Author: Tim Olsen
Job title: Refining Program Manager
Company: Emerson

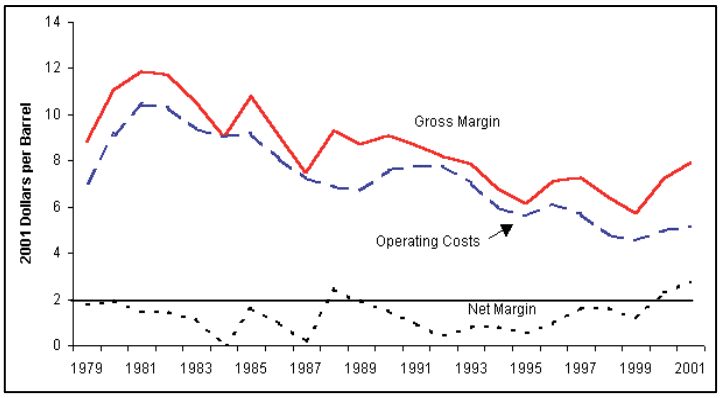
Country: USA

Advances in Digital Automation within Refining

Over the past three decades advancements in process control technologies have allowed dramatic improvements in plants' operating efficiencies, productivity and asset utilization. Distributed Control Systems (DCS) established in the 1980s brought a step change in capability and efficiency over pneumatic and electronic controllers. Throughout the 1990s, technology advanced to enhance DCS performance with widespread use of Advanced Process Control (APC) applications. During the 2000s, Digital field architectures brought another step change in performance over DCS platforms. With intelligent field devices and digital bus technologies to communicate the information for display, refiners now have advanced diagnostics integrated with asset management functionality to achieve new levels in efficiency, reliability, and safety. The introduction of wireless technologies has given refiners the opportunity to add additional process measurements without the cost and concerns of pulling new cable through an operating process unit. These additional process measurements enable the refiner to manage the health and efficiency of the refinery equipment in ways that were not available before; process engineers can now have the information they need to make operational decisions for optimal performance and reliability.
This paper will show how advances in technology have changed the refinery work culture to be more informed about the assets, thus able to make better decisions that effect operating performance, reliability, and safety.

Refiner Challenges

Most people consider gasoline and other fuels products as commodities making it difficult to extract premium pricing and additional margins from a differentiated product; the reality is that additional margins come from operating your refinery more efficient and reliably than other refiners. That is easier said than done, or is it?



While there are niche market opportunities to extract higher margins, overall the refining industry is a commodity market where an individual refinery has limited control over raw material costs and finished product values. Refinery net margins have historically averaged below $2 per barrel for 31 of the past 34 years (see graph below). Refiners have a significant investment in fixed assets which are expensive to maintain and subject to costly environmental, health and safety regulations. These realities give rise to an industry focused on cost reduction without jeopardizing plant reliability or safety.

There are many challenges in operating a refinery that also present opportunities for reducing costs. Refiners that buy crudes on the spot market can be subject to wide variations in price and quality, with the more sour and heavy crudes typically being less expensive. Many refineries will bring in crudes in large quantities and run them in a “blocked” operation. They will switch to a new crude tank when the current one gets low, every 1-3 days. Each crude switch, depending on the severity of the change, can upset the crude unit for 1-4 hours, often causing off-spec production as well as upsets to downstream units. Refiners with limited intermediate storage between units will have more impact from a crude switch further downstream.

After raw material costs, energy is the second largest variable cost component in a refinery operation. Large refineries will have 8-10 major process heaters bigger than 70MMBTU/Hr, 12-15 major compressors, hundreds of pumps and thousands of heat exchangers. Most sites operate their own utility systems with multiple boilers supplying multiple levels of steam, electricity, water, hydrogen, nitrogen, air and fuel to the refinery units. Making sure all the equipment is operating at or close to its peak performance and capability is a key challenge for the plant’s reliability engineers. Optimally balancing the utility supply in a refinery on a minute-by-minute basis is extremely difficult given the real-time fluctuations in demands, energy prices and distribution constraints.

Engineering and operations labor represent another challenge and opportunity for improving a refiner’s cost position. The refining industry has invested millions of dollars in plant information and integration projects to link corporate business systems with plant operations. These projects are intended to improve efficiencies and streamline business processes across the entire supply chain. Many of these projects have fallen short of expectations and have failed to deliver the promised benefits. Careful planning and execution of refinery information and system integration projects is essential to ensure a successful result that meets corporate business objectives and is sustainable over the long term.

Efficient use of maintenance resources, both for on-going maintenance and turnarounds, is an area that can often be improved through the use of modern technologies. Process and control

equipment deteriorates over time and eventually needs attention. Heat exchangers, compressors and turbines foul over time, becoming less efficient and increasing production costs. Without maintenance, instruments tend to drift, control valves wear, and process dynamics change, decreasing the overall effectiveness of the control system. The question of when to pull a piece of equipment for repair is a complex issue that should be based on its performance history, the operation performance cost of degradation, the cost of repair and the risk and consequence of a failure. In a cost-cutting environment, the appeal of delaying maintenance activities must be weighed against the increased risk of unplanned shutdowns and the cost of operating below peak equipment performance.

A large refinery may have 300-400 tanks and average more than 2 million barrels of inventories of crude, intermediates and finished products. A key issue for refineries is balancing the consumption, production and logistics for all units in the refinery such that tanks do not overflow or go dry and ships are not held up waiting to load or unload material. The more uncertainty a refinery has in its operation, whether it is related to supply, production, logistics or quality, the larger the inventory needed to manage the risks. Larger quantities of inventory result in cash later compared to cash in hand today.

Forecasting demand for products and pricing for oil can unpredictable; this creates challenges meeting ever-changing market demands. Higher margins have been seen in the US for diesel products, thus refiners want more flexibility to process and maximize higher margin products within the limits of their crude and product contractual commitments. Refiners without flexibility will not be able to capture additional revenues when market opportunities arise.

Last, but certainly not least, safety and environmental are on the top of every refiner's list of important concerns and issues operating the refinery. Safety and environmental programs represent large, on-going cost to the refinery, and incidents can be extremely expensive. With thousands of employees, many hazardous areas and working with explosive, carcinogenic and poisonous materials, refiners are extremely interested in systems that can provide early warning of pending failures and prevent unsafe or environmentally unfriendly conditions.

Opportunities for Cost Management

A typical 100,000 BPD refinery has an operating budget of close to $1 billion per year, which is roughly broken down as follows:

Raw Materials (crude, catalyst & chemicals)	80 – 90 %
Energy	5 – 10 %
Labor	2 – 5 %
Maintenance – Ongoing	2 – 5 %
Maintenance – Turnaround	1 – 3 %

Even a small improvement in these cost categories can amount to a very large dollar value for the refinery.

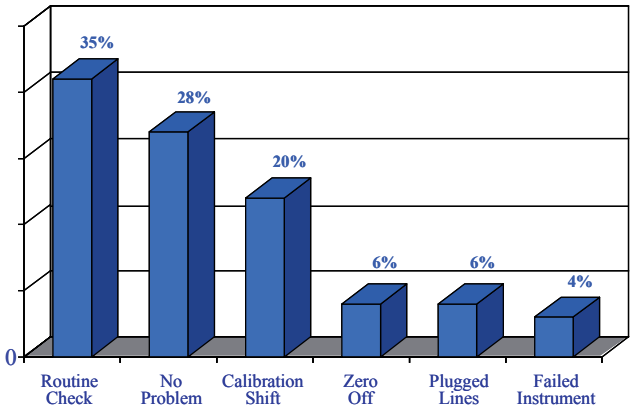
Refineries that have flexibility in their crude supply and processing capabilities have an excellent opportunity to reduce the overall cost of their crude slate by operating closer to refinery limits on a day-to-day basis. Acceptable crude specifications for a refinery are set by the refinery configuration, hydrogen balance, sulfur plant capacity, hydrotreater limits, crude/vacuum column design or capacity of the heavy oil conversion units. A coastal refinery that can respond quickly to take advantage of distressed crude shipments can generate savings worth several dollars per barrel of crude, or many thousands of dollars in a single transaction. For a 100,000 BPD refinery, trimming $0.05 from the average crude price is worth $1.75 MM annually in crude costs.

Refineries that change crudes often can also be subject to substantial crude switching costs, particularly when downstream units are affected. Many times operators need to decrease unit charge rates until the column is stabilized on the new crude. Off-spec production as a result of a crude switch can also be expensive. Crude switching costs for 100,000 BPD refineries can run up to $5,000-10,000 per switch, depending on the severity of the change, the reduction in throughput required and the amount of off-spec products produced. With 100 crude switches per year, this represents more than $500,000 in production costs.

The energy bill for a refinery, including internally generated fuel and outside purchases, averages 8% of the total crude cost according to the US Energy Information Agency. ("*Performance Profiles of Major Energy Producers*", www.eia.doe.gov) Improving the efficient usage of energy, whether through advanced automation, more informed and timely maintenance, or other means can have a direct impact on the refinery profitability. Major process heaters are good candidates for increasing efficiency by minimizing excess air, balancing multiple passes and stabilizing the outlet temperature control. A 2% improvement in efficiency of a 90 MMBtu/Hr heater, typical of those found in many refinery units, is worth almost $70,000 annually in fuel savings at a price of $4.50/MMBtu. The value to the process of stabilizing heater controls to reject disturbances in fuel supply and composition, the preheat train and charge rate can be even greater than the energy savings. Optimizing the operation and cleaning cycles for complex heat exchanger trains such as those found in crude/vacuum units, FCCU's, cokers, and other major process units can result in increased heat recovery and lower fuel costs for process heaters. For very one degree Fahrenheit increase in inlet temperature, a 100,000 BPD crude unit can save $20-25,000 per year in fuel costs.

Operations and engineering personnel represent a large fixed cost component in a refinery operating budget. Any opportunity to improve the efficiency and effectiveness of refinery staff can be translated into economic benefits by increasing the value of the activities they perform. Timely information is the key to augmenting the performance of operations and engineering; information to help identify sub-optimal process control on critical loops.

Maintenance activities, both on-going and turnaround, are another area where timely information can be utilized to prevent an unscheduled shutdown or safety incident or help identify and plan the required maintenance. Maintenance costs can be reduced by improving the efficiency of the maintenance staff, reducing the frequency of unplanned shutdowns and reducing unnecessary maintenance work. Studies have shown that more than 60% of a typical instrument technician's trips to the field result in either no action or a minor configuration adjustment that could be done from their office with smart instruments.



Refiner feedback estimated a manpower savings of 1.6 hours per instrument per year by automating instrumentation work practices and reducing trips to the field. For a large refinery with over 10,000 process inputs, a digital solution could save 16,000 hours per year for instrument and valve maintenance. This allows the opportunity to create a predictive maintenance culture that acts on alerts and root cause information in real-time, rather than reactive.

Unplanned shutdowns are expensive beyond the lost production they incur. Emergency shutdowns and subsequent startups put abnormal wear-and-tear on the equipment, increase catalyst and chemical losses, produce off-spec products and require additional manpower, overtime and expedited 24-hour service. Just one unplanned shutdown in a major FCC unit can cost a large refinery over $1MM per day. Similar costs can be incurred by shutdowns in any of the refinery's key process units. Part of the opportunity for unplanned shutdowns is having the ability to repair all required assets during a turnaround without unnecessarily repairing assets that don't need work.

Excess inventory represents working capital that is not available for use and should be valued at an average cost of capital for the corporation. In addition, off-sites tankage carries depreciation costs for the tanks themselves, their maintenance and the real estate they encompass, estimated to be about $50,000/year per tank for a large crude tank. The carrying cost savings alone for a 10% reduction of a 2 million barrel inventory represents $600,000 annually at an 10% cost of capital and average inventory value of $30/Bbl. This calculation is summarized below.

Total Inventory	2,000,000 barrels
Average Inventory Value	$30/bbl
Cost of Capital	10%
Inventory Reduction	10%
CARRYING COST SAVINGS	**> $600,000/year**

For a hypothetical 100,000 BPD refinery, the potential cost improvement opportunities are summarized in the table below. Each refinery situation is different and not all of these benefits are available to every refinery.

		K$/Yr
Crude Slate Cost Savings	$	1,750
Crude Switch Cost Savings	$	500
Heater Efficiency Improvements	$	423
Heat Recovery Improvements	$	258
Inventory Holding Costs	$	600
Operations Manpower Savings	$	400
Instrument/Valve Maintenance Savings	$	560
Total Potential	**$**	**4,491**

The Solution – Utilizing Advances from Digital Automation

Utilizing modern digital automation, like PlantWeb® digital plant architecture offered by Emerson Process Management, can address the challenges and opportunities for cost reduction identified in earlier sections within this paper. For example, field instruments that are equipped with smart diagnostics can alert in real-time key maintenance, operations, or safety personnel about asset problems before they fail or cause abnormal operation. The diagnostics identifies the root cause of the troubled asset, so maintenance can effectively correct the problem. In addition, this same root cause predictive diagnostic capability can be utilized to identify and plan for a smarter turnaround by repairing only the assets requiring work. Smarter turnarounds allow for cost cutting without negatively impacting reliability or safety of the plant; refiners utilizing smarter turnarounds have experienced operations benefits (related to better reliability and utilization) a magnitude higher than the benefits associated with cost cutting (only repairing items that need work).

Crude Cost Savings

Starting with crude purchasing, better measurement and control of refinery processes combined with Advanced Process Control (APC) applications allows a refinery to run closer to its true maximum limits, whether that is a sulfur unit capacity limit, hydrogen limit, hydraulic limit or otherwise. By widening the allowable limits, advances in digital automation have allowed the opportunity to increase a refiner's flexibility to run different crudes, giving crude buyers more leverage to choose different crude suppliers, take advantage of distressed shipments, and shave thousands or millions of dollars from the annual refinery crude bill. One should note that a year's worth of APC benefits can be lost with one day of unscheduled shutdown.

Crude blending applications further improve a refinery's ability to operate with different crudes and significantly reduce the severity and recovery time of a major crude switch. Coriolis mass flow meters, with their on-line density measurement, are ideal for monitoring and controlling crude blending operations. This application stabilizes the feed quality, reduces stabilization time and minimizes off-spec production and upsets to downstream units during crude switches. This means that refineries can blend in poorer quality crudes and still observe overall refinery constraints and product quality limits.

Energy Cost Savings

Energy costs are minimized by advances in digital automation technologies in one of three ways:

- Reducing process variability that causes units to operate in a non-optimal region
- Increasing the average operating efficiency of the refinery's major energy consumers: fired heaters, boilers, exchangers, pumps, compressors and turbines
- Optimizing the utility system to supply plant demands at minimum cost

Reducing process variability directly impacts a refinery's bottom line in terms of energy efficiency, capacity and quality. Modern digital automation can automatically identify high variability in key control loops to ensure visibility to both operators and operations engineers. Properly tuned and performing control loops can extend catalyst life and improve yield and quality which directly benefit the bottom-line revenues.

APC applications reduce energy costs by further stabilizing the process and pushing closer to actual equipment constraints and quality specifications. Modern APC applications are built with these standard tools that allow fast execution so distillation columns can be operated at minimum reflux, compressor recycles lowered, heater excess air reduced, catalyst losses minimized, heat recovery maximized, and so on – all impacting the total energy consumed by the refinery. Using APC technology, refiners can be assured that the control system only utilizes the right amount of energy needed to economically recover the most valuable products.

Real Time Optimization (RTO) allows a refinery to optimize the entire site utility system including steam, fuel, electricity, water, air, nitrogen and hydrogen. This advanced automation application applies on-line, real-time optimization techniques to determine the best combination of equipment, outside purchases and operating targets that satisfies the site's demands at minimum cost. Rigorous equipment models used by the optimizer are updated frequently from on-line process data to match the actual plant performance and constraints. RTO unique mixed-integer optimization capability is used to determine the best set of equipment to run for a given set of demands – not something easily done with traditional technology given the complexity of a refinery's utility balance.

Labor Cost Savings

Advances in digital automation dramatically affect the efficiency and effectiveness of Operations, Management and Engineering personnel, allowing refiners to reallocate resources. Flexible console features as well as smart alarm management, and APC applications all contribute to increasing the number of control loops that an operator can handle to the range of 300-400 per console operator. Consolidating control rooms and combining consoles allows refiners to reallocate the total number of console operators required to operate the refinery safely and effectively.

Easy availability of process and historical data through the continuous historian, integrated with Microsoft Office and Internet access tools, saves engineers' and managers' time and effort. Troubleshooting operating problems can be done quicker and more timely decisions made that save the company money. Internet tools allow specialists located anywhere in the world access to plant data and displays to aid in problem solving and analysis. Key performance indicators, equipment alerts, status information and quality data are available in real-time for display and alerting the appropriate personnel of impending problems before they happen. These tools allow refineries to accomplish more with less by maximizing their entire staff's productivity.

Maintenance Cost Savings

Maintenance costs, both internal and external, can also be minimized with advances in digital automation and FOUNDATION fieldbus installations. Some of the same technologies mentioned above that help keep control systems, field instrumentation and process equipment operating at peak performance are also productivity tools for the individuals assigned to optimize maintenance activities.

On-line monitoring tools and automatic alerts can help prevent unplanned shutdowns and their associated costs. Certainly, not all of the causes of unplanned shutdowns can be addressed by process control and automation systems, but faulty measurements, malfunctioning instruments, operator error and equipment failure are some of the common problems that smart field devices address. The online monitoring tools allow the opportunity for a refiner to become a more predictive maintenance culture that acts on information in real time to prevent shutdowns or safety incidents, rather than the traditional reactive or preventive maintenance culture.

A large part of a typical turnaround budget is allocated to preventative maintenance items, such as valves, exchangers and pumps. For example many refineries remove and service all of their valves strictly on a time basis, such as every 2 years. With smart field devices, the advances in digital automation allow the system to monitor valve stem travel, signature, hysteresis and component health to determine when valve service is actually required. Often small pumps and motors are maintained on a similar periodic basis. Online vibration monitoring helps determine whether a pump or motor needs maintenance. These tools have demonstrated how modern maintenance tools and methodologies can be used in a predictive manner to save both time and money during a turnaround without sacrificing reliability or safety.

Inventory Cost Savings

Inventory of both intermediates and finished products are the “safety buffer” for refinery operating problems. The higher the uncertainties in the operation, the more inventories are needed to manage the risk of a process problem affecting product delivery. Advanced digital automation solutions that stabilize operations, reject disturbances, minimize variation and prevent unplanned shutdowns give refiners confidence to lower average inventories and potentially eliminate one or more tanks. In addition, tanks do need inspection for leaks that take them out of service. Better utilizing operations to minimize off-spec can reduce the impact from having tanks offline for inspection.

Production accounting solutions utilizing accurate measurements and tank monitoring can provide credible numbers integrated to an ERP system for better tank management and terminal allocation. The primary benefit is optimized inventory management.

Conclusion

Advances in digital automation can increase a refinery’s operating margin through a combination of enhanced revenues and lower operating costs. On the revenue side, improved equipment reliability, unit availability, higher sustainable capacity and more profitable yields drive the top line higher while more efficient operations, less maintenance, lower inventories and reduced quality giveaway drive production costs down.