ADVANCED AUTOMATION:

How Intuitive Design Enhances Control Systems

An engineer's guide on intuitive control system design

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PART 1:

Introduction to Automated Control Systems

Every material handling system in a manufacturing facility has a control system. If you were assigned the task to buy new production equipment with its own control system, could you do it? The design of automated control systems is a challenging task with many variables to consider. This white paper will provide some handy terminology and thoughts for any control system. We will also address what constitutes an "intuitive control system," which provides a stronger return on investment (ROI) in the long run.

Intuitive design can be defined as software that is easy to use and understand. Every control system includes software that is the heart of the system, but an intuitive control system offers improved capabilities to track process functions and effectively communicate information to operators. Intuitive control systems have higher upfront costs but offer many operational benefits that lower the total cost of ownership (TCO).

While automation implies a complete lack of human interaction (where machines do 100 percent of the work), we believe this is both unrealistic and not cost-effective. Let's face it, unexpected stuff happens, and production shutdowns are expensive. We believe operators and control systems should work together to immediately assess the situation, solve the problem, and get production up and running again as quickly as possible.

Written together by AZO and our partner Bachelor Controls Inc. (BCI), this guide will define various terms and concepts we believe should be integral to the design of manufacturing control systems. The first half of the guide provides a general overview of control system nomenclature and concepts as they relate to generic system design. With a general understanding of these basics, the second half of the guide will provide a more advanced set of design principles which describe a truly intuitive control system.

New ingredient automation systems are large investments. Control systems that are unreliable (or just difficult to operate) severely reduce the owner's ROI. They ultimately reflect poorly on the manager responsible for the system design. The purpose of this paper is to help the reader specify control systems that facilitate faster problem resolution, better equipment utilization, and lower production cost. We believe these traits define a truly intuitive control system.

The Difference Between Automation and Controls

Let's start with a basic concept: Controls and automation are two topics that are closely related (and synergistic), but both terms should not be used interchangeably. There are nuanced differences worth understanding.

Automation is anything that replaces human labor with a machine. That machine usually includes mechanical, electrical, and electronic components.

For our purposes, controls are the electrical and electronic components that link the mechanical machines together using a common software program or an integrated collection of programs. Therefore, controls should be viewed as a subset of automation. Control systems are made up of electrical hardware (motors, sensors, etc.) acting as the communication network between machines and software. In other words, the control system defines what is being automated. It is essentially the plan in which the automation is intelligently utilized.

Effective automation provides many individual benefits to a production facility that can be summarized as three general benefits.

1

The most obvious benefit is lower cost as direct labor is taken out of the process. More product can be produced by fewer workers because that manual work has been automated — machines have replaced workers.

2

High-quality automation is reliable and will minimize errors to provide greater efficiency and reduce downtime.

3

Automation provides excellent accuracy — weighments or other processes are completed more precisely resulting in better quality control and reduced waste.

Now that we've established the difference between automation and controls in this guide, the topics to follow will explain basic control system terminology. More advanced concepts that make up intuitive control system design will be explained in the second half.

Control System Cost Drivers

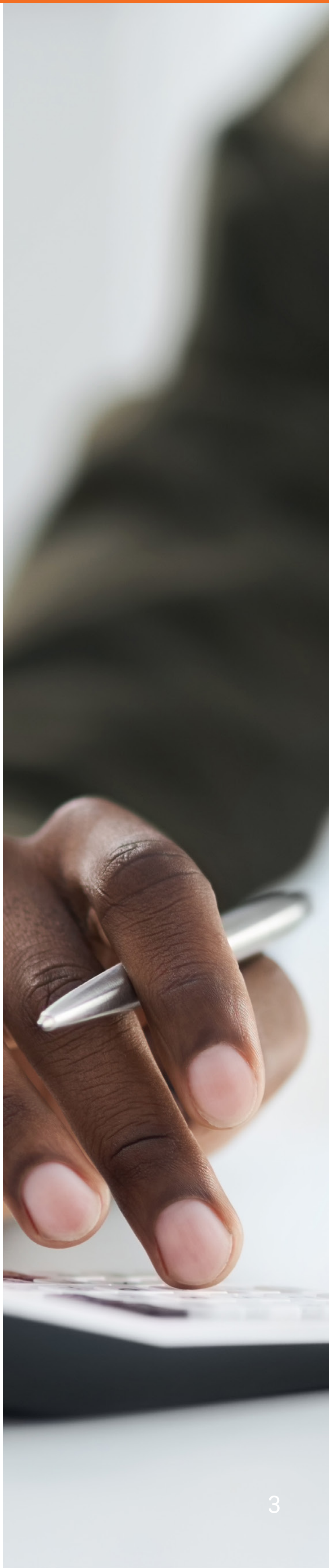
It is important to identify control system cost drivers to understand the cost/benefit aspects of different features that follow. While it is difficult to know all the factors that could impact the cost of a new control system, we will present a short list of common cost drivers that every manager should keep in mind.

The number of ingredients to be automated is, itself, the single largest control system cost driver. This is because some ingredients require an exclusive container for storage. Each container, in turn, requires devices to dispense, weigh, or clean the ingredient before moving to production. Each of these devices must be linked to the control system. As a result, the larger the number of ingredients, the higher the cost of that control system.

Another cost driver is the system's mechanical complexity. Mechanical complexity refers to the number of production lines, process steps, or other production requirements. Complex systems with many ingredients that feed multiple mixers with many recipes require complex programming to optimize production efficiency. The greater degree of complexity, the higher the control system cost.

While looking to buy new ingredient handling systems and comparing competing quotes from different vendors, the engineer should check to see if the Input/Output (I/O) counts on each vendor quotation match. The total will always be different, but if the variance is large, the two quotes should not be considered comparable. This leads us to the fourth cost driver.

The decision to use event-driven or time-driven sequencing will greatly impact the I/O count and could potentially lead to a large price variance in the two quotes.



Event-driven sequencing is, by design, a control system that cannot go to the next task without explicit verification that the prior task is complete. Event-driven sequencing typically requires more sensors because each task must be confirmed. For example, one sensor is needed to confirm that “the valve is open,” and a second sensor confirms “the valve is closed.”

Time-driven sequencing assumes tasks have been completed based on an assumed time duration — the time it generally takes for that process to be completed. Unlike the example above, one sensor is used to verify the valve is both opened and closed. When this singular valve is activated, an internal clock is also activated. After a programmed period of time has passed, the control system assumes the valve is open. This is a capital purchase savings as the second sensor is not required, is not wired, and requires no termination block in the control cabinet. This type of savings does come with a cost. We will explain in more detail in Section 3 that follows.

The addition of analog devices in a digital control system is also an additional cost driver. Analog devices are more complex in their operation. They require special transmitters to read the device output. Extra care and effort are required for calibration, which involves setting up internal set points and triggers based on an analog value. The cost of an analog device is also higher than digital versions.

A Factory Acceptance Test (FAT) is a cost driver for a new control system, but it provides the new owner with a significant value-add. Testing the program in the shop against a software model of the actual system uncovers potential problems which will save time and energy in the field during start-up. A FAT allows operators to familiarize themselves with the look of a control system and the way it operates. A formal FAT can also train operators to deal with potential problems such as abnormal exits (unexpected shutdowns) and other disruptions. Operators can then see how the notification system works and how the system helps to fix problems. All in all, with a FAT, manufacturers can rest assured that the system delivered to the job site will actually work.

There are many other possible control system cost factors, but the number of ingredients to be automated, the number of devices in a system, the types of devices, the type of sequencing, the mechanical complexity and including a FAT are likely the most significant cost drivers. Control systems are expensive, but they ensure the automation investment will operate more efficiently.

The False Economy of Time-Driven vs. Event-Driven Sequencing

Sequencing is defined as the logical order of steps that need to be completed to successfully produce a desired outcome. There are two types of sequencing: event-driven and time-driven.

Event-driven sequencing allows the system to advance to the next step only when the previous step has been successfully completed. Event-driven sequencing typically requires more sensors on a particular device to ensure the control system knows the current state of the device. For example, a valve would have two sensors — one for the open position and a second for the closed position, which adds cost. This extra cost is an upfront cost, offset with the absolute confirmation of the valve position for the entire operational life of the valve.

Time-driven sequencing relies on a set amount of time, programmed in the software, to assume the task is complete. Time-driven sequencing cannot confirm that a task has been completed. Rather, it assumes the task been completed after the allotted time. It does not require a second sensor to confirm the task is finished as compared to event-driven sequencing. Time-driven sequencing should work accurately during commissioning, but later after the system has operated for thousands of cycles, the allotted time to operate the valve may no longer be valid. If the variances between assumed and actual become large enough, the throughput of the valve may become limited (decreasing over-all system efficiency). Such a variance is difficult to troubleshoot because it is difficult to know which valve is out of specification in a large material handling system.

The authors of this paper believe that event-driven sequencing is fundamentally more reliable than time-driven sequencing. When using event-driven sequencing, operators always know the actual current state of the control system. In the event of an unexpected shutdown, time-driven sequencing cannot provide the current state of the system to the operator. With event-driven sequencing, the controls software could create a database of valve operations (such as the length of time it took for the valve to close). This could then be compared against a standard.

As aspects of Industry 4.0 are implemented, such analytical review between the actual and standard (with the assistance of machine learning) could help to optimize this process. While time-driven sequencing has a lower upfront cost than event-driven sequencing, it is a false economy. The cost of reduced production, caused by a material handling system operating at reduced capacity is substantial, especially when extrapolated over the entire useful life of the system.

Graphics — Process Visualization

Graphics that appear on the operator's computer screen are the primary communication tool between man and machine. It is important to keep them in mind when considering control system investment.

A well-designed set of graphics that depict the mechanical system should communicate a great deal of dynamic information to the operator. The old saying, "A picture is worth a thousand words" applies, but graphics quality is not always a reliable indicator of a quality control system. The physical mechanical system should be presented in the computer visualization through effective use of layout, shade, color, and other details. For example, if the equipment is stacked on multiple levels, it should be laid out that way on the computer screen. The closer the graphics represent the actual system, the easier it is to communicate to the operator what component is working and what is not. Explained another way, graphics are essentially art that communicates status. Good graphics don't necessarily mean the system will operate well, but the quality of graphics can indicate a company's attention to detail and is a type of product branding.

Ultimately, operators interact with the control system through the graphics they see on their computer screens. The efficient operation of this system requires clear and concise messaging between man and machine. This is facilitated by high quality graphics, timely communication, and faster problem solving.

Screen Alarms

There two types of screen alarms — banners and summary screens. Any message that appears on a control system screen should be meaningful and actionable by the operator.

Alarm banners are dedicated sections of the operator's screen that announce the presence of any current unacknowledged problem in the system. These messages point to general areas of concern for maintenance or failure. The alarm needs to be visible and provide a clear message to the operator.

Alarm summary screens provide more detail about alarm history. They generally allow operators to review a database of the system's alarm history that has occurred along with respective date and time stamps. The alarm summary screen allows operators to study how the system has been running to see if there have been reoccurring alarms or if there is a pertinent area of the system that needs attention.

All screen alarms make faults known to an operator, but alarm banners and alarm summary screens differ in the immediacy of the notification. Banners identify a problem when it occurs — the alarm summary shows all the alarms while providing historical information for each.

Electrical Cabinet Considerations

Proper electrical cabinet layout begins in design and seeks to avoid a mess of real-world problems in the field. The separation of voltage levels (460-volt, 120-volt, control voltage, instrumentation, analog signals) is important for both code compliance and signal integrity.

While messy bundles of wire should be avoided, the benefits of proper electrical cabinet design extend farther than simple cable and wire layout. Wires should be laid out in a logical and easy-to-follow configuration. When troubleshooting a system, it’s far easier to see where a wire comes into a cabinet, travels through it, and to which connector it terminates. Adequate space in the cabinet allows for logical wiring pathways and proper ventilation. Lastly, proper wire management practice should include the appropriate minimum wire-bending radius to ensure safety and long life.

Labeling is a critical part of proper cabinet layout and it is often overlooked. Clear labeling leads to quick identification and allows technicians to compare the actual cabinet details with the drawing bill of materials (BOM). This saves time troubleshooting and ensures accuracy. Proper wire labeling also allows the technician to verify terminations during input/output (I/O) checkout in the field against the electrical schematics in the drawing set. Lastly, labeling is very helpful after commissioning when repair or replacement is needed. The technician can properly identify each component in the panel with the as-built drawings.

Effective cabinet layout is a critical step in assuring that the actual cabinet matches the design. Troubleshooting can then be accomplished quickly and accurately. This is another example of a solid up-front practice that provides long term benefits over the life of the equipment.

When to Replace or Upgrade?

Legacy control systems pose dilemmas for managers: can a control system be upgraded or is an entirely new control system necessary? Before such a decision can be made, the manager should first investigate all the options available.

Let's start with components. Different scenarios call for upgrades or replacements for specific components. Simple **replacements** occur when a component wears out and a new, equivalent part is put in its place. For example, a failed PLC replaced with the same model number and firmware version would be considered a "replacement." **Upgrades** involve replacing equipment/software with a newer version, which might provide added functionality (such as improving cyber security).

Software is a little trickier. Generally, software is identified by release numbers which inform managers if their control system is up-to-date or not. Upgrades usually raise the release number. Upgrades that involve a small numeric jump (release 7.0 to 10.0, for example) might be possible. Upgrades involving large numeric jumps (release 3.0 to 10.0, for example) could require multiple steps (from 3.0 to 7.0, then 10.0). These may simply be impossible in the worst case scenarios. Ultimately, you will need to talk to the manufacturer or software developer to know if the upgrade can be accomplished for a particular software. If an upgrade is not possible, then a completely new control system may be required.

It's completely natural for a control system owner to have hesitations about upgrading a well-running legacy control system. The adage "If it isn't broke…" is an argument the authors commonly hear. Still, the simple truth is that reliable production (and ultimately the bottom line) depends on the efficiency and reliability of the control system.

Other common misconceptions we hear about upgrades include the fear that the new control system simply won't work after the new upgrade is installed. This opinion is especially strong if the owners have had negative experiences in the past. While this concern is understandable, it is more about the integrator that botched the upgrade than the reliability of the new control system. On the other hand, postponing upgrades have their own cost as well.

This cost has been described as a technical debt — the cost of an investment not made. One such example is a cataclysmic control system failure that cannot be repaired due to obsolete software/hardware that can't be replaced or upgraded. Such a failure will shut a production line down for an extended period. At the very least, management's reluctance to upgrade or replace can ultimately reduce production efficiency. This is because the ability to make improvements becomes more and more limited. Therefore, good operating practices should always include timely upgrades to all components and software. This is a much lower-risk proposition than replacing the entire control system.

Replacements due to failure are simple decisions. The decision to upgrade gets more complicated and expensive. It's always easier (and immediately less expensive) to assume that what has worked in the past will continue to work in the future. Still, as time goes on, this reluctance to keep equipment up-to-date will increase your technical debt. When that debt balance becomes exceedingly large, a complete production line failure becomes more probable and more expensive to repair. Since your bottom line ultimately depends on reliable and efficient production, a cataclysmic control system failure might be considered a "black swan" event (low probability but very high cost), but is the risk worth it? To truly understand how efficiency can be improved and what benefits are possible with a new control system, you should consider changing the status quo.

PART 2:

The Next Level — Intuitive Control Systems

So far we've defined and discussed topics integral to basic control system design. The balance of the paper will feature topics that truly constitute *intuitive control system design*. These topics generally ensure that operators and their control system communicate and work together to improve the reliability and utilization of a bulk material handling system. The following topics also go into more detail than the basic topics already reviewed.

Like any engineered product this extra functionality comes with a cost, but AZO & BCI believe these features set us apart from our competition. We also believe, in the long run, that they provide a better return on investment (ROI) for our customers. Intuitive control system design ultimately lowers the total cost of ownership (TCO) for automated material handling systems. We'll begin the second half of this guide explaining how an intuitive control system can improve your TCO.

A WORTHWHILE INVESTMENT:

How Intuitive Control Systems Reduce the Total Cost of Ownership (TCO)

The added hardware and functionality required to make a control system "intuitive" is often a hard "sell" when budgeting for a new material handling system. In this section, we will make the case that such an investment is worth the extra cost when compared to the long-term operational savings an intuitive control system offers to its owner. The average material handling system has a useful life of 10, 15, or even 20 years. These savings, over the system's useful life, can increase dramatically and ultimately provide a lower TCO.

Intuitive control system designs offer many features not included in an average control system. As we defined previously, intuitive software is defined as software that is easy to use and understand. In other words, intuitive control systems are much better at communicating with operators. Operators should be able to simply glance at the various screens and get immediate feedback (with graphics and messaging) of the system's status. This is especially important when something unexpected happens (a power failure, for example).

Intuitive design could include the following:

- The Human Machine Interface (HMI) accurately portrays the basic layout of the system's equipment in a manner similar to the physical process. A superior HMI should mimic the material handling system and display system dynamics to the operator. For example, motor colors should reflect a running, stopped, or faulted condition. Conveying line colors should change when lines are active. Scale displays should show the amount of material being weighed.

- In the event of an unexpected interruption, also known as an "abnormal exit," the graphics should alert the operator that there is a problem and that the system is no longer in a normal condition. Diagnostics should then display to the operator what action is needed and if human intervention is required.

- Recovery from a system failure is more than simply getting production running again; it includes figuring out what was running at the time of the failure and ensuring that no data is lost in the recovery. This type of recovery requires the system knowing where it was within a given sequence. An intuitive system can then provide the operator with a plan of action. This could include an organized "resume" function or a "step-by-step" recovery. Many times, an intuitive recovery will also assist the operator to save the batch in process, reducing waste. Keep in mind, the speed at which a system is brought back online matters because every minute that the system is down is also a minute of lost production.

- An intuitive control system should also provide maintenance support to assist the maintenance staff in knowing what components within the system require service attention. Such a system could log motor time, the amount of time since the last service, and the amount of power consumed by specific machines.

While the upfront costs of an intuitive control system will be higher than a run-of-the-mill control system, the addition of the intuitive design features described above lead to higher equipment utilization, improves data integrity, and reduces scrap. These benefits will continue throughout the long operating life of the material handling system, ultimately offering a lower TCO.

Advantages of Add-On Instructions

AOI, short for Add-On Instructions, is a reusable set of standard programming routines provided by software providers like Rockwell or Siemens. AOIs provide programmers with a repeatable way of accomplishing common tasks such as weighing, conveying, or feeding a screener. Why is this important?

Instead of rewriting code every time, programmers can use blocks of code already written and be certain that they will work properly. BCI rigorously tests each AOI to ensure the code-block is completely reliable. For example, whenever a motor needs to be included in the system code, the programmer can access an AOI that has already been designed for that specific motor. The same functionality applies for any commonly used component such as valves, scale hoppers, and other components. Every AOI also includes a library of supporting code (for the HMI display, alarm messaging, starting & stopping, etc.) with supporting code that reduces the chance of a typing error while programming.

Testing each AOI adds cost, but a reliable AOI reduces programming time. Troubleshooting AOI-supported software code is reduced as compared to freelanced programming. Best in class integrators like BCI extend the AOI concept to another level (see ‘Best Practices are the Foundation of Intuitive Control Systems’ on page 14 for more detail).

Finite State Programming — Knowing Where You Are

Finite state is a style of programming that requires each system activity to be identified, defined, and assigned a “state” identifier number. It forces the software programmer to use a structured and logical process to write control system code.

The primary benefit of finite state programming is allowing operators to know what operation is currently taking place within the material handling system. It also establishes a logical sequential order of operation for all the components in a system. With finite state programming the developer can use the state identifiers to display useful information to the operator. As a result, operators can keep track of where the process is, at any given moment, in a system programming scheme. PLC code that has been generated with a defined plan is well structured and leaves the owner with the best supportable control system after it goes into operation. Finite state also avoids random code development (a.k.a. spaghetti code).

Spaghetti code is written in an unstructured style without modular grouping, which often results in random add-ons and “Band-Aid” patches to correct errors. In development, such a programming “style” usually results in code structure that matches how the programmer thought of it. Spaghetti code is difficult to support, troubleshoot, or expand by anyone other than the programmer who wrote it. Because of its random nature, code modification during testing is difficult because it can’t be found (even by the author). It is also difficult, if not impossible, to eliminate “dead code” (code that is no longer used). One doesn’t have to stretch one’s imagination to appreciate the difficulty supporting this type of code after commissioning.

One final comment on finite state programming — its organized methodology makes it much easier to recover from abnormal exits (like power outages) because the code follows the flow of operations. Since each stop is labeled, it is possible to precisely determine what step was in process when the shutdown occurred.

Finite state methodology utilizes a more structured modular programming style that is fundamental to intuitive control system design, better organization, better tracking, and better communication.

Best Practices are the Foundation of Intuitive Control Systems

One of the most important characteristics of high-quality capital equipment is its reliability. If it doesn't work, it can't make any return on investment. It stands to reason that high-quality equipment also needs a high-quality reliable control system. Intuitive control systems deliver that reliability. In addition to AOIs and finite programming, BCI has developed a controlled library of "best practice" routines that are time-tested and proven.

These best practices include:

- All details of control engineering, HMI design, software development, panel fabrication and system testing are governed by formal procedures that have been audited by Control System Integrators Association (CSIA).
- The BCI Best Practice programming routines are maintained in a specific library and maintained by their Technical Oversight Committee.
- These "best practice" routines are applied to the unique requirements of each ingredient automation system as defined in the sequence of operations.
- The final step in intuitive program development should include a Factory Acceptance Test (FAT) to test all the code against the project's sequence of operation. This testing debugs the software and allows an accurate and intuitive interface for operators and stake holders to observe and comment. This testing ensures full functionality before leaving the warehouse.

The utilization of best practices offers many advantages when a new material handling system is brought online. Startup runs smoother because the software has already been tested and debugged. The operators have seen the HMIs and are familiar with the system messaging. If problems do arise, finite programming allows for faster problem identification and correction. Together, best practices will reduce commissioning time, facilitate the start of production, and allow production to begin.

BATCH OPERATIONS MANAGEMENT:

From Complex to Intuitive

Intuitive control systems should also include a function to help operators manage production. Batch operations management is a collection of software to accommodate the management of production batches and/or campaigns by simplifying operation, improving efficiency, and increasing over-all system reliability.

Plant personnel responsible for executing the daily production plan must produce all the various products required by marketing and ultimately the end-customers. High-quality control systems seek to optimize the sequence of production, organizing production campaigns while acknowledging process limitations (like the number of mixers available), recipe challenges (allergens), and available ingredients.

This is accomplished with batch operations software that offers a specific yet intuitive workflow for operators. This kind of software also allows operators to adjust for last-minute priorities and unexpected disruptions. With more complex process systems, batch operations software becomes more valuable as it will assist an operator's plan and implement the hourly plant floor production. By building production rules of thumb into the software, the software can assist and validate the plan as the operator sets up daily production schedules. It does this by checking to see if all the necessary ingredients are in stock and available. For example, products that are allergen-free can be scheduled together as the first products to be run after the production clean-out is complete (followed by other products that include allergens).

Batch operations management can also proactively alert the operator of potential ingredient shortages based on the requirements of a planned campaign against the amount of a specific ingredient stored in the material handling system. The system notifies the operator of specific ingredients that are in short supply. This "look-ahead" feature ensures that a production campaign cannot start without an adequate amount of ingredients available.

BCI CORE™ is one such intuitive batch operation management software, but many integrators offer similar products. All batch management software should include bidirectional communication with the operator. It should be noted that batch management software is not an ERP inventory system. It does not keep track of all the ingredients in the warehouse or on-order, but it does monitor the amount of each ingredient currently available in the automated ingredient handling system.

There is another functionality worth mentioning that could be included in a batch management program. The program could also include the ability to track production (what is queued, what is currently in production, and what has been completed). A formula editor gives the operator the tools needed to set/alter mix times and speed with simple drag and drop functionality. The program can even set/alter targets for individual ingredients. All this functionality can be displayed on the operator's computer dashboard for ease of use and convenience.

Batch operations management software helps make a control system intuitive if it is easy to use and reliable. The authors highly recommend such software for complex production facilities with multiple lines (each running a variety of products). Still, it will also improve production efficiency in any plant. This software is another upfront investment that offers incredibly large operational benefits. Arguably, such an investment will pay owners back for many years.

MESSAGING:

Alerts, Prompts, and Alarms

Messaging describes the way information is communicated from the control system to the operator. An intuitive control system should have a variety of messages (each with a different level of urgency) as the control system works its way through a batch campaign. In this section, we will cover alerts, alarms, and prompts. No matter the type of messaging, all such communication should be clear and informative.

Let's start with **alerts**. They tell the operator useful information but do not require any immediate action. Alerts are not alarms. Alerts keep the operator aware of the system's activity and status. They may also provide some limited instruction.

Prompts let an operator know that something must be done by the operator before the production process can continue. Such action might include taking a product sample or manually adding ingredients into the mixer. As can be seen in these examples, the operator must complete the task and notify the system before it moves to the next production step.

Alarms indicate to the operator that there is something wrong with the system and that attention and/or intervention is needed. Alarms generally halt the production process and wait for both an acknowledgement and some corrective action before allowing production to restart. Intuitive alarms should be able to direct maintenance personnel to the problem and provide some useful information on corrective action. Effective messaging is critical for quick problem-solving.

Messaging specifically describes how a quality system interacts with the operators. Effective messaging should include options for various levels of concern and/or action. Messaging gives the operator peace of mind when work is progressing normally. It also provides a warning when there are issues.

Abnormal Exit Management and Recovery

An abnormal exit is an event that interrupts a system program (causing the program and production to completely stop). Abnormal exits can be brought on by equipment failure or electrical failure within the plant or from the local utility. How the system responds will be dependent on the “fail safe” strategy that was incorporated in process design of the control system.

With intuitive control system design, abnormal exit response should be included in the software process design with functionality that will help deal with the problem. That extra functionality can be described as a **special recovery routine**. As we mentioned before, finite state programming facilitates a speedy recovery by automatically providing information on the system’s status when the shutdown occurred. The special recovery routine will help the operator determine how to recover best from that interrupted condition. The routine should be able to assist and guide the operator’s efforts in both finding and solving the problem. It may also assist in finishing the batches in process when the line stopped to minimize scrap.

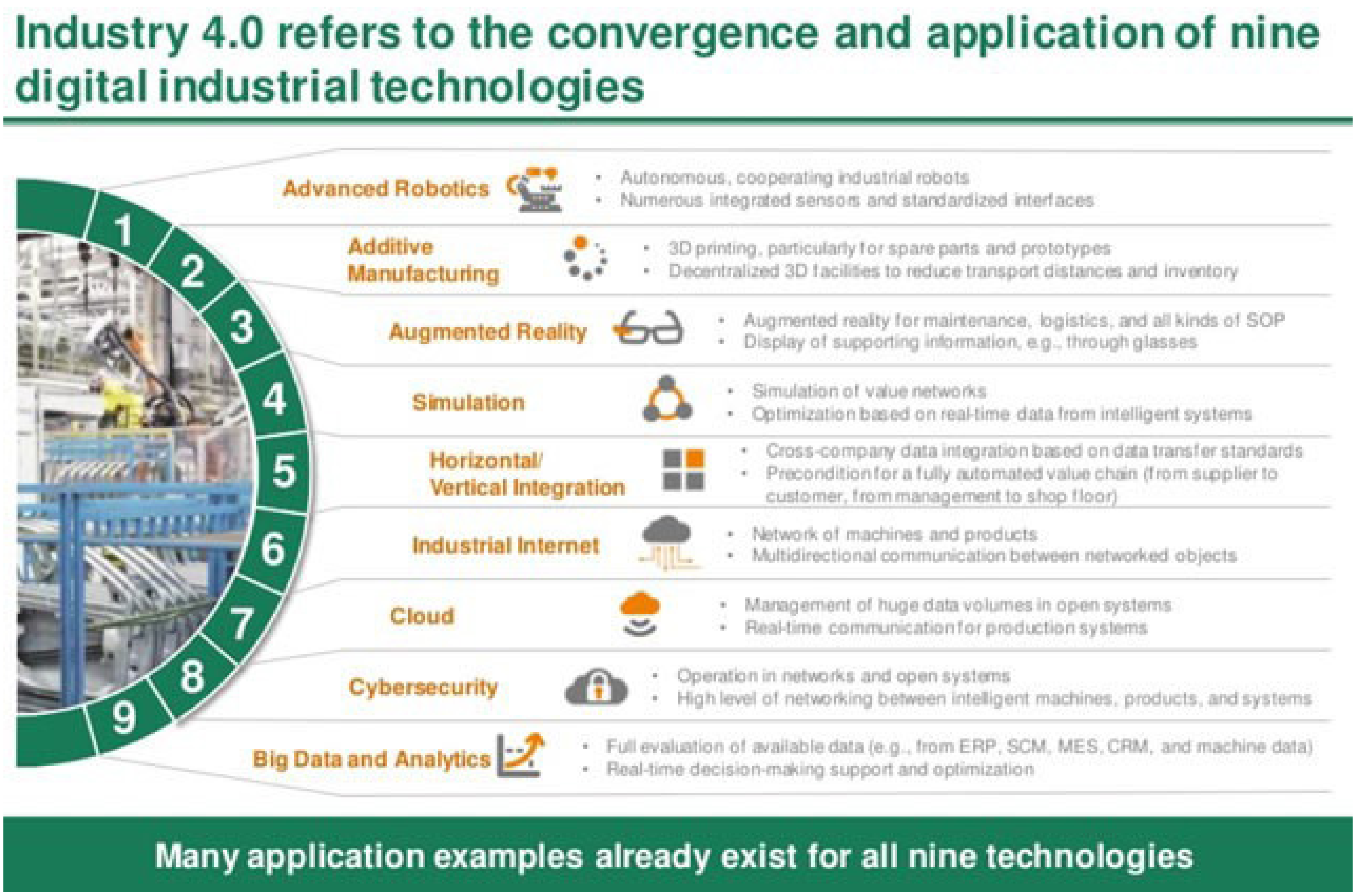
Once the failure has been corrected and production is back online, it is good practice for the operator to understand what went wrong to prevent it from happening again. This type of resolution may require some operator/administrative interaction, but the control system can provide appropriate guidance for such interaction. Such interaction should be spelled out as a deliberate sequence so the operator knows what action should be (or should not be) taken in the future.

Data integrity in the control system is another aspect of a system shutdown that is unique to manufacturing. With typical data management, programmers have absolute control of data because the data is the product. In production control, programmers must deal with equipment control, data collection, and the residual product in the system after a production process shutdown. Not only does the data need to be checked for errors, but equipment needs to be cleared of material and reset. A truly intuitive control system would include abnormal exit management routines that harmonize the physical equipment, the data, and the product.

While abnormal exits are rare events, they do happen. To be prepared for the unexpected, designers should include special recovery routines in their control system programming. Intuitive control system design plans for abnormal exits and includes special recovery routines that minimize the scrap, the time to solve the problem, and the time it takes to bring production back online with full data recovery.

Industry 4.0 Impact on Future Control Systems

Industry 4.0, also known as the "Internet of Things" (IoT) or "Industrial IoT," may mean different things to different people, but it can be defined in the graphic below from Boston Consulting Group (BCG). While it is always difficult to predict the future, Industry 4.0 will impact everything (including the future of material handling systems). Industry 4.0 technologies that are useful make a plant more profitable and reliable. These are the technologies that will drive investment. Let's investigate some specifics.



Courtesy of Boston Consulting Group (BCG) and their report "Sprinting to Value in Industry 4.0"

As you can see above, Industry 4.0 technologies cover a wide range of industrial applications. We believe that machine control systems will involve the following technologies: 6) Industrial Internet, 7) Cloud 8) Cybersecurity and 9) Big Data and Analytics. How fast they will be applied is anyone's guess, but you can be sure the most successful will be those that provide the greatest value to an operation. Industry 4.0, like any technology, must provide manufacturers a measurable ROI that will enhance their business' performance and profit.

One surefire way to improve profitability is to improve reliability. On the plant floor, reliability means improved, consistent, and safe production. One could say “Reliability 4.0” is a term that refers to new technology-enhanced investment. Reliability results in solid financial and administrative improvement. Reliability in a manufacturing plant includes production, quality, training, and MRO (Maintenance, Repairs and Operations) control system functions. It can also include inventory as well as the incoming and outgoing supply chain functions. Industry 4.0 technologies that improve reliability successfully will drive future investment.

One place to start are the “things” that Industry 4.0 technologies impact:

1. The **assets** (machine, device, sensor, etc.) that help produce products.
2. The **products** themselves (supply chain) and resources used to move them.
3. The **people** who make the products and support the assets.

These key aspects require devices to be useful and to capture their associated data. Next, we will need to do something meaningful with the collected data (i.e. analyze it). The objective is to improve lean manufacturing and business processes, looking for throughput losses or inefficiencies. That then leads to a reduction of downtime, better efficiency, or improved quality.

These goals are not new for manufacturers, yet current conditions offer significant room for improvement throughout the value chain. Unfortunately, many manufacturers aren’t aware of most of these business-altering Industry 4.0 technologies. This is not surprising since most equipment manufacturers aren’t aware of these technologies either. There is significant technology development going on now throughout the capital equipment supplier network. Currently there are only a few “killer apps” currently available, but that will likely soon change.

Technology accelerators offer improvement opportunities that have not been previously available through other methods and can start manufacturers down the Industry 4.0 road. They include:

1. Connectivity options to legacy Operational Technology (OT) using improved PLCs
2. Additional devices and sensors for OT; such as temperature, vibration, pressure, and level sensors (many utilizing lower cost wireless devices)
3. Devices and sensors for people delivered via mobile devices, such as cameras for safety, security, and augmented reality (AR) for remote support
4. Sensors for product tracking, heat, and other relevant product information
5. Seamless integration of all OT assets, IT assets, and people
6. Technology to digitize SOPs (Standard Operating Procedures) and Checklists to improve workflow efficiency
7. Improved analytics driven by machine learning
8. Intuitive dashboards with access to both real-time and historic data
9. Cybersecurity management software and hardware to secure an operation from external threat

The downside of global accessibility is an increased need for cybersecurity. All manufacturers should be aware of cybersecurity threats as they are not unique to these new technologies. Cybersecurity should become a focus moving forward, just as much as the equipment or the control systems have been in the past. While introducing new technology for either IT or OT adds risk that needs to be managed, legacy control system technology should also be viewed as a potential risk.

Quite often, older technology is vulnerable because cybersecurity was not included in the original design specifications. Improving cybersecurity represents one exceptional reason to modernize your plant floor technology. In the end, the value of cybersecurity is not how much you add to your bottom line but rather, how much you avoid losing from that bottom line. The authors believe the advantages that Industry 4.0 technologies offer are greater than the inherent risks associated with it.

Here is a real-world example of the value proposition of Industry 4.0: The addition of a heat sensor on a bearing will provide real-time data concerning its operating temperature. If the bearing begins to wear (causing a temperature increase), the sensor could alert the maintenance staff directly with specific information to correct the issue before possible or complete failure.

While this view of the future is positive, it still must make good financial sense to add the additional sensor. Each new sensor added carries a cost; the cost of the device, the control system IO required, and the software to monitor it (as well as trigger the alert to the operator). Still, these new sensors also provide potential savings. The manager will have to decide if the potential failure of the bearing has a “cost” that is greater than the investment. If it is a component of a $10M asset, the potential loss could be large. If, on the other hand, it’s part of a $1,000 asset, the loss might be quite small. Like any investment, the cost of the new sensor must offer a solid return on its initial investment. Ultimately, Industry 4.0 technologies will provide the tools — managers will have to decide where and when these technological tools need to be applied.

When it comes to automated control systems, future improvements are closer than they may seem. Industry 4.0 will introduce many advancements in technology that will alter how products are manufactured. When that will happen and how that will happen will be determined sooner rather than later.

Conclusion

In this guide we’ve presented several factors that we believe should be considered when designing both basic and intuitive control systems. We first covered general topics related to basic system design. By defining and providing examples of these topics we have illustrated that there is more to both automation and controls than “flipping a switch” and “walking away” — control systems are put in place to monitor automated systems. This is done so that man and machine can work together in such a way that their interaction may prove advantageous.

Then, we moved on to specific innovations that define intuitive control systems. To become knowledgeable about intuitive control system design, we recommend the reader to understand these key terms and concepts described in this guide:

- Add-on instructions
- Finite state programming
- Alert diagnostics
- Abnormal exits
- Event-driven sequencing
- Batch operations management

With a firm grasp of these terms and concepts established, it can be clearly stated that *intuitive* control system design will provide a better Return on Investment (ROI) as it makes for a more informed and capable operator. Intuitive design also provides a lower Total Cost of Ownership (TCO) as the benefits provided by an intuitive control system will lead to more efficient production as well as the ability to recover quicker from unexpected interruptions and abnormal exits.

Industry 4.0 capability also presents an opportunity for bulk material handling users to leverage their data/intelligence to improve their performance and lower costs. Both AZO and BCI employees actively collaborate with each other to tackle the new technologies associated with Industry 4.0. As industry 4.0 continues to evolve, more features and innovations will become available.

With this guide we've hoped to ultimately illustrate and support our belief that true value is found in the combination of both a dependable automated ingredient handling system and operator-friendly controls. From all of us at AZO and BCI, we hope that we've offered some food for thought when it comes to your automation and manufacturing technology needs.

If you'd like additional information related to bulk material handling or pneumatic conveying, feel free to contact the engineers at AZO. Altogether we have more than seven decades of experience in handling raw materials and shaping ingredient automation along the way. BCI, our control system partners, have over 25 years of experience designing, building and installing integrated control systems specifically in AZO automated material conveying systems. Both AZO and BCI publish respective blogs online that act as updated resources full of information related to pneumatic conveying, ingredient automation, and the reliably accurate equipment that both companies manufacture.

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