

The Safety Issues of Batch (and other) Controls

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8:45 – 9:30—Keynote Address—

The Safety Issues of Batch (and Other) Control

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Mr. Nimmo will review a history of batch control and look into what the future may bring and how the role of people has changed over time. He will discuss a new approach to safety, breaking the traditional barriers of people, organizations and culture, and will put the control engineer in the driving seat again for performance improvements—optimizing not just control algorithms, but people and the way they interface with technology.

Keywords

Human Factors, Operator Staffing Arrangements, Human Error, Control Room Design, Safety, MOC, MOOC

Abstract

The paper will discuss a new approach to safety breaking the traditional barriers of people, organizations and culture and will put the control engineer in the driving seat again for performance improvements optimizing not just control algorithms but people and the way they interface with technology.

In the past the control engineer has been asked, “how many loops can an operator manage” this paper will once and for all provide a rational answer to this question based on years of research and the Best Practices defined by the ASM Consortium. The paper discusses practices and controls in modern control rooms and how human factors are becoming a reality and will force management of change of personnel and organizations.

The Evolution of Batch Control

Industrial manufacturing has been around since man first learnt the basics of chemistry and physics. We have no start date but we do know that man first developed crude batch control during the Iron Age. The production was people intensive and was often marked with injuries and fatalities.

Since the early days of batch control the production process has not changed significantly, although there are now many different and new types of processes.

The production processes are determined by the LAWS OF PHYSICS AND CHEMISTRY. These laws are the most fundamental and UNCHANGING aspects of production. All other aspects (such as technology, layout, organization, structure, supply chain, payment systems, work methods, planning systems, etc.) are variables in relation to the scientifically-determined structure of the production process.

If the purpose of manufacturing is to produce a product effectively, then it is obvious that all other systems exist in order that the production process may be carried out as efficiently as possible. For example, a planning system is only justifiable if it facilitates the operation of the production process; likewise a maintenance system, the plant layout,

the technology, etc. All these systems are a MEANS to an END, and as such are ancillary or subordinate to the production process.

A more up to date term used by Jack Pankoff and the Center for Process Plant management (CPPM) is production centered operation, one that focuses on operational excellence OpX™. The model is based on over twenty-five years of experience in process plant manufacturing. The model consists of six (6) core support systems.

“Operational Excellence (OpX) is a term that is used to describe a corporation’s and/or plant’s approach and standards of manufacturing. Operational Excellence (OpX) provides the plant with defined support systems and processes involved in operating a plant to produce product(s). Operational Excellence (OpX) consists of support systems and processes based on best practices. The best practices must reflect the most highly regarded practices applicable to a specific industry and a plant’s current situation and needs”. They are shown in Figure 1-1.¹

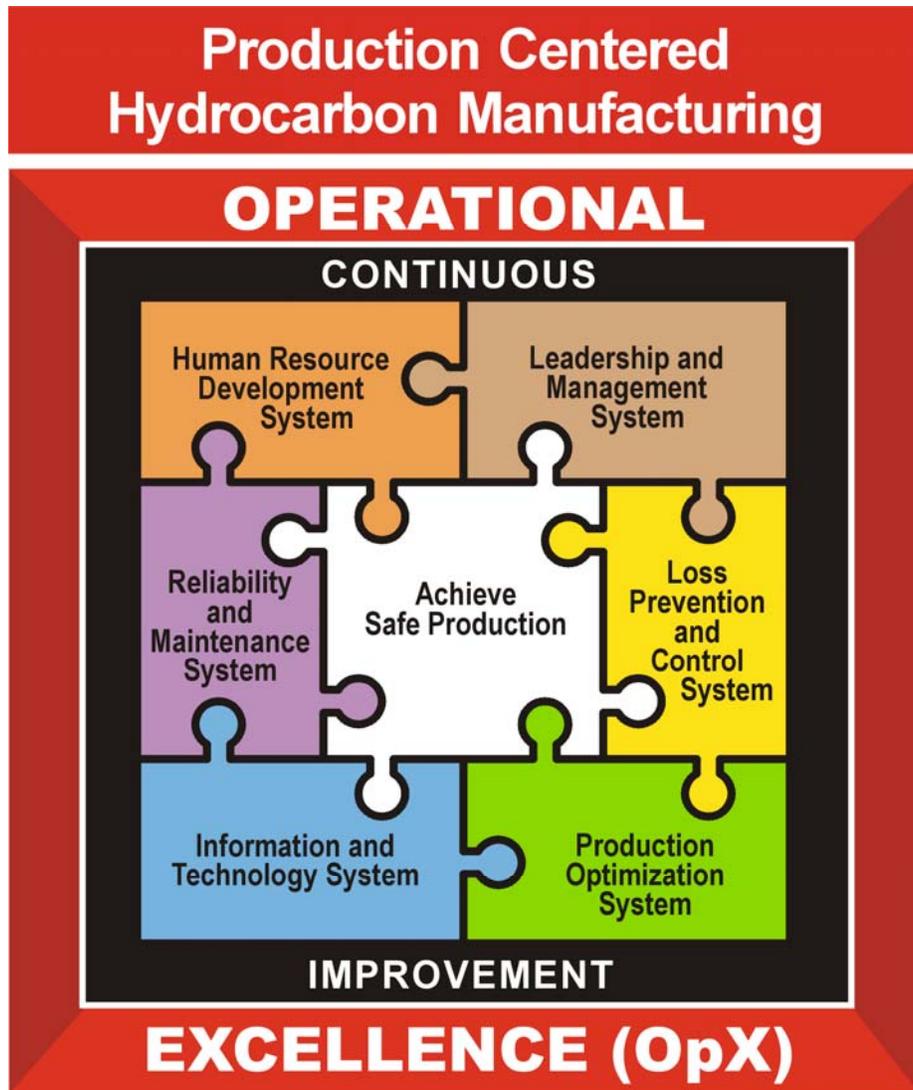
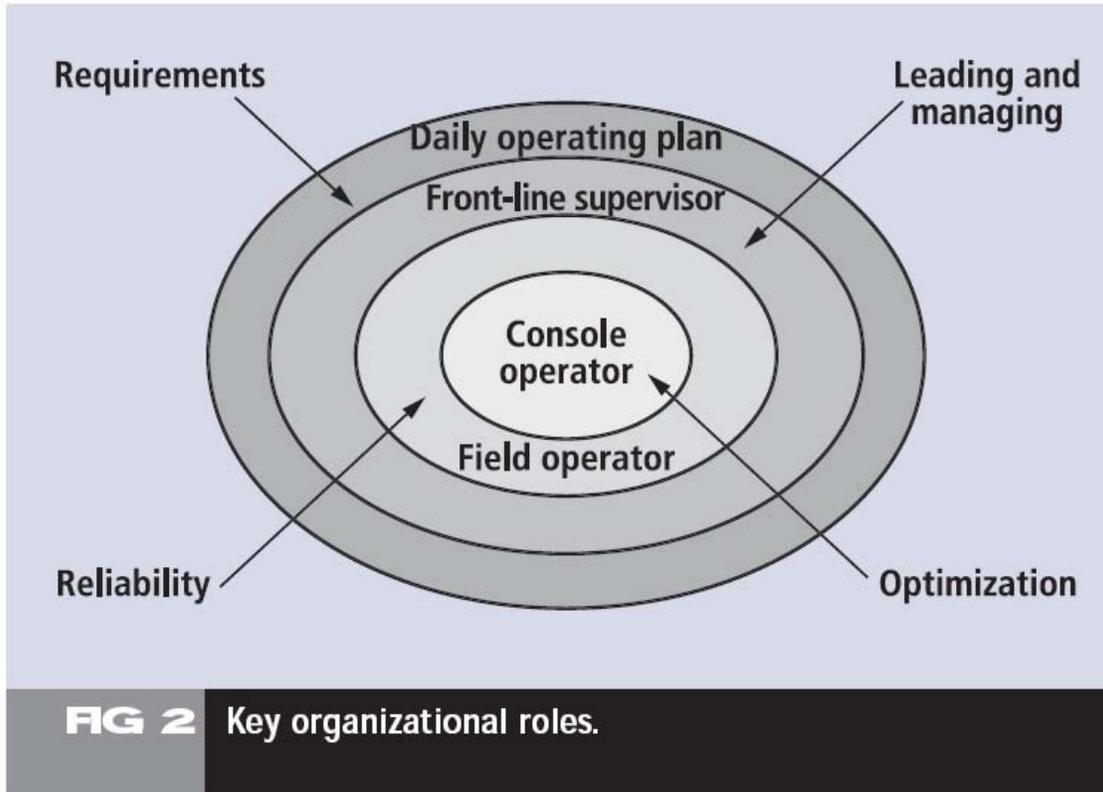


Figure 1-1. OPERATIONAL EXCELLENCE (OpX) MODEL

¹ Improving and Sustaining Operational Excellence Operational Excellence (OpX) (OpX) in Process Plant Operations – CPPM
http://www.cppm.net/brochures/Symposium_2005.pdf

In a production-centered organization, key jobs are the front-line supervisor, field operator and console operator (Fig. 2).



Front-line supervisor. This role is to manage production at the point-of-manufacturing. The front-line supervisor is responsible for managing the daily operating plan and managing operators' performance.

Field operator. This role is to own and operate the equipment to achieve the operating plan. The field operator is responsible for attending to the equipment, monitoring its conditions, coordinating predictive and preventive activities, and performing minor maintenance.

Console operator. This is the centric job. The role is to manage the process under multiple steady-state regimes to achieve the operating plan. The console operator is responsible for starting up and shutting down the process, maintaining process safety, stabilizing the process at steady-state, meeting product specifications, responding to deviations, and optimizing process costs and production performance.

Job performance profiles need to be developed for these three key positions. The profiles describe the roles, responsibilities and competencies required for the job position. The

profiles include behavioral indicators for the competencies so that the employee's behavior can be objectively evaluated.²

In an operational excellence site production is most influenced by the process control operator. The process control operator is the centric job in a Production-Centered Organization. The role of the process control operator is to manage the process under a multiplicity of steady-state schemes and conditions to achieve the operating plan. The process control operator is responsible for:

- Starting up and shutting down the process
- Maintaining process safety
- Stabilizing the process at steady-state
- Meeting product specifications
- Responding to deviations
- Optimizing process costs and production performance

Most sites do not have this model and are process technology focused; process control/automation systems and operators are treated as ancillary systems. The evolution of production processes depends on the rate of scientific discovery. This usually involves much longer time-spans than the evolution of new operating systems, new planning systems, and new control technology. It has however, recently accelerated with the advancement of computer technology but is limited to those laws of physics.

Major changes in the production process (e.g. ammonia production from natural gas instead of coke and water, chlorine production from a diaphragm instead of the use of tank or pot furnaces, iron from a blast furnace instead of a puddling furnace) usually entail massive changes in all other systems, large capital expenditures, long-time horizons, etc. No other system change makes similar demands.

If the production process is stable, why change anything?

The challenge for the production unit today is to manage change, change in the support systems, that the changes are justifiable and that they facilitate the operation of the production process.

One of these challenges today is justifying new control technology. Savings are difficult to quantify and often have not been well documented or validated.

² Look beyond traditional organizational structure Production-centered design improves, sustains total plant performance – Hydrocarbon Processing January 2003 issue, pgs. 70-72 - **J. A. PANKOFF, SR.**, Center for Process Plant Management, LLC, Denver, Colorado

The production unit very often only focuses on the process technology changes and does not understand the need to replace control systems or the need for these changes. Hence, progress is only made when the production unit is made to address specific problems such as: environmental control and recording, ISO 9000 quality improvements or competitive pressures which force fixed costs down.

Investment in control systems has often been unsuccessful because of no formal cost and benefit analysis compared to more traditional capital projects such as changing catalyst technology, or replacing mechanical equipment which have been well defined.

The area in which technology has been a great disappointment is in the area of management information. Firms have invested millions of dollars and received little return on investment. When we examine why these developments did not deliver their expected returns we find that:

- They are not necessary requirements.
- They do not facilitate the production process.
- They have failed because of lack of commitment.
- The dependant data is often incompatible from other systems.
- The technology has been developed in a haphazard way.
- The system could not keep pace with the requirements.

It should again be stressed that the control function is only a means to an end. Production units suffer from poor design of these functions and islands of technology that are difficult to coordinate.

Today's leading suppliers have a vision of the future and will offer integrated solutions that have received formal analysis against business and CIM strategies.

Market demand frequently fluctuates; established products become obsolete and need to be replaced, while new products are developed and commercialized to capture new opportunities.

Can Society influence the working environment?

The influence on industry by society has been dominant right from the birth of industry as we know it. The first example is the Industrial Revolution. The term was coined in the 1830's by French historians to describe the change from a world in which farming was the most important occupation, to one dominated by factories and machines.

The Industrial Revolution also changed the old rural, aristocratic, deferential society and the political system that went with it which has been described as "an oligarchy tempered by the mob", to an urban, more independently-minded, society and a political system accountable to a mass electorate.

The Industrial Revolution, which began in the 1700's developed in Britain first because that country was united and free from wars.

The settled state meant that people were generally prosperous, and so had money to buy manufactured goods.

The invention which started the revolution was the flying shuttle, made by John Kay in 1733. This enabled weavers to produce cloth more quickly and in greater widths. Fast spinning machines came over 30 years later.

The new machines were too big to drive by hand, so factories were built beside rivers where water-wheels could provide power.

By the early 1800's, nearly all spinning and weaving was being done in factories, after having been a HOME PROCESS for thousands of years.

The first steam engines built in the late 1600's to pump water were very inefficient. James Watt, a Scottish Engineer, devised the first satisfactory steam-engine in 1769, and in 1775, with Matthew Boulton, he formed a company to make them. It meant, too, that factories were located near coal mines, the source fuel for steam engines, though the rivers were still required as a water supply and an easy means of transportation.

The Industrial Revolution changed the face of the countryside. The new machines were housed in large factories, and towns sprang up around these to provide homes for the workers. The introduction of organized work places and machines demanded instrumentation and control starting with basic measurements of steam temperature and pressure.

What other external influences have affected industry?

The changes in industrial Instrumentation and Control over the last 50 years have been driven by many different events and external influences.

The 1940's were clouded by world war which caused the skilled labor to leave industry and women to take over many of the roles previously occupied by men. Women soon became technically competent to do this work but some of the more physical work had to be done by machines. The war demanded increased production as supplies were needed by allies.

The 1950's were complicated by women returning to the home and the baby boom. But all the men did not return from the war in the 40's. A new war broke out in Asia, hence demands increased and the labor force was still changing. Organizations were being changed by management to respond to these situations. The trade unions, which became powerful in the great depression in the 30's, were regaining power and influence and trying to establish social reforms and better terms and conditions for workers.

The 1960's produced another decade of change as the youth introduced social pressures and they launched the environmental awareness programs. Competition was severe as Japan introduced cheap products and trading conflicts throughout the world. The markets were flooded with cheap, low cost solutions.

The 1970's were influenced by a demand from the consumer to provide improved standards and replacement of the cheap environmentally unfriendly products. Industry was still fighting a competition war and was responding by flooding markets and trying to capture market share. This led to the smaller groups folding and not being able to compete with the multi-million dollar conglomerates.

The 1980's were highlighted by a fall in demand for products, world over-production and global competition. Standards and environmental concerns were still growing in popularity. Industry was going into recession. The industrial scene was dramatically changing as traditional industries were dying (coal, steel, shipbuilding, man-made fibers, housing, etc.). The population increase of the 50's and 60's had reversed and a fall in the birth rate led to school closures and changes in society.

The 1990's maintained the momentum generated in the 80's for assured quality improvement, enforced safety, and environmental improvements and accountability for standards and traceability of materials as they are transformed into finished products.

The 2000's have seen a new wave of low cost computer technology that has finally allowed industry to make changes and integrate systems in a new way, everything is moving towards the familiar web-based interface that becomes a common black-board for information from many systems. New computer technology applications are making flexible or agile manufacturing a reality.

The last fifty years have marked the beginning of the end of the Industrial Revolution the large factories have been through several changes.

The Industrial Revolution brought widespread mass production and swept away many of the craftsman skills and attitudes. The focus of attention for both managers and operators shifted away from Quality to speed and quantity. Breaking up each task into specializations meant that people could do that limited task faster.

Inevitably, this form of production took away both the opportunity and the incentive for employees to take responsibility for the Quality of their work. If they did stop the line, they would be holding up the stage of production. Although mass assembly began in manufacturing, it also spread to clerical jobs.

Manning reached a peak of employment in the 60's and is continuing to reduce by about 10% per year. The industry started with efficient power and services but because of growth energy costs went out of control and are only now being re-addressed.

Pollution control was not considered in the early days but is now raised to the same level as safety by many firms. Competition from overseas has forced manufacturers to respond to quality improvement programs.

To cope with all the errors, companies hired inspectors. While these inspectors could, in theory, stop faulty goods going out to the customers, they had little opportunity or involvement in stopping errors occurring in the first place.

Quality inspection did not hold down costs, because it encouraged people to expect errors and provided a safety net for those that were missed. Today, manufacturers can not afford to make these mistakes and secondly, customers will not tolerate these mistakes the inspection process is only partly successful. If we consider the Nylon process, only 1 in 500,000,000 of a batch is tested for errors.

These standards require that all of the production system's ancillary operations work together and in-line with the contours of the production process. No longer can the Management Information system, the planning system, the maintenance system, and the control system be islands of technology with no external communication or relationship. They must be integrated and tuned to facilitate the operation of the production process.

Impact on control technology?

Before we try to predict the requirements of industry for the next decade, it is useful to reflect on the technical changes to the instrumentation system. These changes can be mapped into the environmental changes that the production unit was experiencing.

A sample of the control and instrumentation changes and the timing of them is given below:

Pressure and Vacuum Control –

The instrumentation used today is more accurate, easier to install and maintain, but the fundamental laws of physics and chemistry again have not changed. Pressure is still defined as a force applied to unit area of a surface. Pressure control was achieved by a man watching a pressure gauge which was driven by a thin, flexible diaphragm which was pushed outwards when pressure was applied: the movement was shown by an indicating pointer. When the required pressure was reached, the operator either increased or released the pressure by manually adjusting a control valve.

The plant used simple U-tube manometers. These consisted of a glass tube bent in the shape of a U and filled with a liquid, such as mercury or water: it was connected at one end to the vessel under pressure. This device was used in low pressure measurements around the plant.

The control of pressure was well established by the 1950's but was often not fully utilized because manning was cheap and in abundance. The principles for control were

very simple. A pneumatic transmitter was used to translate the position of a pressure element into air pressure that varies in strict proportion to the element position, so that this instrument air can be piped to other components as a measured signal. By using finely calibrated bellows, linkages and diaphragms using a standard 3-15 psi pressure pneumatic control was achieved.

In the 1960's, industry was reluctant to invest in electronic control even though it had been around for almost 10 years in one form or another. This may have been partly due to the old school pneumatic controller sponsors who burned dollar bills to prove electronic controllers were unsafe. To demonstrate the inherent danger of electronics, C.B. Moore demonstrated the ease of ignition of alcohol by setting fire to dollar bills with an electric current.

The move to full pneumatic control was established during the 1960's due to the demand for more and more product from industry. Operators were becoming supervisors of instrumentation systems. The birth of a new position for tradesmen was established. The role of the instrument technician would cause a big impact on the production unit.

The boom saw a shortage of this skilled labor and the pneumatic measurement and control was not meeting industry needs. The 1970's saw a need to transmit information further. Process control was becoming more complex and fast responses were required from the instrumentation.

The suppliers responded to this need by supplying electronic equivalents to the pneumatic instruments. These initially were more expensive and suitable for large plants where long distance transmission of signals was a requirement. This was the birth of the complex control room.

The electronic instruments enabled more complex operations as digital signals became available and the computer was introduced. The technology did have a few problems when it was first introduced. Maintenance increased and an added cost for safe components was required to use the equipment in intrinsically safe areas.

The installation was a lot easier, but the skill levels required for installation and maintenance meant that the role of the technician would again change. The skills required to calibrate a loop were also reduced. This would eventually lead to a lack of understanding of the control loop.

The introduction of digital computing control by Honeywell was achieved with the TDC 2000 system. It replaced electronic stand-alone controllers and greatly contributed to increasing demands for all electronic and digital instrumentation.

The measurement and control of other process conditions such as temperature, level, and flow evolved in much the same way.

Batch Control.

The batch plant is different from continuous in that there is generally a greater need to control the processing of a finite amount of material by subjecting measured quantities of it to a time-sequential order of processing actions using one or more pieces of equipment. This control is characterized primarily by on/off actions.

The batch process was initially controlled by an electro-mechanical drum. It is a cylinder which increments one position for each step. A typical drum could have over 60 steps. As each step progresses through its operation, digital contacts open and close changing the state of valves around the plant. The drum was programmable by inserting plastic wedges or plugs into slots on the drum. A change to the program was achievable but required a thorough understanding of the process and the drum technology. Operators soon became very familiar with these devices and soon learned how to hold or bypass operations.

Unfortunately, this operation was not always done for the good of the process. A common practice was to stop the drum just before the batch was ready to discharge from the reactor (casting). This practice was often done if the operation coincided with a change of shift time. Once the Autoclave (reactor) was casting, the operator was required to be present all the time to witness that the product has no visible deformity and to confirm that the product was fully cast.

The introduction of the monolithic process control computer at the end of the 1970's immediately increased the production unit's output as the little delays between batches were removed. Product consistency was also improved as the computer produced repeatable batches.

The computer was still very much supervisory control. Regulatory control was achieved by electronic stand alone controllers. Initially, operators set the set-point of these controllers until it was identified that different shifts used different settings and batch inconsistencies were again introduced. The computer was then used as a supervisory controller sending new set-points down to the electronic controllers.

The continuous process plants in the late 1960's and early 1970's were evolving down a different path. A new electronic distributed control system was introduced in the 1970's and was handling the regulatory control. However, this again was very expensive and not viable for batch control, which had very few control loops. The lessons learned from this technology were now influencing batch control and new control blocks were being added to the monolithic computer to mimic its distributed brother. These changes were again in response to the reduction in workforce, the shortage of skilled labor, and the need to increase production and reduce fixed costs. The evolution continued as industry went into a competitive war and standards of production, batch consistency, and repeatability were primary requirements.

Case Study “Nylon Polymer”.

The Instrumentation requirement in the 1940's and 1950's was designed around the production requirements at that time and they were influenced by the other subordinate functions. Technical advancements do not just happen; they are usually coordinated from a need. A good example of a real requirement is as follows:

A production plant designed in the 1950's operated successfully producing a product to the standards dictated at that time. The technology for the instrumentation was pneumatic controllers and electro-mechanical sequence drum controllers.

The plant was producing one tenth of the world's supply of Nylon. In the early 1960's, the plant produced 40,000 tons of Nylon Polymer and then the growth in the market for cheap man-made fiber forced the production unit to increase its production by 50% in 1962 and a further 20% increase by 1963. By 1968, annual salt production had topped the 100,000 ton mark for the first time and in 1973 the 1 million ton mark was passed.

The existing equipment was coping with this increase but the people organization had increased by 3 times. As the demand for the cheap products fell, this brought some plant closures and unemployment. However, the plant output was not reduced. The products were improved and aimed for specific markets that were not so market dependent.

The instrumentation and control system had to be updated to cope with the loss of people. Automation was the only alternative for industry. The first monolithic computer systems were introduced to replace the electro-mechanical controllers and the pneumatic controllers were replaced by electronic digital controllers.

The method of changing set-points was no longer by an operator moving a mechanical arm, but by the computer monitoring the plant state and adjusting set-points according to a known recipe.

The plant produced the 3 millionth ton by 1984 and 4 million tons by 1987 with an average of 300,000 tons per year – which gives an average of 15 tons for every hour of every day for 30 years!

The 1980's brought with it high losses for the Nylon business with 144 million dollars loss. The production unit responded by reducing people, improving fixed costs by reducing the energy consumption by 30%, improving conversion efficiency, better control, and focusing on products that competition found difficult to produce.

The instrumentation and control system had to take the load for this strategy using what was available because capital expenditure was not available due to the heavy losses and the recession within industry.

More modern control systems could have made a big impact. However, in these real life situations, improvements are very difficult to justify. Hence, the process development engineers and the control engineers had to use the existing tools to solve this problem.

Within 2 years, the business was again very healthy and the new products had secured a future for the business.

The pressure continued as the 1980's brought with them new quality standards and the goal of zero defects and compliance to International Standards for Quality, Safety and Environmental Control.

The production unit required a sound Supervisory Control System that was capable of organizing batch control strategies, monitoring batch consistency and duration. With this information, plant cleaning and maintenance could be better facilitated.

There has been a move away from laboratory testing. The significance of a one sample in several million was always suspect and the delays of many hours to produce the results does not fit today's lean manufacturing profiles. Hence, on-line diagnostics and abnormal condition monitoring have been developed.

Unfortunately, this has a significant burden. A large data storage system is required. Systems for material logistics, plant production records, services, maintenance, accounting, planning, safety, and employee records need to be closely interconnected and dependencies defined.

The production unit has improved its ability to reproduce grade-1 specification product so that the need for blending batches has been significantly reduced and an individual production line blending has been developed, allowing production runs to large finished product containers for delivery to customers.

This again has shortened the production time and removed several transportation and storage stages in a campaign.

What of the future?

How does the industry justify changing its dated 1970's equipment to meet these new challenges?

What can the Instrumentation Suppliers do to help industry?

The first thing we must decide is that this type of change is not a direct old for new replacement. There must be a more cost effective reason for making this change. However, we must not lose sight that the original equipment is a plant asset and as such depreciates and has a limited physical life.

Whatever we must do must be coordinated to the needs of industry both now and in the near future. This is no longer an isolated instrumentation system, but an integrated plant business and production strategy.

When we developed and purchased our 1970's control system, many large firms developed the technology in house because of poor response from suppliers. Firms did not re-install pneumatic instruments because times had changed, organizations had moved on, production improvement was a clear goal, and reduction in fixed costs was a high profile activity. The electronic age had arrived and in most cases it justified its existence.

Vendors implement new standards for Batch Control.

Vendors have responded to the needs of the batch community by introducing a modular batch automation solution. The solution may not be a prerequisite for all batch processes but the standardization and common terminology actually address some of the major problems that the industry is experiencing.

Our customers have been combining forces to define standards and guidelines for instrumentation suppliers on how to structure batch automation systems. These standards are being issued through working groups and institutions such as ISA, NAMUR, and IEC.

Based on these requirements and vendors in-depth knowledge and experience, this modular batch methodology has been developed. The key to the success of this development is that it goes beyond customary process control objectives, addressing lifetime automation investment and requirements for flexible batch processing operations.

Modular Batch Automation (MBA) is based on these principles:

- A hierarchical, modular system structure that matches the physical and logical structure of typical batch processes.
- Standard modules exist at each level of the system structure.
- Modules are implemented by straightforward configuration rather than complex programming.
- On-line modifications are easily made.
- Standard displays and reports provide the operator with a window to the process.
- The MBA concepts are mapped in the distributed control system architecture.

The benefits of this approach are:

- Cost reductions during the design and implementation of the automation strategy.
- Easy configuration of recipes and procedures.
- Simple operation for process engineers and operators.
- User-friendly maintenance techniques to identify and correct failures.
- Safe and secure operational procedures.
- Easy control strategy modification to implement new or improved manufacturing procedures and changed formulations, with automatic documentation of the changes.

A New Approach to Safety

You will find that human factors studies place a lot of emphasis on Human Error, but it's not a question asked so as to assign blame. The goal is to find the reason why errors are made. The traditional safety approach focuses on modifying the behavior of workers. When an incident occurs, the most common thing to do is to investigate what the worker did or did not do. Were the workers following management systems; were they paying attention; did they do tasks in the correct order? The traditional approach often blames the individuals and seeks a solution such that after punishment the worker will work in a safer manner.

Human Factors takes a different view. Instead of looking only at individual behavior to explain an incident, human factors looks at what made the error possible. It tries to identify and eliminate "error likely" situations by studying the whole operation, then seeking ways to remove weaknesses.

The human factors approach is to reduce human error by changing the workplace—and sometimes worker behavior. Sometimes operator error is very likely or even inevitable, given the way the system is setup. You have to look at the whole system to find out why an error happened and find ways to eliminate future errors. This is not very comforting to a widow, so we are challenged to do everything possible to eliminate the weaknesses in our systems before an error occurs. This ideal means we have to be diligent in human factors in design, procurement, installation, operations, and maintenance. Hence, our **vision** to engage the entire production organization in improving reliability, performance, and quality whilst improving efficiency of people, equipment, and materials has just received a little more insight and direction.

New batch configuration techniques have eliminated errors, have promoted good operator interaction and tracking and have reduced some of the human errors associated with programming. However, batch needs to become more aware of the latest good situation awareness techniques and revisit the poor design of Human Computer Interface and the management of alarms and alerts.

Human Factors and Organizational Accidents

Two of my favorite authors, Professor James Reason and Trevor Kletz have both published many books on this subject and have made the subject matter as simple and easy to understand as it can be. Yet, these incidents and near misses continue and we the engineering community keep making the same mistakes over and over again. Our companies don't have mechanisms to pass the knowledge we accumulate on to the next generations, so they learn from the same mistakes that we made. This is what the engineering community calls "Loss of Corporate Knowledge". So what is the problem, how do we fix it, what benefits will it produce?"

In studies done by the ASM Consortium, API, AIChE, CCPS, CMA, etc. all have concluded that 80-% of our catastrophes have a significant contribution from human error, design issues around human factors and how they relate to our basic management systems such as training, procedures, permits, incident investigation, process hazard assessment (HazOp), contractor safety, communications, process safety information, management of change, mechanical integrity, etc.

The research also shows that companies lose significant production opportunity, impact quality, and run at poor efficiencies. The ASM Consortium measured sites with lost opportunity figures in the 3 to 12% range. The data emphasized the role that people and people systems play in contributing to these losses—from simple mistakes like opening the wrong valve to poor response times to intercede when an event is detected. Sometimes this can simply be caused by poor situation awareness because of distractions in the control room. So it goes to show that improved profitability and reduction in fixed costs can be achieved by paying attention to this subject of Human Factors.

Determining Staffing Levels

Up until recently, the method most often employed to determine staffing reductions was Management Edict. Some manager would determine that a consolidation would take place and it was imposed upon the workforce. Unfortunately, many managers, while well intentioned, don't have the skills or experience to understand the full scope of the change. Previous education has predominantly been Engineering and Accounting with little in the way of Human Factors and personnel development.

Then the Task Analysis method, or time-in-motion study, came along. With this method, someone followed around a few operators observing the amount of time they spent doing certain tasks. This method, which is still in use today, has obvious shortcomings. Most glaring is that even the most dedicated operator will change their behavior when they are being watched. Likewise, any unusual conditions that occur during the sample period, such as a shift with a large amount of maintenance activity, will cause the job to look busier than it really is. Further, this method does not even attempt to address any management system issues. It's an improvement over the management edict, but is still sorely lacking. Many companies have done one Task Analysis and few have followed the recommendations from the analysis.

There are other methods which better account for the issues we will discuss; such as a method that examines all the factors discussed below. One method that is factual, using empirical data, and has a qualitative risk assessment at the conclusion of method is outlined below.

Components of Workload

Sometime back, a rule of thumb was developed, and generally accepted, that a console operator could handle about 200 control loops, with an upper limit of around 280 loops. Interestingly, it's very difficult to find the origin of that rule of thumb. A literature search yields no studies or published articles rationalizing that figure. However, like a good urban legend, it's widely believed, and still used today to determine console loading in many facilities.

But what really impacts the console operators work load? Is it really as simple as just the number of loops? Let's take a moment, think about the situation in a little more depth, and see what comes to mind.

Loop count is a measure of span of control and it is certainly a factor in console operator workload. Loop count does give us an idea of how many things the Operator needs to keep an eye on at any one time. But, does storage tank level controller create the same workload as a reactor temperature control? Is a small wash water flow adding as much to the workload as a furnace fuel gas flow controller? I think we can all agree that the answer to both questions is "No". We would propose that it's not just the number of loops, but the type of equipment and the complexity of the process that contributes to the workload.

Anyone who has spent any time in a control room knows that a large portion of the operators work can be caused by upstream and downstream disturbances. A unit that draws feed from tankage, and sends its products to storage is typically much easier to run than a highly integrated unit that takes hot feed from other processes and feeds another unit(s) directly. These interactions can have a huge impact on job complexity and must be considered. Likewise, it requires more effort for a console operator to communicate with a large number of closely linked units than if the feed and products are isolated by tankage.

How about the physical situation of the operator? Can that impact the workload of the operator? Are all positions created equal? We know the make-up of a duty station varies from working out of a local shelter, where they may have process control and field responsibilities, to dedicated console operators based in a centralized control room. Might we reasonably expect the dedicated operator to handle more control work than an inside/outside operator?

How about the type of control hardware and the level of automation? A wide range of control hardware is still in use today, from pneumatic field controllers to distributed control systems and everything in between. To complicate the situation more, some plants have advanced dynamic control and on-line optimization, while others have poorly tuned loops with a large percentage not running in their optimum mode. It seems reasonable that the operator with the Distributed Control System (DCS) and advanced control can handle more than the operator with poorly tuned loops who is forced to make frequent manual adjustments.

Let's look further at the DCS, since this is frequently used as a vehicle to justify staffing reductions. While the DCS can be a huge improvement over the old panel boards, it can also introduce its own problems. Poorly laid-out graphics can make it difficult to find critical information and cause important information to be missed in the clutter. Poor navigation schemes can cause operators to waste time during an emergency, flipping from screen to screen to find critical information. Overly detailed displays can create a situation where the operator is looking at the plant through a keyhole. Poorly designed alarm systems that generate thousands of alarms in minutes during an upset can cause the operator to miss important alarms.

These and other issues are created by poor DCS implementation and have caused console operators to reject the DCS's capabilities, ignore the Human-Computer Interface and try running the unit using the DCS Controller faceplates that are arranged in small groups. They long for the old panel board days, when the controllers were laid in large

groups and it was easy to monitor the whole picture. Surely, we would have to consider these issues when deciding on proper staffing levels.

Combing these metrics into a model has allowed clients to compare their staffing across their own complex, other sites within the company and competitor sites. A current industrial practice has been established and an indication of where Pacesetters are or are intending to go. The model itself can be used to anticipate staffing changes as units are added or are shutdown, as units change either mechanically or from a control perspective. The model also demonstrates the impact of poor DCS implementation and the impact on operator workload. Many Managers have wondered why they have two consol operators for a relatively simple unit, or group of units. The union and the operators insist that they cannot do the job with one person, and any attempt would lead to an increase in incidents. This method can highlight the factors affecting this and allow managers to get the manning under control.

Having established a model to objectively compare operator workload and mix and match units under any given operators control; the final step is a Risk Assessment based on an analysis of the Management Systems and includes a review of scenarios based on different operating modes³. These areas are frequently overlooked when considering staffing changes, but they are critical to success. It's rather obvious that a well trained operator with well designed support systems at their disposal can handle more workload than an operator who does not have this advantage. While assessing the quality of the plants management systems can be seen as challenging, requiring internal and external resources, this must be done before a staffing change can be safely attempted. Let's look at some of the key Management Systems in a bit more detail:

- Selection, Training and Development of Operators

The quality of the operators obviously has an impact on their ability to take on greater workloads. Who hasn't experienced times when activities have been postponed because the *wrong* crew was on?

In order to assess the ability to reduce staffing the facility must take an honest look at the quality of the workforce. A few examples follow:

- How are new hire operators selected? There should be a careful screening process to select the best available, rather than throwing a few API tests at the candidates to make sure they can walk and chew gum at the same time.
- How are console operators selected? The move to a dedicated console operator post should be treated as an upgrade in duties and pay. The selection should not be based solely on seniority, but based on testing and competency models to ensure the best are selected.

³ Assessing the safety of staffing arrangements for process operations in the chemical and allied industries

- How are the operators trained initially? There should be a formal training process that concentrates on all pertinent aspects of the position, not simply six weeks of new hire training and all the rest is on-the-job training. There should also be separate formal training for the console job.
- Procedures
 - A good set of operating procedures can be an invaluable tool, but only if the procedures are correct, up-to-date, easily accessible, and the operators actually use them. Procedures should be available to cover all pertinent situations, such as normal operations, abnormal situations, and emergency situations. Further, they have to be written at the correct level of detail, and in the correct format, so that they are useful to new operators as well as experienced operators.
 - Roles and Responsibilities need to be clarified before implementing the procedure. In the past the team used to huddle and split the procedure workload. This was often done differently by each shift team based on experience and personal preferences but was well understood by that individual team. Having Console Operators in a remote location often removes them from this initial planning phase. Word of mouth casual communication and visual feedback are reduced to garbled information sharing via the radio communications.
- Management of Change
 - As a consequence of OSHA 1910, everyone has a Management of Change policy. But not all policies are created equal, nor are sufficient resources and discipline always devoted to ensure the policy is fully implemented. When done properly, the Management of Change policy is a powerful tool to communicate critical information to the operators. All Management of Change policies should cover the following areas:
 - There must be a mechanism in place to keep all operators informed of changes in the plant in a timely fashion, especially those remote from the unit.
 - The system should scrutinize changes to ensure they are well thought out and well implemented.
 - The system should be fully utilized in the field and periodically audited to ensure compliance.
 - The system must be applied to control systems and organizational changes as well as the traditional mechanical changes.
- Teamwork, Roles and Responsibilities
 - The current organization must be structured and implemented to fully support the operator during normal and abnormal situations. It must also be assured that the organization is capable of continuing to support the operators when they take on additional responsibilities. It is important that everyone knows his/her role in the organization. Good, reliable communication systems must be in place. Key support personnel must be

available when needed. All these issues must be reviewed before a proper determination as to the wisdom of staffing changes can be determined⁴.

- **Willingness to Act**

This area is vitally important to the success of the console operator. Is there an environment of support and empowerment in place so that the operator feels free to act? Does the operator have to clear every move through a Foreman to avoid getting reprimanded? Management must routinely stress safety over production, and actually walk the talk. Management must reward operators for taking initiative in an emergency. If the plant culture is one that fosters hiding mistakes due to fear of reprisal, and stresses production at all costs, the console operators will not be able to achieve the level of performance required to reach Best in Class staffing levels.

- **Alertness and Fatigue**

A modern operating facility expects the console operator to be awake, alert and ready to take decisive action at a moments notice. However, we frequently provide working conditions that actively work against that goal. Are light levels kept very low? This is frequently done to combat glare from the CRT's caused by poorly designed lighting systems or to reduce eye strain caused by a black DCS screen backgrounds. Is the ventilation poor, causing extreme changes in temperature? Are the air vents filthy and the air quality poor? Do schedules allow, or even require, operators to work excessive overtime and consecutive days so that they can't get any rest? All these issues create situations where, at best, the environment is uncomfortable, and at worst create a situation where the operators are drowsy and inattentive.

Case studies

Example 1 – An independent refiner wanted to perform a staffing analysis in conjunction with a new central control building project. The client had existing dedicated console operators working out of a number of individual, widely separated, local shelters. He planned to consolidate them in a new state-of-the-art centralized control building facility. In this particular case, the facility manager had preconceived ideas as to the correct staffing levels. He was expecting to reduce console operator positions by 50% and was expecting the study to validate this number. The workload model, which includes the equipment, interaction, and control system scores, indicated that the proposed consolidations were very aggressive, but not beyond workload levels that were being handled successfully at other facilities. However, the management system review showed significant gaps in the areas of training, console operator selection, procedures, communication systems, teamwork, and willingness to act. As a result of the study, the refiner slowed down the console operator consolidation plans and began focusing on

⁴ Effective Teamworking: reducing the psychosocial risks by Dr Sharon K Parker and Dr. Helen M Williams Institute of Psychology University of Sheffield – HSE Books. ISBN 0 7176 2149 9

making improvement in the management systems to insure that proper support system would be in place to support the new positions.

Example 2 – Another independent refiner wanted to perform a staffing analysis, also in conjunction with a new central control building project. In this case, however, the facility was still using inside-outside operators, where each operator had a smaller span of control, but had both field and control responsibilities. The refiner had identified an opportunity to create dedicated console operators positions and move these new operators into a new central room facility. In this case the staffing analysis identified the best fits for which units should be combined under the control of a single operator, as well as a reasonable target number of operators. While the refiner also had some management system issues to address, we were able to safely recommend console operator staffing reductions of 30%, with another 12% that could reasonably be achieved after some improvements in the management systems. This was significantly higher than the client was anticipating.

Example 3 – As part of the study in example 2, the client decided to pursue a consolidation proposed by the study. This consolidation was then taken through the Risk Assessment process, where the existing and proposed staffing arrangements are rigorously reviewed. During the review of the existing staffing arrangement, worst case scenarios are examined and detailed timelines are developed indicating tasks to be performed by all operators. During this analysis an interesting problem surfaced: A few years back the site had added a new polishing reactor system to the plant and assigned the new equipment to the field operator that had the geographical area of the plant. It was perceived that the complexity of the equipment was fairly minor and no formal job analysis was performed. While this was true, the catalyst load was valued at about \$1 million, and the design of the system requires significant operator attention during an emergency to prevent damage to the system. As the Risk Assessment was developed it was determined that one outside operator had over three hours of tasks that had to be performed within the first 45 minutes of an incident! It quickly became obvious that the existing arrangement was deficient and if the incident occurred today there would be a significant loss. As the risk assessment was extended to the proposed staffing case, a reasonable method of distributing the effort over the reduced number of operators was developed and the consolidation was determined to be feasible. After the meetings the refiner immediately made changes to the existing procedures to address the conflict uncovered.

Management of Change of People & Organizations (MOOC)

The Contra Costa County regulation requires each employer's safety plan to consider human factors in five areas:-

1. Process Hazard Analysis
2. Root cause incident investigation
3. Operating procedures
4. Management of Change – staffing cuts
5. Employee training

Each of these subjects is important, but for today I want to focus in on one of them—the MOC of people.

Control room staffing studies help you rationalize your plant staffing based on your current and future automation, your operating philosophy, and hiring and training practices. The study methodology is based on an assessment framework developed by Entec on behalf of the Health and Safety Executive in the United Kingdom. This framework aims to systematically cover all the relevant issues and prevent overlooking potential problems in process operation staffing arrangements.

While control modernization projects often afford us an opportunity to reduce control room staffing, such changes cannot be undertaken without some caution. For example,

- Reductions in staffing levels could impact the ability of a site to control abnormal and emergency conditions; and
- Reductions may also have a negative effect on staff performance through an impact on workload, fatigue, etc

Because of these concerns, organizations need a practical method to:

- Assess their existing staffing levels; and
- Assess the impact on safety of any reductions in operations staff.

Method

The new staffing assessment methodology concentrates on the staffing requirements for responding to hazardous incidents. Specifically, it is concerned with how staffing arrangements affect the reliability and timeliness of detecting incidents, diagnosing them, and recovering to a safe state.

The method is designed to highlight when too few staff are being used to control a process. It is not designed to calculate a minimum or optimum number of staff. If a site finds that it's staffing arrangements 'fail' the assessment, it is not necessarily the case that staff numbers must be increased. Other options may be available, such as improved user interfaces, event detection, alarm or trip systems, training, or procedures.⁵

Workspace Designed To Optimize People and Technology

A production-centered organization will strive to provide a work environment that facilitates the shift team's production efforts. Shift team members should be able to perform their tasks in safe, well-equipped areas for repairs and administrative work should be provided, and both tools and personnel should be adequately protected from the elements and from process hazards.

Current technology not only allows information to be available at any physical location in the plant, it also allows automated decision making that can hold multiple process conditions within optimum ranges. Automation can be employed to reduce variation in

⁵ The author acknowledges the work of Entec & H&SE (UK) staffing methodology.

equipment operating conditions, to maximize throughput, and to hold product specification within tight limits.

Shift team members who have direct and immediate access to accurate, pertinent information have an advantage when troubleshooting and controlling abnormal situations.

Providing operations personnel with a plant work environment that minimizes stress and supports high performance. This practice provides the plant with a physical work environment that allows operators and support personnel to meet production and operational demands.

Control Building Location Issues

The location of a control building can significantly impact the operating team's performance. The trick is to understand if there is a requirement for a strong collaborative structure and the quality and reliability of remote communications. The question comes down to who is it more important to have face-to-face communications with? Is it other field operators on the same unit or other console operators on an adjacent unit that may impact control through feed or utility relationships between units?

An example of the complexity of this question was defined in the Nova Chemicals Ethylene Project. A methodology was developed for making a decision on the location for the control building/room. It was more complex than just selecting a space on a map—the decision included discussion on whether all three of the existing Ethylene plants should be consolidated into a single control building; should other units on the site be consolidated into a centralized control building; what would be the benefits; what impact would a consolidated control room have on operations?

The project team first did a literature search to identify what existed in the industry to indicate what are the current standards, issues and benefits. The team identified a draft ISO standard, which was a good basis for a design methodology although it did not address control-building location. The only path forward was to follow sound engineering practices of good project management and identify opportunities and review possible problems.

Multi-disciplined teams met and brainstormed alternative control building solutions and attempted to evaluate strengths and weaknesses of each of the proposed alternatives. Finally each solution was boiled down to four key areas, which were Cost, Impact on People, Safety implications, and Business Opportunities or Issues.

The three solutions reviewed were:

- Remote – Centralized Control Building
- Centralized Control Building within Battery Limits
- Individual Distributed Control Buildings

Initially the team had expected to recommend a remote centralized control building, which would serve all units on the site; though virtually everyone one on the team had their own preconceived ideas on what the best solution would ultimately look like. The

great value of the process followed was that the team achieved a **shared vision** for the ultimate solution, including a clear understanding of why compromises had to be made and what it would take to strengthen the identified weaknesses with the identified solution.

Cost was an issue, just like any project, but the team did a good job of identifying the real costs for the project; for example, the costs associated with building a remote centralized control building did not end with the single building's estimate. Instead, the team also identified that any centralized building would require some form of local building structure for field operators and a safe haven for maintenance and contractors. The difference between a remote site and one within battery limits would impact building costs—the local solution would require a blast resistant structure, while a remote structure would require additional buildings.

Costs associated with demolition were also taken into account such as moving existing piping and equipment.

Impact on People focused on communications, collaboration, team activities, distractions, delays, reliance on technology, manning levels and placement of expertise.

Safety Implications looked at the compromises associated with exposure to hazards. It is argued that the closer the building is to the unit the more effective the occupants could be in operating and maintaining the plant by being closer to the hardware they manage or the people with whom they interface most frequently. It is arguable that there is less likelihood of there being an accident due to better communications between key groups of people.

The closer the people are to the unit the higher the risk they run of being exposed to the consequences of the hazards of the plant should these consequences be realized.

To balance these hazards it is important to consider the protection given to the people by the buildings they occupy. The closer to the hazards the more protection the buildings must provide, hence the more it will cost.

Business Opportunities such as optimization and speed of response to change must be weighed against poor performance due to communication breakdowns, lack of teamwork, loss of knowledge and expertise.

The team selected individual control buildings for this site based on the evaluation. This solution was more expensive, but had a stronger positive impact on people as several of the plants units were batch processes which required strong collaboration between field and console operations. The individual ethylene plants had no strong requirement to improve communications between units over and above existing solutions such as computer monitoring of other units by a single unit, use of telephones and radios. In fact a best practice was identified in the way Nova operators work together during a disturbances and how they rehearse potential scenarios after an event. The team felt that this solution provided a better business opportunity as individuals would be focused on the business, security would be improved, increased ownership of problems, less interference and confusion, and less impact on common mode failures.

Control Building Design Process

From this initial project a new way of doing control building projects has been established and used successfully. The first critical step is to create a shared vision for the control building and how it will operate. The activities in this first step include:

- Interviewing a cross section of management, engineering and operations personnel, usually over a one week period.
- A review the current operating practices and opportunities to implement Best Practices
- An analysis of building location based on cost, people implications, safety related risk assessment with consideration of API - RP752, and a business case.
- A review of the impact of the project and it's alternatives on people and organization.
- Developing an order of magnitude cost figure for each of the alternatives based on building type and square footage
- Identifying the benefits and project risks
- And finally developing a list of recommendations covering priorities and ways of achieving long and short term vision goals.

Once the shared vision is created, the work of the detailed control building design can commence. The design process begins with the operator and works outward. The major activities include:

- A task analysis needs to be completed for present and future jobs, especially when remote centralized solutions are implemented. Key issues include whether rotation is required between jobs and if field operator jobs will migrate to equipment specialist roles.
- A clear description of the current human machine interface needs to be documented—what information does the operator need, when does he need it, how and where will he get it, as well as which tasks will be done manually and which will be done by automation.
- Development of a functional specification that includes console layouts and room adjacencies and priorities.
- And finally, development of a control building detailed design specification that includes mechanical systems HVAC , security, lighting, communications including operator log books, telephones, video conferencing, large overview screens, etc. It is in the development of the detailed design that you will find the greatest benefit from an experience control room architect.

Lessons Learned on the Nova Project

The draft ISO standard (11064) did help us with the Nova project; it did not explain how to do the job but gave us some very good clues. Section 1 (of 6) explains that the most important step is to get a shared vision and involve all relevant employees. We have found from past experiences of doing this type of activity it is important to get the senior management's view of the current situation and extract a challenging vision, initially for the next 5 years for the unit and then for 20 years. Our interviews with other managers, project staff, and other employees identifies how well (or poorly) shared the management vision is and how much understanding the management have of what really happens at the sharp end, i.e., if policy matches culture.

Interviews with users of the building such as engineers, managers, supervisors identifies how they interface with the process and the primary users of the building—the operators. Their needs and requirements will be different to the primary users as they are usually on days. The primary user may not be able to articulate what the future looks like but they are a great source for revealing what works and what does not work in the existing environment and they have an insight into what will and will not work in a new solution.

Our experience has been that it is more efficient and productive to interview management individually over a 1-hour time slot and to spend a good part of a shift in the control room with operators observing and asking casual questions and getting their buy-in to a potential solution. We explain that the process we use is an iterative process and the design is refined by lots of reviews with this multi-disciplined team until each person understands why we have proposed something and why we might have rejected an idea or two.

The shared vision will also help us understand how people do their jobs currently and how they may do them in the future; who they need to be adjacent to; who they have loose communications and collaboration with; and which support functions must have a priority adjacency to the control room. The information we gather will identify if the operators need to see each others screens, if they should always have eye contact, how much verbal communication is required, what shared facilities are and were are common mode failures. How and when do we segregate people to avoid disturbances such as permit issue and closure at the beginning and end of the day? How traffic is controlled in the building, how the design will allow view but will isolate disturbances and noise.

Once we have this information we can develop a console layout based on communications and collaboration, a control room layout based on the operators' need for information, and finally an entire control building layout based on priority adjacencies (for example, which is most important, the bathroom, the kitchen, the conference room, the supervisor's office, the engineering workstation, etc.).

The Nova project was a great example of how we managed to maintain one-on-one communication and collaboration between field operators and console operators, and at the same time directing work permitting traffic flow to one segment of the building away

from the console operator. This was done by creating a separate field operator work area. Other requirements were to provide supervisors and managers a place where they could observe without crowding the operator, and giving the application development engineers where they could work in isolation but be close to observe and communicate with operators during the testing and commissioning of new software applications.

The other turn that the project took was that Nova had a vision for providing tools for operators on 12-hour shifts maintain vigilance and deal with sleep deprivation in the transition from day shift to night shift. They had developed a loss prevention standard that would support the healthy-body-healthy-mind attitude. For example, operators often struggle to stay awake because their body is physically telling them it should be asleep and not much activity is going on because the process is running smoothly and is not disturbed. As a solution, Nova invested in an exercise room for operators to use during quiet periods and at scheduled breaks. They also have Rest Recovery Rooms (nap rooms) where an operator with a sleep problem can obtain permission to take a 40-minute nap as long as the plant monitoring is covered, and the nap is genuine and approved by the team of operators. The operator does not get into the full sleep cycle, but in a reclined chair can get into the first couple of stages of non-REM sleep and be fit for over eleven hours of productive shift work rather than being slow to respond, sluggish and brain dead for the whole shift. Nova has also invested in dynamic circadian lighting systems to also help operators adjust to night work.

This control building was also unique because it has a maintenance block and a small administrative office facility associated with it, due to the extreme winter conditions in that part of Canada. This impacted traffic flow, parking, noise, and available adjacencies.

In all the methodology produced an outstanding building. But, the building is not the only good thing to happen on this project. The design process identified other opportunities for business advantage. The building is designed to ensure the operators and other personnel have good situation awareness, which is also reflected in the console design and the use of custom consoles to meet the needs of the operator. The information presented at the consoles is also optimized and designed to best practices. After reviewing the best of the best companies alarm management and graphic displays, Nova Chemicals took the work of these companies and the ASM Consortium guidelines and developed a state of the art alarm management system, which was not done as a one-off. They developed a company loss prevention standard that reflected the work of AIChE Automation Guidelines, EEMUA Alarm Management Guidelines and IEC 1508 standards.

And finally, a major issue in the past in control rooms is poor design of displays so Nova addressed two major issues; navigation of information and quality of the displays based on ergonomic and human factor standards identified by the ASM Consortium and work that Nova Commissioned with the University of Toronto.

Today we are moving to a new environment one in which Situation Awareness is a key deliverable by moving away from reactive control and dependence on alarms. This has

introduced improved Human Computer Interfaces that are standardized through a comprehensive style guide. The style guide drives good navigation and clear screens to enable good awareness of change. The style guide limits the use of color and promotes pattern recognition.

Conclusion

Once again the impact of this project has changed the way control buildings will be designed, built, and maintained. Nova is an example of how the ISO 11064 parts 1 and 3 can be implemented and what the benefits are of applying best practices. The project has prompted the ASM Consortium to sponsor a project to measure the benefits of things implemented at Nova.

The basic methodology has confirmed that the shared vision is so important and if no feasibility study has been done this step needs to be done first.

The future of batch control should excite control engineers, the opportunities that computer technology is finally facilitating major changes in operations; they are supporting the important role of the console operator. It has been determined that we need to ensure we have the right number of people, with the right skills, doing the right things in the right environment.

Operational Excellence is the key to success and whilst being production centered is nothing new, the OpX model adds structure and becomes a focus for the important systems that influence safe, efficient production.

Reference Material

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- Assessing the safety of staffing arrangements for process operations – H&SE (UK) Entec (UK)
- California's Contra Costa County Human Factors Industrial Safety Ordinance 98-48
- Cal/OSHA's Process Safety management (PSM) standard
- Cal/EPA's Risk Management Plan (RMP)

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