

Benefits of State Based Control

**White Paper
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Abstract

State Based Control is a plant automation control design based on the principle that all process facilities operate in recognized, definable Process States that represent a variety of normal and abnormal conditions of the process. State Based Control, implemented with the latest developments in object-based technologies, delivers direct benefits to its adopters in a variety of Operational Excellence categories. It results in productivity increases, higher asset utilization of both people and process, automated responses and recovery for abnormal conditions and provides an environment for knowledge capture directly into the control design.

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Executive Summary

State Based Control is a plant automation control design based on the principle that all process facilities operate in recognized, definable Process States that represent a variety of normal and abnormal conditions of the process. State Based Control, implemented with the latest developments in object-based technologies, delivers direct benefits to its adopters in a variety of Operational Excellence categories. It results in productivity increases, higher asset utilization of both people and process, automated responses and recovery for abnormal conditions and provides an environment for knowledge capture directly into the control design.

Process States are characterized by definable differences in processing condition where changes in rates, product grades, or abnormal conditions dictate changes to the automation and control parameters of the process. These include but are not limited to:

- operating conditions of equipment (in/out of service, setpoints, etc.)
- enabled and disabled alarms,
- varying alarm limit values,
- loop tuning for optimum performance,
- interlocking conditions
- operator access to interact with key pieces of equipment

Overall production improvement is created by simple situational optimization. By managing the parameters across Process States, optimized process conditions can be maintained during process conditions considered both normal and abnormal. In traditional designs, changes to these parameters are limited or completely ignored, limiting process optimization to only a single, arbitrary normal condition set.

Operator effectiveness, measured by reductions in operator errors, attention to Key Performance Indicators, or performing true value-added activities, is greatly enhanced by State Based Control design. State Based Control reduces the numbers of items that require direct attention by an operator, creating the bandwidth necessary to allow for the improvements. In a traditional design, operators need to spend their attention managing the vast number of individual control items rather than focusing on improvement opportunities.

Even abnormal conditions provide opportunity with State Based Control. Direct management of many situations is possible with State Based Control, both within process units and between process units. Automating the management of abnormal conditions with a State Based Control design can provide much faster, properly coordinated response, eliminate human errors, and optimize processing conditions, even though the conditions themselves may not be optimal. When conditions allow, State Based Control can automatically return a process to normal, more profitable

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conditions. Traditional designs require that operators react to the conditions themselves. Potentially, slow reaction times, lack of familiarity with procedures, a multitude of decisions to make in relatively short time frames and many other conditions can lead to less than optimal conditions, hazardous conditions, or result in production losses. During situations that do need operator involvement, the simplified design and resulting operator interface of State Based Control create opportunity for the operators to have clear visibility of the situation, uncluttered by the number of items typical of a traditional design.

Engineering resources can realize improved utilization levels at all stages of a project from specification and design through the complete lifecycle of system maintenance, and during improvements and expansions that are typical of most facilities. State Based Control creates an environment for standardizing much of the basic control design methods and elements for all of corporate facilities, regardless of process type; continuous, batch or hybrid. Adopting this methodology provides the end user company an opportunity to achieve broader utilization of any automation resource trained in State Based Control methods, regardless of whether those resources are internal or external to the company.

More effective training is a side benefit of adopting State Based Control, and the benefits apply to all aspects of designing, operating, and maintaining the system. Engineering resources, both internal and contracted, can be rapidly trained in State Based Control techniques, providing for a broader support base over the lifecycle of the project. Operators can be trained more rapidly and more completely, making them more valuable resources at significantly reduced cost.

The structure of State Based Control also provides an easy mechanism to capture process knowledge within the control design. As process condition procedures or parameters need to change or be added to the design as the process understanding evolves and expands, the underlying sequential design provides a format that makes it easy to integrate new information.

With all of these great benefits, why haven't control systems been delivered using State Based Control methodologies before now? Until recently, the features of automation systems did not make State Based Control easy to implement. A few companies have been utilizing the methodology; however, doing so with earlier generations of control systems has lead to generally complicated and costly to maintain configurations based on large, monolithic programs that were designed with structured text or ladder logic. These solutions have been based on one-of-a-kind, custom implementations for every project, even when it would seem that common features should apply from one project to another. Two recent developments, using state-based engine features of control systems, and true object-based system design features, now make using State Based Control available to anyone willing to make the effort to adopt and utilize the methodology to realize the benefits it provides in Operational Excellence.

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It should be noted that while State Based Control can be implemented with most current generation automation systems, not all systems deliver on all of the benefits at equal levels. Of the two key features that enable broader implementation--object based technology-- is not available with most systems.

ABB System 800xA is equipped with a state engine control feature and object technology. The two together create a powerful combination. Objects can be applied from the lowest individual control element level (Control Modules) through increasing levels of complex objects (Equipment Modules and Unit Modules), creating a high degree of reuse and providing for wide-reaching corporate standards. The object features are combined with a state engine control feature that can be embedded inside the objects to manage Modes of Operation for Equipment Modules and Process States for Units. The object-embedded state engine feature accounts for much of the simplification that makes delivering a State Based Control solution more cost effective than ever before.

Finally, using a State Based Control design requires that its users have visibility of the state operations for troubleshooting and understanding. Most systems require that users have direct access to engineering configuration tools or, when access to these tools needs to be limited, custom displays are built to provide the necessary interface, creating additional complexity and more lifecycle system maintenance. ABB System 800xA provides a standard, operator level feature to provide visibility access to the state engine directly within the Operator Workplace, creating a simple solution to this need and providing for lifecycle cost savings when compared to other automation products in the market today.

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Does your automation control design provide you with one button control of your Equipment Units for start up, shutdown, or the variety of process condition transitions that your plant can experience? Does your control design provide for automatic processing degradation and recovery from faults in upstream or downstream process units? Does the design of the process control contribute to Operational Excellence by addressing key areas such as overall operator effectiveness, knowledge capture for continuous improvement, abnormal condition management, resource utilization, lifecycle cost management, and meet industry recognized standards for best practices leading to increased production and profitability?

This sounds like a lot to ask, but most or all of these conditions can be approached or completely satisfied by using a State-Based Control (SBC) design. SBC is not new, having been applied sporadically since at least the early 1980's; but it did not really have an identifiable name or recognition within industry standards and best practices until very recently.

Additionally, SBC has historically been relatively costly to implement, but with availability of the newest automation technologies and software designs, SBC can now be widely implemented against most process applications. Few companies have made the commitment on a wide scale to utilize the foundations of SBC across their enterprise, but where it is applied, the benefits are clearly identifiable.

Two noteworthy companies, The DOW Chemical Company and Boeing Company have utilized State Based Control as a general standard for many years with success. State Based Control was highlighted as a key technology that would be at the core of Automation Systems in a 2002 ARC *Collaborative Process Automation System of the Future* (D. Woll, D. Caro, D. Hill) report. Although that vision has not yet become widespread reality, ARC has confirmed that they still stand by their recommendation.

Introduction

State-Based Control is a control design philosophy that embraces a concept where all manufacturing processes operate in a series of definable "states." Generally, SBC is recognized in discrete manufacturing or in batch processing with staged unit operations such as Filling, Heating, Reacting, etc. However, SBC can be applied more generally to all processes, including those normally considered continuous. For many processes, the states may be more generalized as Out-of-Service, Starting, Running, Reduced-Capacity, Shutting Down, etc., but regardless of the labels applied to the states, SBC is a means of providing a far improved solution over traditional, monolithic automation designs.

The states, referenced hereafter as Process States, are recognized as having different operating characteristics from one Process State to another:

- Enabled & Disabled alarms. Alarm management becomes part of the design. An alarm is only active when required for the state of the process, which will significantly reduce the nuisance. Current alarm management tools are typically mitigating the alarm flow while state based alarming addresses the root cause of alarm showers.
- Loop setpoint values, loop configurations (single or cascade), loop tuning for turndown
- Active and inactive interlocks and permissives. Like alarming, interlocking and permissives generally change requirements based on the process conditions and those changing requirements become part of the design. Most control configurations are built for a single, specific condition set and then require high level override security features or even on the fly configuration changes to deal with any other conditions.
- Providing Operator direct access or lock-out for loop operation or tunable parameters. Again, it is not uncommon to need to lock out an operator from manually interfacing to devices in certain situations, and then need to allow that same operator manual access to some or all device features under other conditions. Traditional designs normally only provide for one or the other. SBC creates opportunity to include any combination of these requirements into the design of the automation.
- Various running or out-of-service states of individual control modules, equipment modules or units. Inclusion of Units is key beyond many traditional implementations. SBC provides a simplified way to manage control modules and equipment modules than is traditionally available, but such controls have been executed in traditional systems. SBC, through much of the same mechanisms, also provides a convenient method for creating intra-unit coordination control.

In some cases, just having the above functionality would be reason enough to want to implement State Based Control. But SBC is much more than a means of configuring a control system. Direct benefits can be derived in areas of Operator Proficiency and Effectiveness, Abnormal Condition Management, Engineering Resource Utilization, and Lifecycle Cost Management resulting in increased production and profitability.

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Some Definitions

Throughout this paper, there are a number of terms used that may not be familiar to a general audience. Below are a few key terms and definitions that may make the discussion more understandable:

- **Control Module:** Generally a single or small grouping of individual control devices
 - Single Valve
 - Pump with suction and discharge control valves

Distillation Tower Control Module Example

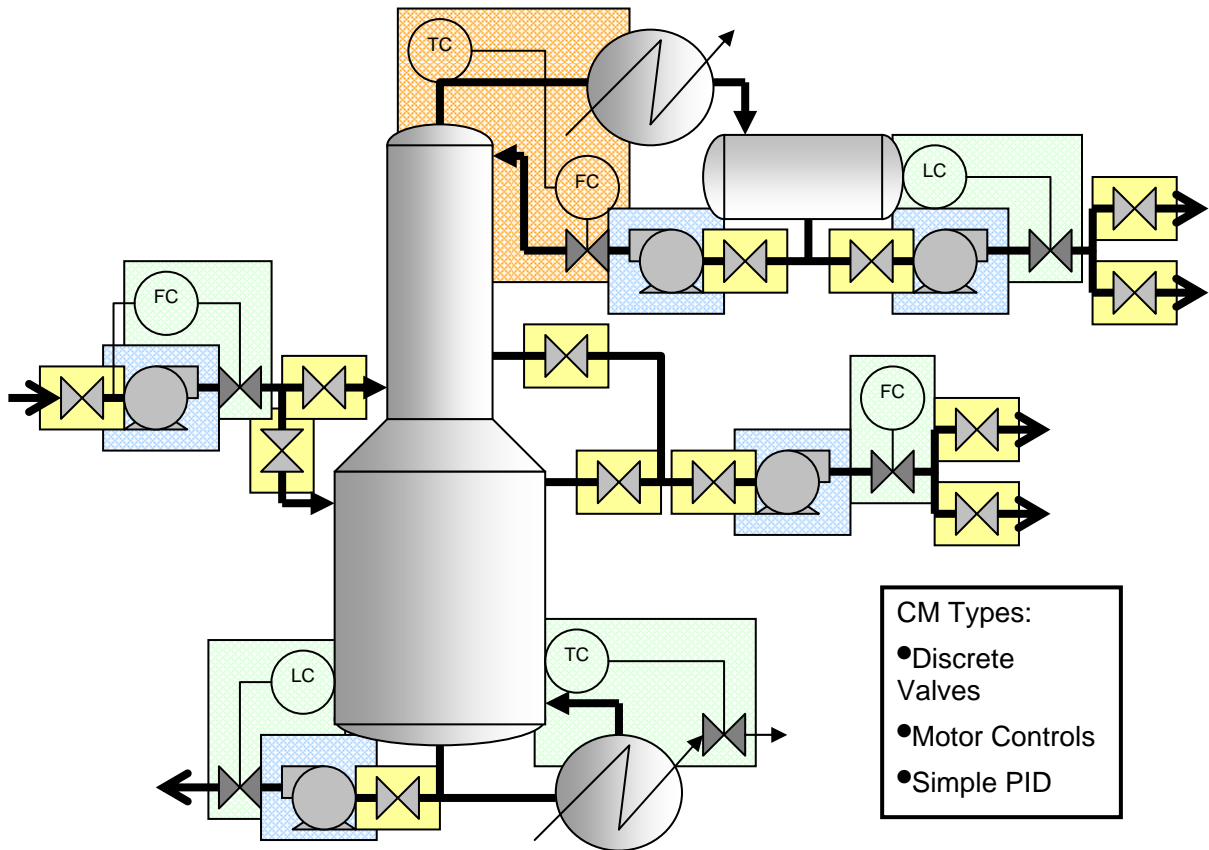


Figure 1

- **Equipment Module:** Groupings of Control Modules that perform a coordinated control function
 - Can be a single Control Module, like a motor that performs agitation.
 - Combinations of pumps, discrete valves, transmitters, and PID control modules to execute a function like “Heating” or “Pressure Control”

Distillation Tower Equipment Module Example

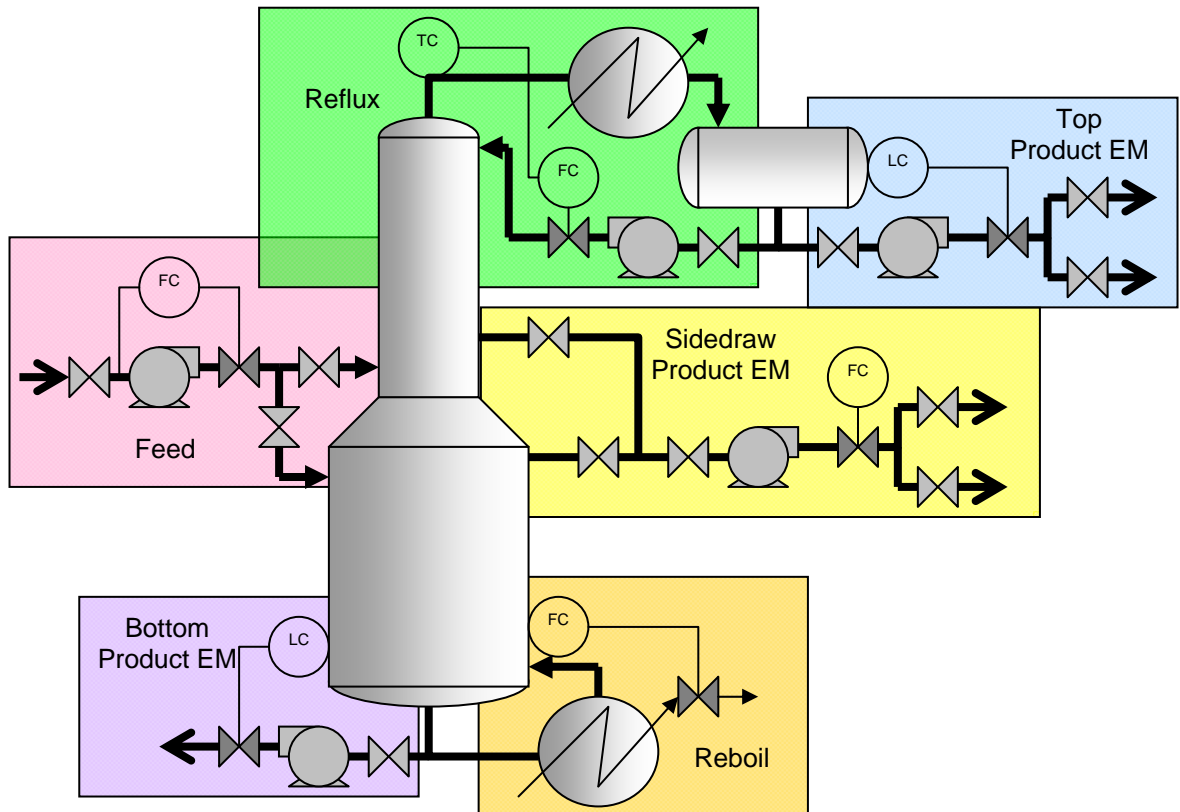


Figure 2

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- **Unit:** A functional grouping of Equipment Modules and Unit Level Control Modules
 - Reactors
 - Distillation Columns

Distillation Tower Unit Example

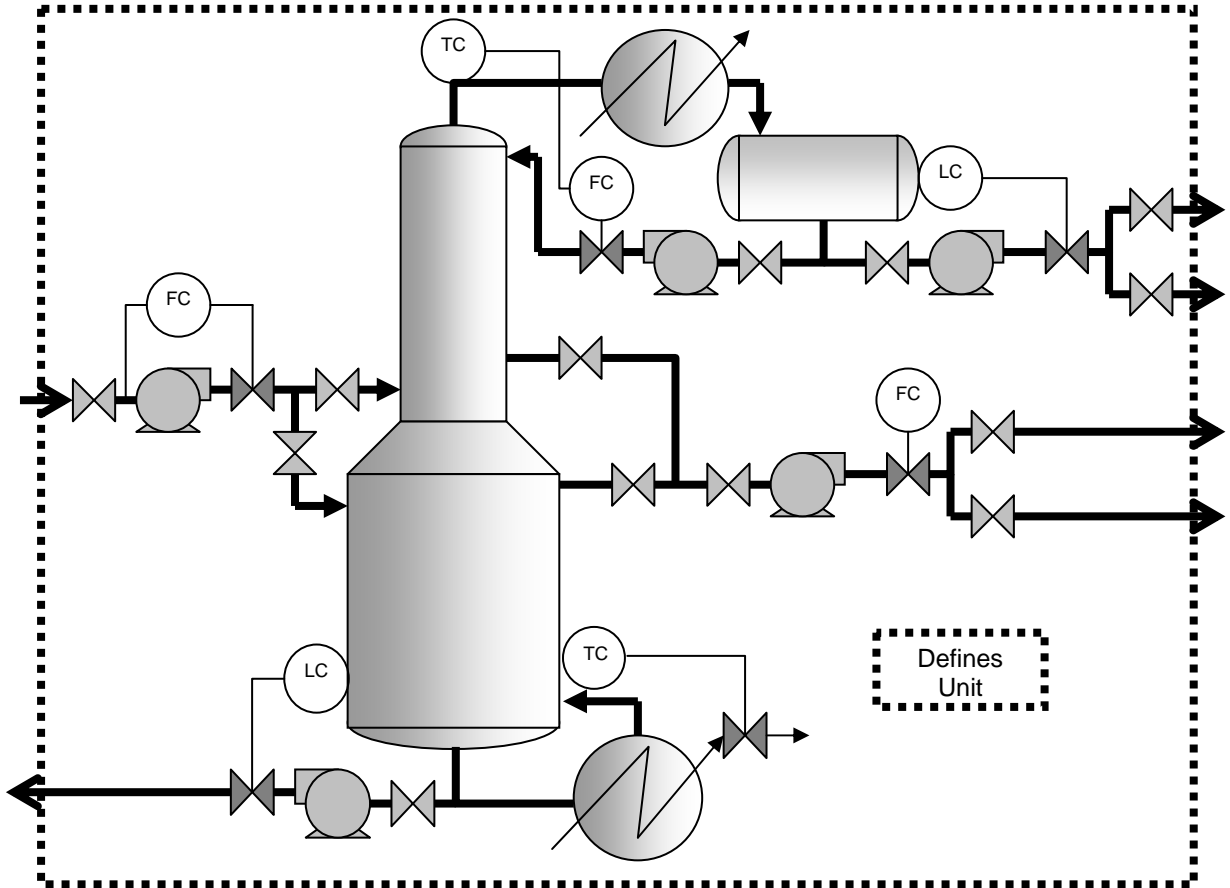


Figure 3

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Benefits for adopting SBC fall into five categories of Operational Excellence for end users include but may not be limited to:

- Operator proficiency & effectiveness
- Abnormal Situation Management
- Engineering resource utilization
- Lifecycle cost management
- Solutions based on Standards (ISA S88 Part 5) instead of individual custom designs

The sum total of these benefits results in situational optimization of the process, yielding increased production and asset utilization. Manipulating the processing conditions and parameters and capturing best practices into the design of the control allows the process to operate at more optimal conditions for longer periods, even when the process situation is not optimal. Thus, a distinguishing characteristic of State Based Control is that it allows the facility to make the best of bad situations.

Operational Proficiency & Effectiveness

Addressing Operator Overload

Automation has evolved and expanded significantly over the years. It started with hand valves and a few field mounted pneumatic loops, expanded to a few hundred single loop controls and indicators on large boards, then to several hundred loops and indicators on single or small clusters of single-monitor Operator Consoles to today's large centralized control rooms. These control rooms have groups of Workstations, each with up to four monitors. Through this progression, a single operator has been tasked with managing an environment of perhaps less than 50 items to today's control rooms where a single operator may have hundreds of loops and thousands of indicators to manage. The proficiency and effectiveness of operators has been a serious concern for Operations Management for many years, as technology has changed the visualization of the process facility and driven up the numbers of devices (loops) under the control of one operator. The large number of devices requires a considerable attention span under normal conditions, but become a greater concern under disturbance or abnormal situations.

An entire consulting industry has developed around studying and recommending workstation layouts, optimal numbers of workstations, graphical navigation techniques and many other *environmental* remedies for avoiding the potential for *Operator Overload*. Many products have come into the marketplace to create artificial intelligence tools to try to help the operator deal with the ever-increasing demands placed on them. The success of those tools has been limited, as they have generally

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required large capital outlays, created an additional layer of system complexity, and significantly increased system lifecycle cost to keep them current to ever-changing process improvements.

Consider that this Operator Overload condition can be remediated with an improved automation design technique in the form of State Based Control.

The Case for Equipment Modules:

By the nature of the SBC design, the number of items the Operator needs to directly control is significantly reduced. At the lowest levels of SBC design, the Operator interface is intended to be the Equipment Modules and not individual control devices as in traditional designs. The EM's, being composed of one or more Control Modules, are managed by a set of Equipment Module Modes of Operation.

Consider a simple Equipment Module consisting of two motor controls for two pumps (A & B) and two discrete isolation valves for each pump (A_IN, A_OUT, B_IN, B_OUT) for a total of six Control Modules. This Equipment Module might have seven defined Modes of Operation:

1. A Running – B Standby
2. A Running – B Out of Service
3. B Running – A Standby
4. B Running – A Out of Service
5. A & B Out of Service
6. A & B Standby
7. A & B Running

In a traditional design, the operator must open, operate, and close six individual faceplates to deal with the six devices. *In an SBC design, there is only one faceplate, the Equipment Module faceplate.* When dealing directly with the Equipment Module, the Operator need only select the Mode of Operation required. All control actions are managed by the Equipment Module to deliver the requested state. To perform a simple task, such as changing from condition 1 to condition 3 above, the traditional design requires the operator to perform as many as 24 actions between the six devices (open faceplates, select the new Mode of Operation values, execute the new values, close faceplates). The same change using the Equipment Module requires no more than 4 actions (open the faceplate, select the new Mode of Operation value, execute the selection, close the faceplate).

In real-world applications, the amount of reduction in items will vary greatly, but reduction factors of three to six can be considered typical. With devices under the control of a single operator now reaching numbers well in excess of 500 some cases, reducing the number of items and actions by three to six times is significant progress in addressing Operator Overload.

The Case for Unit Modules:

Further reductions in items to control can be achieved by extending the State concepts to entire operational units or Unit Modules. By grouping several Equipment Modules and Unit Level Control Modules into a Unit Module, the entire unit can be managed with the application of Process States.

Consider the Continuous Distillation tower with a single feed, top and bottom product draws, and a two point side draw product option (refer to the Unit diagram in the Terms and Definition section above). The Distillation Unit groups together six key Equipment Modules. Based on the concepts discussed previously about Equipment Modules, controlling this distillation tower using that design has already improved the Operator's effectiveness, as now only six things need to be monitored and controlled, instead of a number in excess of 20.

The benefits of Unit Module design appear when true Process State changes are required. Process States for this tower may be wide-ranging but will certainly include categories like Out-of-Service, Starting Up, Full Reflux, Normal Operation with High Sidedraw, Normal Operation with Low Sidedraw, Normal Operation with No Sidedraw, and Shutting Down. Other Process States that could be included are Standby (different than Out-of-Service), Reduced Operation (caused by downstream unit problems), and states for producing different products that are as simple as implementing key setpoint changes only.

A simple example of providing for Operator Effectiveness is changing from any "normal" Process State to Full Reflux due to operational problems somewhere else in the manufacturing train. This change requires manipulation of all of the Equipment Modules in the Unit:

- Feed needs to be stopped.
- Products need to be blocked in and pumps shutdown.
- Reboil and Reflux Equipment Modules need adjustment to maintain the Full Reflux status while minimizing energy consumption and possibly reducing or eliminating flaring.

In a traditional implementation, this would require the operator to interface to nearly every loop and valve on the unit; not just "one time" attention items, but a variety of things that need to occur in a proper sequence. This effort is time-consuming and diverts the Operator's attention away from determining and addressing the root cause of the disturbance elsewhere in the train that required these actions in the first place. This is a significant loss of focus and loss of effectiveness for this Operator resource. Perhaps more compelling is the lost production due to the time lag in dealing with the root cause of the disturbance, and additional time in getting the train back to full production after the root cause has been addressed. In many plants, a situation of this type often requires other operators to step in and assist in performing all of the

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necessary actions to focus on both the root cause issue and all of these peripheral items that result. This further reduces the effectiveness of the operating personnel.

With the Equipment Module design, things are much improved as there are fewer items to deal with, replaced with true priority items that require the Operator's attention.

With the Unit Module design of SBC, the Operator can access the Unit Faceplate, make a selection to change Process States from the current conditions to Full Reflux, and all of the necessary control actions occur in the proper sequence automatically. The Operator is free to deal with other critical items and is provided with an environment that maximizes his/her overall effectiveness. This also maximizes the effectiveness of others involved in addressing the root cause of the problem to correct it and return the facility to full operation faster. Less time spent at the abnormal condition means more time at profitable, full production. Additionally, during the problem resolution, the process was operating at optimal conditions for the situation, providing best available profitability for that situation.

Improved Visibility of the Process

There has been much published recently about graphics designed around Abnormal Condition Management (ACM) principles. One key principle is to make the graphics much easier to interpret so that when problems do occur, corrective action can be taken in a more focused way. Reducing the number of elements displayed is a major step toward accomplishing Operator Proficiency. Fewer items on graphics provide a much clearer view of the process in general. Now instead of needing graphics that are crowded with symbols of individual control devices, information can be displayed in the form of status of the Equipment Modules and Unit Modules.

Consider the two pump, four valve example used previously. In a traditional design, in order to interface with all six elements to change operational states, all of the elements have to be displayed on a graphic. This provides a means of accessing the faceplates or other graphical elements needed for the operator to be able to perform all of the required actions.

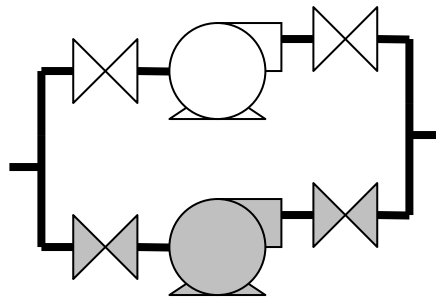


Figure 4

In an SBC design using Equipment Modules, it would be possible to have a single pump symbol showing the running, standby or out-of-service Mode of Operation of the entire Equipment Module. The symbol would also include some other simple icons that indicate which pump is operational and any faults or alarms of the Equipment Module that might occur. The Equipment Module faceplate provides access to the individual Control Module faceplates if that access is needed.

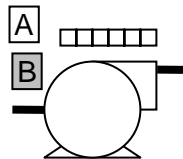


Figure 5

Similarly, the Unit Modules also contribute to improved process visibility. Simple status information displayed about the current Process State and important setpoint information can be provided within the graphics in a Unit Information area rather than displaying them individually, distributed around on individual control elements. This is the same information as used now, but provided more concisely and focused to aid in Operator Effectiveness.

Providing Benefits from Business Focus, Training, and Knowledge Capture

In many facilities with a traditional design, it is difficult for Operators to proactively improve performance of their process because they don't have the bandwidth to constantly monitor the large number of control devices and spend time on profitability. Reducing the number of control items through SBC frees the bandwidth needed for Operators to contribute to improvements and focus on Key Performance Indicators (KPI's), and attend to other profit oriented activities.

Training can be very time consuming and very costly. When training is done for handling abnormal situations or process state changes, the large numbers of individual control devices related to key situation management scenarios can lead to weeks of training time. This is frequently done on overtime hours. Operators that are well trained to perform their functions provide better profitability for their company. SBC reduces the numbers of control items and embeds many of the scenarios into the programmed actions of the Equipment Modules and Units. Training time is significantly reduced while learning retention increases; this is the result of the reduced amount of information that must now be remembered and more effectively applied. This improved training efficiency positively impacts the bottom line.

A system that is more easily learned also allows for more people to be trained. Cross training allows an enterprise to more effectively utilize their Operator assets to deal

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with sickness, vacation and other temporary time periods where the primary individual in a position is not available, again contributing to profitability.

Promotions, retirements, position changes and attrition create a need for training. These also lead to an even more serious impact; loss of operating experience. Most facilities have written procedures about how things should be done, but at most sites, the experienced operators do things “a little different” from the procedures, and frequently with better results. Even when the “best practices” of these experienced operators is captured in the written documents, each new Operator will likely execute things differently because the procedures are not always readily available when the Operator needs them.

Using SBC, and committing to a policy to have the programmed actions updated over time to represent the “best practices” known about the operation, retains the knowledge of those expert operators and provides a means for each new operator to execute their actions just like the experts following a documented Operating procedure. Rather than being faced with the loss of experience that usually leads to lower profitability, the knowledge is available to all who need it, and can be applied to Maintain the same level of operational and financial performance.

Enforcing Operational Discipline:

A related issue to capturing best practices from an experienced Operating team is often the need to enforce certain key operational practices. It can be difficult to have every Operator execute critical procedures in exactly the same way. In manufacturing facilities, deviating from a best practices procedure can cause injuries or loss of life, as well as reduced quality, loss of assets, loss of production, and/or create an undesirable environmental impact.

SBC creates a very structured mechanism to allow for critical procedures to be executed the same way, every time they are necessary, without the variability of the human factor. This can be very important in situations where a critical procedure is not frequently executed. One simple example might be lighting-off a furnace or fired heater. In many large, continuous processes that run for years at time, it is not unusual to find that following a shutdown, many, and perhaps all of the operators now working a unit have never performed such a procedure. Startups are known to be one period of a plants operating cycle when most of the costly and/or catastrophic mistakes are made. Automating the process provides for consistency and safety in executing the procedure.

Another example of a requirement for consistently providing for a well defined operating discipline can be found in processes that operate over a wide range of conditions (Process States). These processes, because of throughput or extreme variations in other operating parameters, need to have PID tuning constants, enabled

alarms, alarm limits, interlock conditions, and any other types of control configuration or tunable information changed to create a safe and profitable operating environment. In many cases today, these types of changes are entered manually from checklists or other types of documents. This creates opportunity for something to be neglected or entered improperly. Such a mistake can lead to less than optimal performance or to an unsafe condition. Attempts have been made to use tools outside of the control environment, like spreadsheets, to provide some automated way of making the changes, but maintaining the accuracy of such tools or their ability to work against changing versions of the control system can have a major lifecycle impact. In many facilities that should perform these changes, a single set of average “tuning” values are programmed for all conditions and provides less than optimal financial performance across the range of Process States.

SBC provides a significantly more reliable and profitable way of executing these changes, using the state processing engines at the heart of the individual Equipment Modules and Units. The changes are configured directly into these building blocks created from core functionality provided by the system supplier, so lifecycle support is designed in. Additionally, in the case of manual entry techniques, if the number of changes is extensive, the time to execute the changes must be considered. SBC can execute the updates instantly if needed, or staggered to address the transitional flow of materials through the process. This capability is directly tied to maintaining prime product quality and minimizing off-specification or lower quality materials during these transitional periods.

Expand the Operators Role:

All enterprises in this ever-changing global economy are looking for every possible edge to reduce costs. Some companies have a vision, or are already trying to actively move minor preventative and repair maintenance responsibilities to the shift Operators, simply because these personnel are always there. To accomplish this effectively, the automation system must provide more intelligent control so that Operators don't need to “sit and stare at a screen” and then react to provide the intelligence for many changing situations. SBC can provide this needed intelligence in certain situations. It has been done previously by creating custom solutions to analyze situations and direct the necessary changes. **SBC, as a function of control application design, can deliver this functionality with far less complexity and lower lifecycle support costs.**

The same Process States internal to Units can be utilized by other units to provide unit-to-unit coordination control. The simple benefit is that the Process State of one unit can be made to automatically react to the Process State of another unit. Unit_1 could change between full and reduced production capacity automatically as a result of Unit_2 changing its Process State due to a fault. When the fault is removed and Unit_2 returns to a Process State that would allow Unit_1 to return to full capacity,

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that healing process back to a Target Process State can occur automatically. Operators are not required to interact with the system to make these changes happen. With SBC applied at this level of functionality, a near “lights out” operating environment can be achieved. With this extension of SBC, the situational optimization provides additional production with the immediate return to target conditions once the faulted unit returns to normal. This optimized performance for the reduced capacity operation can deliver financial improvements over traditional implementations.

When SBC is carried to this level, Operators focus on proactive troubleshooting and operations analysis, performing key preventive maintenance tasks, simple basic maintenance and repair functions, or other high value activities. This is a much better use of their skills and time instead of simply monitoring the process; constantly waiting for something to happen, as they did in the past. Normally these items, necessary for good overall plant health and performance, are not performed adequately because available time on a shift is spent managing the large numbers of control devices and little or no time is left to work on the things that ultimately lead to big problems. To remediate this condition and to prevent problems from occurring, either more than the optimal number of Operating or Maintenance staff is required to meet the plant health goals, or the work is performed using overtime hours. Either one of these reduces the profitability of the facility. SBC can provide the bandwidth necessary for these types of activities to be addressed and contribute to the overall profitability of the facility.

Abnormal Condition Management

Abnormal Condition Management (ACM) is a hot topic in Process Automation circles today. There are two main focuses at present:

- Alarming (with many sub-categories)
- Graphics (discussed briefly above)

Both are important, and both have the intended result to improve Operational Excellence. The focus on graphics is to make the visual environment more appropriate for clear understanding of the process conditions. The benefits of SBC for this have been discussed above.

Alarming has many sub-categories that include but may not be limited to:

- Reducing the overall number of alarms
- Eliminating nuisance alarms
- Addressing “bad actors”
- Managing “alarm floods”

The efforts applied in these areas are all targeting one key result: get the proper information to the Operator, clearly and concisely, so an informed decision can be made about what the primary problem is and what to do next. There are always going to be situations where the Operator's decisions and actions are required to remediate an abnormal condition. In those cases, having clear and concise information is truly important, and the human problem solving and actions are going to remain key to maintaining Operational Excellence.

There are a number of abnormal situations that can be clearly defined and categorized, in advance, into identifiable Process States, and many of those states need not be emergency or serious failure conditions. By the very wording of the subject, Abnormal Condition Management, the concepts are to address everything that is "not normal." SBC provides the basis for the automation system to react to the abnormal situations with best practice methods, and deliver key benefits that help address ACM with the full features of automation.

As described in Expanding the Operator Role, SBC can be designed to detect an abnormal condition in a downstream unit and alter the state of upstream units to compensate for the changed condition. An example might be that a condition in a downstream dryer unit might require that a distillation tower unit be moved to a total reflux condition until the dryer condition is corrected. Not only does the state change in the distillation tower manipulate pumps and valves, but it probably requires different alarm conditions, interlocking conditions, loop tuning parameters and other configurable updates to maintain efficiency and provide for safe operation. The state engine design provided by SBC can do all of this safely, quickly and automatically, and then return the distillation unit to normal when the dryer condition clears. As above, the same situational optimization benefits are available from production increases and optimized condition management.

Engineering Resource Utilization

SBC provides an automation design philosophy that is applicable to nearly all automation situations; continuous, batch, discrete, or any combination of processing requirements. Recent advances in Automation System technology by some vendors increase the efficiency in engineering SBC applications and reduce lifecycle support efforts. These advances include:

- Modular design that creates opportunities for significant reuse
- Utilization of standard state engine features eliminate custom logic code creation and maintenance
- Standardized implementation and maintenance techniques across all process types (continuous, batch, discrete) eliminate the need for segregated pools of specialists to execute projects or maintain systems throughout the lifecycle.
- Techniques available to reduce specification and documentation impacts

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Modular Design Benefits

End user companies that process materials in sequential or batch processes have benefited for many years by implementing software with features like Control Modules, Equipment Modules and Units. Applying these same equipment elements with SBC to continuous control applications offers this same basic set of benefits. The degree of reuse for most companies can be widespread at the Control Module level, somewhat less at the Equipment Module level, and may be limited to certain key processes at the Unit level. But where common sets of Control Module and Equipment Module components can be applied generically to both continuous and batch processing, there will be a significant reduction in upfront engineering hours.

Modular design is best implemented with a system that provides true object-based functionality. Benefits can be derived from template-based implementations, but the lifecycle support cost using templates will be significantly higher than with object-based systems. Objects provide a true design, test, and document-once environment, not only at the original design point, but also when updates and changes are required, significantly reducing validation and testing throughout the lifecycle of inevitable changes. Object functionality, by design, supports the parent-child relationships exhibited with using Units, Equipment Modules, and Control Modules design. This eliminates the need for special design requirements to make drill-down functionality within the operational environment possible, as is often typical of template-based designs.

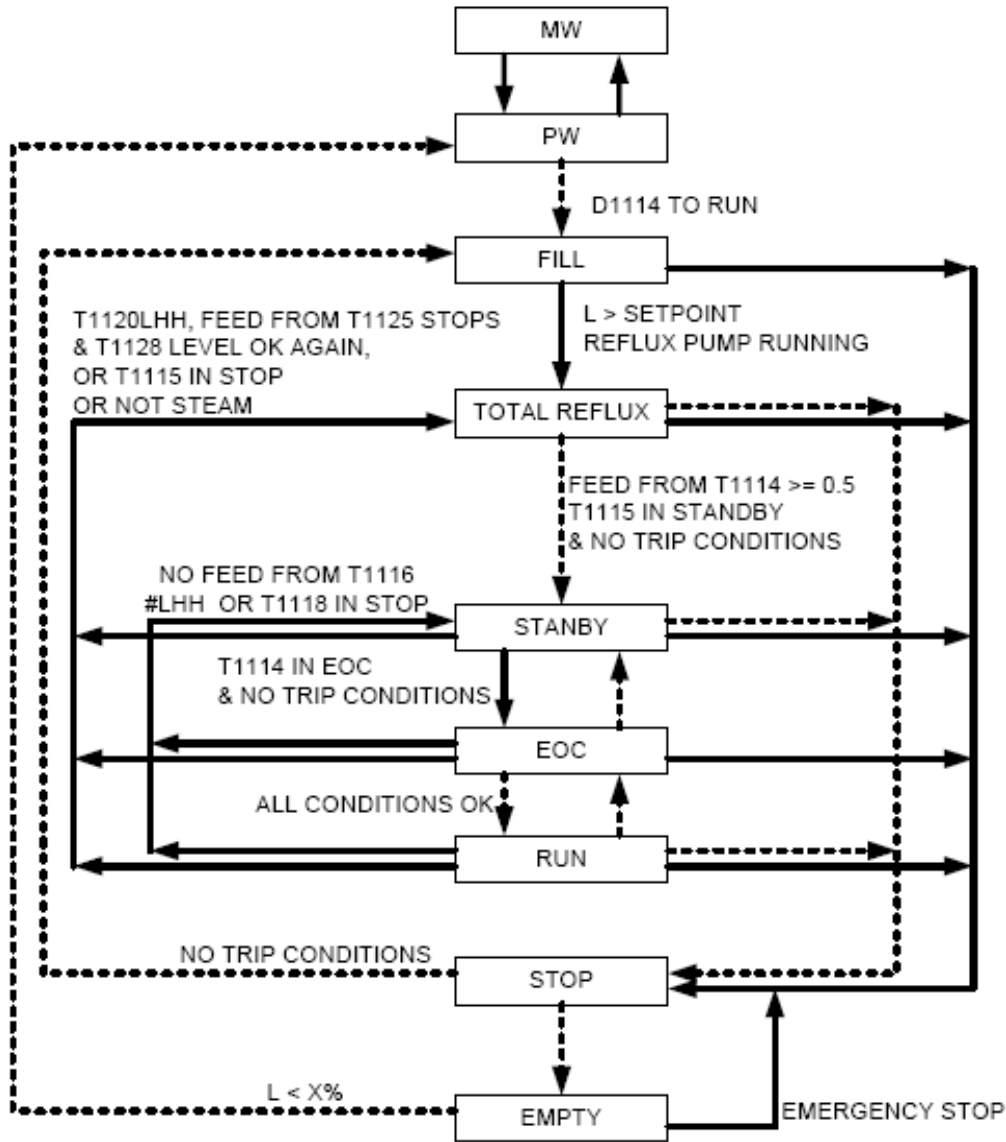
Reduce Custom Coding with Standard Features

In addition to the reuse benefit in continuous applications, the state based coordination design, using the sequencing and state management features available in most systems, is significantly more cost effective than trying to perform the same functionality with traditional coding methods.

Most implementations of the types of control identified in the earlier examples were previously done with a significant amount of if-then-else or complex ladder logic coding resulting in applications that were very costly to implement initially, and generally increased in complexity and the costs to maintain them over time. In the case where the plant has remained unchanged for many years, and a process expansion or major process retrofit is required, there may be no resources remaining that readily understand the original coding. So, not only is there a need for engineering hours to modify the old code for the new process updates, but a significant number of hours must be added to first interpret, understand, and document what already exists.

Benefits of State Based Control

Figure 6: Example State Based Sequence Control Design



SBC, designed around the use of a sequencing engine configured to manage Process States, significantly reduces or eliminates the need for custom logic coding structures. The sequence engine design for Process State management in Units and for Modes of Operation in Equipment Modules provides an easy to configure, and easy to visualize, means of programming all of the state-managed parameter manipulation that can be required by a highly complex process. This significantly reduces the time associated with standard coding processes. The use of the sequence engine also provides a form of self-documenting information that can be easily tested and verified at initial project testing steps like FAT and SAT, and provides a simplified base for understanding the code for maintenance, updating, or expansion requirements.

Benefits of State Based Control

The operator plays a key role here also. The sequence view of process control is one that is easy for an operator to understand. And it is important that the Operator can easily access the sequence and troubleshoot it directly from their workplace with appropriate visualization tools. Having operators read structured text or ladder logic for understanding and troubleshooting is difficult. Systems that require operators to use engineering tools for this purpose greatly increase the inefficiencies, and increase the chance of errors or misinterpretation.

Improve Overall Individual Resource Effectiveness

It is not unusual for the system owner companies to have their automation resources segregated by the three automation disciplines; continuous, batch and discrete. The same is often true within the project implementation groups of the automation suppliers and system integrators. This division of knowledge can prevent an end user company from effectively utilizing all of their available automation resources, not only during project execution phases, but also throughout the entire lifecycle of the system.

Having segregated internal teams and segregated contracted support teams means that scheduled usage of these resources is hard to manage; as an individual with the correct skills may not be available when support is required. With this situation, a key impact is the failure to realize income from projects that cannot be executed fast enough because of limited resource availability. Having nearly all automation resources trained and able to execute from the basis of SBC will provide an environment where nearly any automation resource can be applied to any project, allowing projects to be completed and delivering benefits quickly.

Lifecycle support can also be impacted by SBC. With traditional automation designs, truly effective troubleshooting and maintenance personnel needed to have extensive knowledge of individual configurations. This is a result of each project being typically a "one-off" when it comes to the general approach taken to the engineering methodology. Adopting SBC and utilizing the core elements, provides a framework for anyone trained in the approach to quickly be effective in supporting almost any system created around the same design basis.

Specification and Documentation Improvements

For the end user company, there are two actions related to a project lifecycle that are frequently taken for granted or often not performed to expectations or desired completeness. Functional Specification and Lifecycle documentation. To be done properly, both can consume large quantities of engineering hours. They do not get completed properly because those hours are not available and take second or lower

priority to other daily responsibilities for the resources that can most effectively perform these functions.

Whether the team that will do the automation system configuration is the system supplier, a system integrator, or an internal group of end user engineers and technicians, that group is normally supplied reference documentation:

- P&ID's and/or PFD's
- Instrument List
- Alarm lists
- Interlock tables
- A "prose" style document normally titled Functional Specification.

Functional Specification documentation is normally a descriptive dissertation about what one person thinks the process is supposed to do and how it is to be controlled. When it is time to develop the control code, a different person interprets that description in conjunction with the other items listed above and creates a control configuration. Often a Design Specification is written as a means of showing the interpretation of the Functional Specification. Additionally, a Testing Specification may also be required to provide detail on what and how testing will be done to show that the design meets the functional requirements. Writing, interpreting, and reviewing these documents is time-consuming and costly.

At a frequency much higher than any of us want to admit, problems in the translation from specification to configuration are not found until actual factory or site acceptance testing. When projects really go bad at this point, this time lost can lead to a late delivery and a corresponding overall project startup delay, as engineering hours are required to correct the problems, and project managers can spend countless hours arguing over fault and compensation.

SBC provides for standardizing on specification information. If the end user is committed to using SBC, then the documentation they provide can be structured in a way that all suppliers or integrators can understand and respond with little or no confusion. There will likely be three basic types of documents in addition to P&ID's/PFD's:

- Listing of Control Module types required for the project with description of functionality.
- Equipment Module configuration table for each module providing Mode of Operation state condition details for each Control Module contained within the module.
- Unit configuration table identifying available Unit Process States and appropriate Mode of Operation for each Equipment Module in that Process State.

Benefits of State Based Control

Table 1: Example Equipment Module Configuration

Equipment Module Template								
Unit Association:	Distillation							
Equipment Module Name:	Reflux EM							
Device Type:	MOTOR_L_SP	PID	PID	PID	CTRL_VLV	CTRL_VLV	Step Used	
Device Description:	Dist/Stub	Reflux Ctrlr	Dist Ctrlr	Level Ctrlr	Reflux CV	Distillate CV		
Device Tag:	P-1115	D1114_Reflux_PID	D1114_Dist_PID	D1114_Low_PID	T1114_Reflux_FV	D1114_Dist_FV		
MOP								
MOP=1	Off	Track = On (Value = 0) AlmHH = Inactive AlmH = Inactive AlmL = Inactive AlmLL = Inactive	Track = On (Value = 0) AlmHH = Inactive AlmH = Inactive AlmL = Inactive AlmLL = Inactive	Track = On (Value = 0) AlmHH = Inactive AlmH = Inactive AlmL = Inactive AlmLL = Inactive	Closed ILock = None Permis = Lock Op_Lock = Yes	Closed ILock = None Permis = Lock Op_Lock = Yes	M.W. P.W. FILL TOTAL REFLUX STAND-BY EOC RUN STOP EMPTY	Yes Yes
MOP=2	Recirc	Track = On (Value = 0) AlmHH = Inactive AlmH = Inactive AlmL = Inactive AlmLL = Inactive	Track = On (Value = 0) AlmHH = Inactive AlmH = Inactive AlmL = Inactive AlmLL = Inactive	Track = On (Value = 0) AlmHH = Inactive AlmH = Inactive AlmL = Inactive AlmLL = Inactive	Closed ILock = None Permis = Lock Op_Lock = Yes	Closed ILock = None Permis = Lock Op_Lock = Yes	M.W. P.W. FILL TOTAL REFLUX STAND-BY EOC RUN STOP EMPTY	Yes
MOP=3	Total Reflux	Track = Off Master [Level] - Slave AlmHH = Inactive AlmH = 80% AlmL = 20% AlmLL = Inactive	Track = On (Value = 0) AlmHH = Inactive AlmH = Inactive AlmL = Inactive AlmLL = Inactive	Track = Off Master to Reflux Ctrlr AlmHH = Inactive AlmH = 80% AlmL = 20% AlmLL = Inactive	Tracking ILock = None Permis = None Op_Lock = No	Closed ILock = None Permis = Lock Op_Lock = Yes	M.W. P.W. FILL TOTAL REFLUX STAND-BY EOC RUN STOP EMPTY	Yes Yes Yes
MOP=4	Take-Off	Track = Off Single Loop PV from FT SP via MMS from T-1115 AlmHH = Inactive AlmH = 85% AlmL = Inactive AlmLL = Inactive	Track = Off Master [Level] - Slave PV from FT AlmHH = Inactive AlmH = 80% AlmL = 20% AlmLL = Inactive	Track = Off Master to Reflux Ctrlr SP from OP PV from LT AlmHH = 30% AlmH = 75% AlmL = 10% AlmLL = 5%	Tracking ILock = None Permis = None Op_Lock = No	Tracking ILock = None Permis = None Op_Lock = No	M.W. P.W. FILL TOTAL REFLUX STAND-BY EOC RUN STOP EMPTY	Yes Yes
MOP=5	Empty	Track = On (Value = 0) AlmHH = Inactive AlmH = 80% AlmL = 20% AlmLL = Inactive	Track = On (Value = 0) AlmHH = Inactive AlmH = 80% AlmL = 20% AlmLL = Inactive	Track = On (Value = 0) AlmHH = Inactive AlmH = Inactive AlmL = 10% AlmLL = 5%	Closed ILock = None Permis = Lock Op_Lock = Yes	Open (Fixed @ 3) ILock = None Permis = None Op_Lock = No	M.W. P.W. FILL TOTAL REFLUX STAND-BY EOC RUN STOP EMPTY	Yes
NOTES								
1. On Low-Level in D1114, switch MOP from Take-Off to Total Reflux irrespective of Unit Stop active.								

Table 2: Example Unit Configuration

UNIT PROCESS STATE EQUIPMENT MODULE SETUP TEMPLATE				
UNIT	Distillation			
Equipment Module	Reflux EM	Reboiler EM	Bottom EM	Transfer EM
EM Description	E-1110	E-1111	Bottom Level	Sidedraw
Step				
M.W.	Off	Off	Off	PCC_OFF
P.W.	Off	Pressure	Off	PCC_OFF
Fill	Off Level > SP1 = RECIRC Level > SP2 = Total Reflux	Fixed SP > 0 & LI-1112 > LowLevel = Flow	Recirc LI-1112 > SP = Level	PCC_OFF
Total Reflux	Total Reflux	Flow	Recirc	PCC_OFF
Stand-by	Total Reflux	Flow	Level	PCC_OFF
EOC	Take Off	Pressure	Level	Line1 or Line2
Run	Take Off	Ratio	Level	PCC_OFF
Stop	Off	Pressure	Off	PCC_OFF
Empty	Empty	Pressure	Empty	PCC_OFF

Providing information in these or similar formats aids in reducing engineering hours and increasing effectiveness of anyone that needs to use this information. Supplying the project specification documentation in a tabular format provides significant lifecycle savings opportunities.

Lifecycle Cost Management

We have already touched on a few examples of where SBC design can ultimately have an impact on longer term lifecycle costs.

There are additional areas of lifecycle benefit that deserve mention, but have not been covered at any level of detail:

- Applying standard features to implement SBC provides for easy migration of applications as control system software versions evolve.
- The modular design of SBC can reduce the costs of evolving an automation configuration to match and evolving physical process.

Designing an SBC solution using modular components based on the core engineering configuration modules of an automation system will generally provide for a system that is easy to evolve from one generation of system software to the next. If the solution is created from a set of one-off custom coded software components, end users frequently find that not all custom coding is “system version compatible” into the future.

One final point in lifecycle consideration is engineering in the years to follow the initial project. The features of a modular SBC design make simple changes like best practices updates or more complex changes like physical process changes that add Equipment Modules easy to design, document and implement. By comparison, similar custom-coded solutions generally require significant evaluation, documentation, code checking and testing to complete, especially if the changes are made many years after the original implementation.

Benefits of Standards-Based Solutions

One last benefit of SBC is that it is an implementation of process control based on the principles outlined in ISA S88 Part 5, and as demonstrated throughout the discussion above, applies directly to continuous control applications as well as batch. Having your automation solution based on standards creates a support environment that extends beyond your company and your suppliers to a host of other end user companies. When solutions are based on the same standards, over time, all of the products from the automation supplier improve to meet and match the standards as they evolve. End user companies stand to benefit significantly, in terms of improved

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process consistency, overall safety, knowledge capture, operator effectiveness, resource utilization, and repeatability of best practices.

ABB System 800xA Removes the Technical Barriers to Implementing SBC

Although it may be true that SBC can be implemented with almost any modern process automation platform, some are going to allow for doing it cheaper, faster, and better than others. ABB System 800xA is the best in class by design ... the true object-oriented features of System 800xA allow for solutions that minimize the engineering requirements while maximizing the ease of use and the overall benefits.

- Object design directly addresses the basic building blocks of SBC. Designs based on Control Modules, Equipment Modules and Units with the parent/child object relationships is at the core of System 800xA.
 - At the Control Module level, object types can be designed and tested once and then reused many times without further need for testing. Documentation on usage can be associated at the type level and is then available for engineering, training, or troubleshooting throughout the lifecycle. Graphics elements for a Control Module type that address the appropriate views and alarming requirements are done at the object type level and are available for each instance deployed in the project, or any project that uses the same object library.
 - The Equipment Module level inherits all of the same benefits as described for the Control Modules. Additionally, the Equipment Module type provides functionality that includes a sequence engine for managing MOP's. A means is provided to run associated continuous logic that might be required outside of the state-based environment. The object nature of the Equipment Module allows for visibility of the connected Control Modules without configuration through parent-child relationships. The Equipment Module faceplate provides for Operator interaction to Equipment Module Modes of Operation without custom configuration of each Equipment Module faceplate. Graphic elements can be created once at the object type level that address the features of each Equipment Module type.
 - Units are similar to the Equipment Modules in most ways, with the same inherent engineering advantages. Like the Equipment Module object type, the Unit object type provides for Operator interaction to manage configured Process States without custom configuration requirements for each Unit faceplate. Information is available within the faceplate feature to access individual Equipment Modules or Control Modules when that information is required. As with the other types, Unit graphic elements can be made for reuse, as appropriate, and can contain the appropriate status and setpoint information so that views are consistent across individual unit types within a project, or even across projects.

- The object core of ABB System 800xA leads to reduced testing and validation. Object types are created for Control Modules, Equipment Modules, and Units and each type need only be tested and documented for performance once.
 - When modifications are required that apply to an entire type class, the changes are made, tested, and documented at the type level and then all instances of that type receive the update without need for further testing and tunable parameters within each instance are retained.
 - By contrast, systems that use templates, and not true objects, require that each copy of the template be updated or that all copies are deleted and replaced with a new version of the template. The former results in a need to test and validate each copy of the change, the latter forces code review and testing of each copy for correct configuration parameter values. In either case, a lot of testing effort is required and opportunities for mistakes exist with each copy.
- The Aspect Object features of ABB System 800xA extend the benefits into the Operational environment.
 - The ease of providing “right mouse click” access to Control Module and Equipment Module documentation with no configuration required at the individual object level is a core design feature of the system. Units designed for reuse and created as object types have the same feature, and a minimal effort is required to create the connections for one of a kind Units.
 - Similarly for details like drill down graphics, alarm lists, event lists, and many other features, the associations made and configured at the single object type level are automatically available on each instance without additional configuration. This can significantly impact both initial and lifecycle engineering costs and creates an environment for reducing management of change costs when significant updates are required across numerous objects.
- One final item of significant importance differentiating ABB System 800xA is visibility of the SBC state engine for troubleshooting Equipment Modules and Units.
 - SFC Viewer is a standard feature that allows Operators to view SFC state logic directly from an Operator Workplace to troubleshoot a sequence that is not advancing or just to gain information about the logic in general.
 - By contrast other systems require access to the system engineering tool to view sequence logic, creating the potential for system security problems from unintended changes to configuration, and may require additional engineering licenses to provide the feature at all.
 - In system implementations where access to the engineering tools is not allowed, the alternate solution is to create custom graphic views to present the logic information to the Operator. These graphics require maintenance

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for each change to the SBC environment structure adding complexity and cost to management of change processes.

Figure 7: SFC Viewer Example: Unit Process States

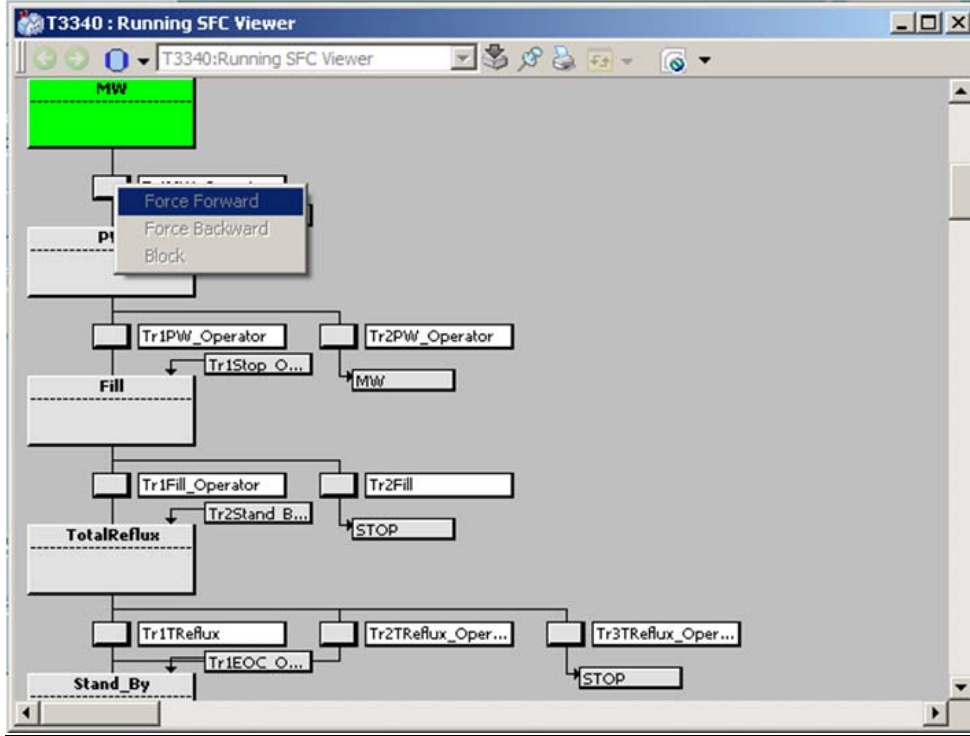
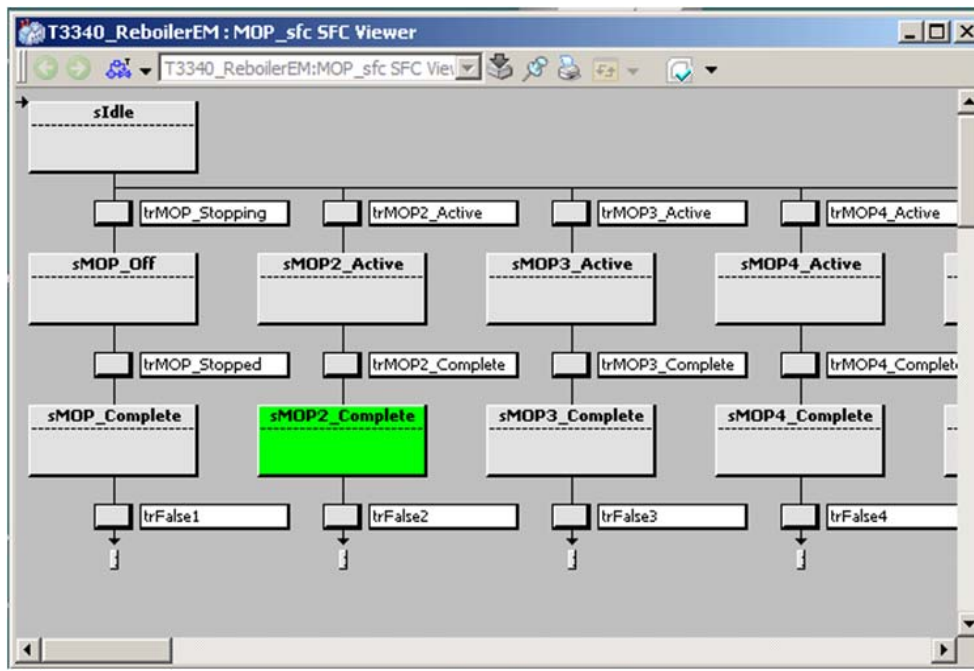


Figure 8: SFC Viewer Example: Equipment Module Modes of Operation



Summary

State Based Control is much more than a process automation configuration methodology. Inherent in its structure is situational optimization that provides for increased production and financial benefits in conjunction with a means to further Operational Excellence through:

- Operator proficiency & effectiveness
- Abnormal Situation Management
- Engineering resource utilization
- Lifecycle cost management
- Solutions based on Standards (ISA S88 Part 5) instead of individual custom designs

While it is true that project costs for executing with an SBC design may exceed those of a simple, traditional, monolithic design, the traditional project will not have a well defined path to achieve the same level of benefits.

Looking backwards, for most end users, the choice was not really available. But recent developments in some of automation platforms bring the option of SBC within reach, and so now the choice does exist. For some projects, choosing to use traditional techniques may be obvious. For most projects, however, it may be difficult to determine if the lifecycle benefits will ultimately outweigh the initial costs when making a determination at the beginning. If your business culture has or is adopting Operational Excellence as a means of business improvement, the option is now there.

Maximizing benefits always helps with overcoming the uncertainty of this decision. Selecting the automation platform will impact the degree of realizing your benefits. There is a full spectrum of system capabilities. There are those that only offer the use of full custom coding configurations that leave many of the Engineering and Lifecycle benefits on the table. At the opposite end of the spectrum is ABB System 800xA, providing a true object-oriented environment in combination with key Operator environment features to realize the maximum benefit of your decision.



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