners and schedulers. It takes lots of deep process knowledge and business savvy to produce realistic plans or schedules. It is often wise to do small “non-optimum” things today to reduce the risks of doing much larger non-optimum things in the future. Prudent risk-taking must be a part of a balanced plan.

The future will be about balanced delivery of the best knowledge in both codified software formats and complementary personalized services. This will be accomplished in a revolutionary new, globally connected environment operating at high speed with entire databases transferred in seconds. Accelerated knowledge that flows through the enterprise will create a more responsive and intelligently acting organization. Businesses may organize more around knowledge and business processes than around facilities and products. And tomorrow’s best business processes and practices may be quite different than today’s conventional thinking.

Managing Knowledge

Management of knowledge is certainly not a new issue. However, the future will be about better, more systematic management to leverage knowledge for competitive advantage. New infrastructures for knowledge management will rapidly emerge that build on the lessons learned from past organization approaches. These organizational approaches for knowledge include:

- Educational – by sciences or disciplines such as computer science, thermodynamics, heat transfer, reaction kinetics, separations, fluid flow, combustion, materials engineering, mechanical engineering, etc.

- Engineering firms – by equipment categories such as reactors, exchangers, furnaces, rotating equipment, instrumentation, electrical, piping, and utilities with overall integration by project management teams.

- Operating companies – by functions such as operations, maintenance, technical, and administrative. Or alternatively, by product lines or major processes such as olefins or polymers.

- Information systems – by functional modules such as accounting, planning and scheduling, custody transfers, purchasing, financial, etc. with integration to common data warehousing.

- Process lifecycle – by planning, design and engineering, procurement, construction, training, start-up, operations, debottleneck expansion, performance improvement, modernization, and towards the end, obsolescence and ultimate replacement.

- Business management – by planning, organizing, leading, and controlling including, strategic plans and goals, and key performance indicators and success factors.

In many companies, knowledge management is a patchwork of many approaches. But people are being connected electronically enabling communication and knowledge sharing in new ways. Incentives are high to capture and deploy across the enterprise the best practices and procedures, business
processes, trouble-shooting or problem-solving capabilities, and more effective decision-making processes. The new motto is learn once and use everywhere.

The new infrastructure must meet the demand for ready access, quality control through very competent oversight or clearing houses, and prioritization based on potential economic value. The infrastructure must accommodate knowledge from third parties, vendors, and alliance partners. “Communities of practice” can be very productive in sharing and spreading the use of best practices and complex knowledge.

The knowledge management landscape will include codified models, applications, tools, and related services. Business processes will become more automated with greater knowledge-based functionality. But each of these success factors must be tied to proven impacts on business performance and competitive position.

Far-reaching collaborative alliances among businesses and individuals will enable knowledge to be shared wider and deeper than ever before. Dynamic trading communities for knowledge, products, and services will be created in ways we do not envision. Companies may both collaborate in novel new ways for efficiency but compete more dynamically in a market place where customers are better informed, more powerful, and more determined to find the best values.

What to do

Based on a historical perspective, certain steps seem to make sense.

- Recognize that IT products and solutions can be very profitable if properly used and maintained for performance sustainability. Learn the “best practices” and “success factors” for sustaining and continually improving the highest value uses.

- Recognize that there is often a right time for each company to buy information technology. Apply too early and you take a risk for the early learning curve, unless your company strategy is to be on the leading edge of new developments and an early adopter. For some large companies, the “early adopter” strategy is correct because successful prototypes can be leveraged by timely rollout across many global applications. Apply too late and you can’t catch up with the competition.

- Appreciate the advantage for codification and “lock-in” of deep knowledge into software for automatic continuous application to enable and facilitate focus on personal knowledge that resists definition.

- Recognize that you do not need to “reinvent the wheel”. Align with experienced software application vendors that have a wealth of experience and “lessons learned” to leapfrog difficult parts of the historical learning curve.

- Understand that problem-solving and decision-making uses are the acknowledged key to IT profitability.

- Remember that when it comes to performance sustainability, IT or automation products and services are not interchangeable. There are important differences that must be evaluated in any sound vendor selection methodology. An important difference could be the business processes and best practices that are incorporated into the software.

- Develop your IT vision and master plan with alignment to business goals and specific ties to performance improvement or KPIs. Determine upfront how success will be measured.

- Collaborate with the right IT vendors that share your IT vision, provide proven delivery capability, and have sound development plans for the future.

- Consider areas where IT advances are opening up new sources of value. Several areas deserve priority attention:
  - Internet: e-business and e-collaboration
  - Real-time visibility of total supply chain information enabling better planning and scheduling with suppliers and customers and more productive cross-functional management throughout the business.
Unify and synchronize plant and ERP information domains
Unified total enterprise planning and optimization with appropriate levels of systems integration

- For making IT investment decisions:
  
  Know the value
  
  Know the total cost of ownership and the risks
  
  Know the key performance indicators

- Maintain perspective. For the hydrocarbon processing industry, information technology is rapidly changing but it is not new. However, it is far from being fully applied and meeting its full performance potential. Increasingly, it is one of the best ways to achieve improved profitability and a competitive advantage

- Prepare for the future. The future will undoubtedly bring more powerful computers, better software with common standards, and innovative sensors. New capabilities could connect almost everything in real-time—data, plants, employees, suppliers, products, and customers. The integration tangle will gradually disappear. User interfaces, portals, and digital dashboards will prove easy access even for those that are not seasoned hackers. Automated analysis will show how the business is doing against plans or goals, and alerts will flag significant deviations, exceptions, and surprises for possible action. Sophisticated software solutions for complex analysis, modeling, simulation, and optimization will be essential to avoid massive data overload and insure intelligent decision-making. Smart software will need to link business processes and best practices into the information flow to synchronize with the organizational and management culture. Some things will not change. Garbage in will still give garbage out. All real-time data will still be historical. It remains to be seen how much better the forecasting of prices, supply/demand, and competitor actions, on which much critical decision-making rests, will become. One will still be willing to swap much real-time data for a little certain knowledge about the future.

About AspenTech®

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