TITLE

Applying S88 to "Non-Stop" Production

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ABSTRACT

While the ISA 88 standard has been successfully applied to many non-batch problems, there is no consistently defined method for applying it in non-stop production. Non-stop production is defined as a continuous product flow through a facility, with no breaks in product flow even when products change. Non-stop production is also typified by small units which perform actions on part of a batch, such as filling a few bottles of a batch at a single time, or packaging a product into a box one at a time for each product in the batch. Non-stop production may be continuous, such as in the production of tobacco, or discrete, such as in the creation and filling of bottles or vials. An extension to the S88 model has been defined, call NS88 (non-stop 88), which allows standard batch execution engines to be applied to these problems, result in simple recipes, and which bring the power of recipes to continuous and discrete non-stop production. This paper defines NS88, demonstrates how it provides a reliable PLC/DCS control structure for these problems, and discusses how it has brought measurable benefits to real non-stop control problems.

INTRODUCTION

While the ISA 88 standard has been successfully applied to many non-batch problems, there is no consistently defined method for applying it in non-stop production. Non-stop production is defined as a continuous product flow through a facility, with no breaks in product flow even when products change. Non-stop production can be either continuous or discrete manufacturing and is typified by small units which perform actions on part of a batch. Examples include filling a few bottles of a batch at a single time, applying a coating a product as it moves through a specialized coating machine, or packaging a product into a box one at a time for each product in the batch. Non-stop production may be continuous, such as in the production of tobacco, or discrete, such as in the creation and filling of bottles or vials.

NON STOP PRODUCTION

Non stop production is either continuous or discrete manufacturing where there are no breaks allowed in the product flow. Non stop production may be required because the physical process doesn't allow stops or breaks in products, such as in fiber-optic cable production. Alternately, non stop production may be required when effective use of the manufacturing equipments means that line breaks between production runs and even different products are expensive and must be avoided, such as in filling and packaging operations. Non stop production occurs in both continuous industries and discrete industries, is a unique feature of these industries, and is a different method of production than the one described in the ISA 88 Batch Control System standard. However, the ISA 88 models (S88 for short) can be applied in non stop production with only minor changes to the S88 rules and some specific requirements for equipment control. This model has been verified in a large continuous product flow system with stringent non-stop production requirements.

The S88 model has become the preferred model for batch production systems. In these systems a production batch will move through a set of equipment as it is produced, but it follows the rule that there is only one batch in a unit at a time. At the time of S88's development there was no attempt to apply it to continuous or discrete manufacturing, but the standard mentions that the models and concepts may be applicable.

There are many continuous and discrete manufacturing problems where there is no commonly accepted control system model. Each solution seems unique and there appears to be no underlying pattern that can be applied form job to job. Usually these problems occur when there are multiple paths through the production equipment, either through conveyor arrays or valve arrays, and where the process can be modified by sending execution parameters to equipment.

Discrete production examples include the movement of discrete products, such as electronic boards, cooked and pre-cooked food products, consumer products, or bottles in a continuous manner through a set of processing steps.

Continuous production occurs when the product moves in a flow and there are no discrete countable elements. In continuous production the product moves in a solid flow (liquid mixing or cable assembly) or as a set of undifferentiated small elements (fruit sorting and tobacco production). Continuous production examples include beverage mixing, chemical production, and various food processing.

Examples of execution parameters include systems with dryers, where the drying temperature and dwell time may vary by product, or fillers which fill a container with different products (apples in apple pie, soda in bottles, drugs into bottles and bottles into boxes) based on equipment parameters.

In non stop production there can be multiple paths, multiple products on the line at the same time, and multiple different equipment configurations.   In these and other cases it is often too expensive to have breaks in the production line, just because the control system is not smart enough to manage this complexity.   The control system must be smart enough to switch product in the middle of the stream, keep track of where each product's production run starts, and track the information about each production run.

Engineers and companies developing control systems for these applications often come up with their own standards.   Many solutions are based on years of trial and error with systems that work but may have little overall structure.   Unfortunately, systems applied in one application are often hard, if not impossible to apply in even slightly different applications.

Non Stop Production Lines

The situation above was the same situation that batch production was in before the introduction of the S88 standard. Fortunately, the lessons learned from S88 can be effectively and efficiently applied to the non stop production applications.   Slight extensions to the S88 rules allow the models to be applied. In addition, the same extensions mean that existing S88 products can be use in "stop allowed" continuous and discrete production.

Let us look at a diagram derived from a real example, illustrated in Figure 1. In this application each box represents a specific process applied to the product. These can be heating, cooling, inserting ingredients, wetting, soaking, drying, filling, capping, labeling, storage, testing, and washing. The arrows between the boxes represent conveyor sections that move the product between units. The places where there are multiple different inputs or outputs on the conveyor sections indicate conveyor switches or conveyor arrays.   Some of the processes, such as soaking, may operate on a whole production run at once, other operate on a stream of product.

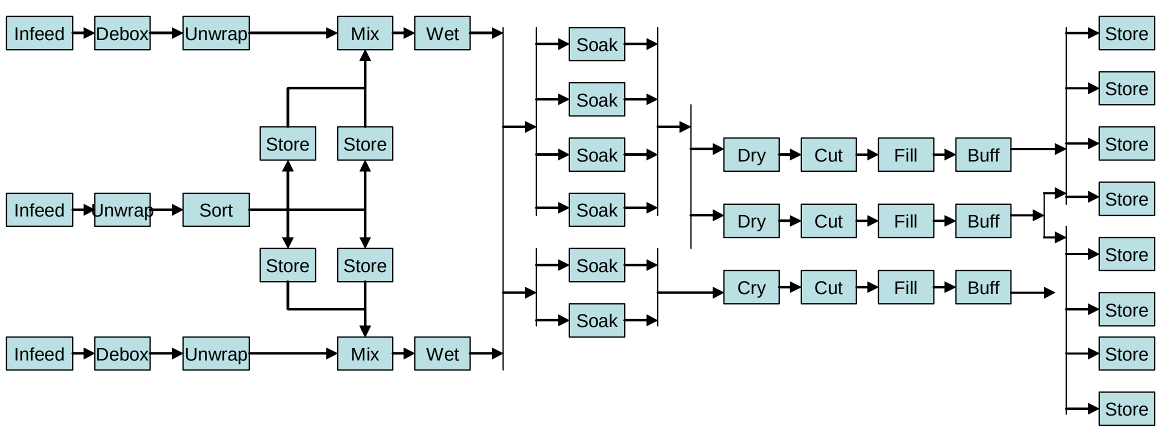

Figure 1 – Non-stop continuous production

If you are familiar with the S88 models, then the diagram looks very familiar, it is a unit layout diagram. In a typical S88 system each box represents a unit, and the arrows indicate material transfer between the units. This diagram is not a P&ID, it is not a process diagram, but is instead a diagram of the equipment hierarchy and equipment connections.

At this point the exact product is not important in determining the design pattern. Many continuous and discrete processes could be documented using similar diagrams. The goal of **NS88** was to define a set of rules that allow a common model across a wide range of processes.

Can S88 Be Applied?

The obvious question is; can the S88 models be applied to this type of production. Equally important is can it be implemented using commercially available batch control systems. Fortunately the answer to both questions is yes. Applying S88 to non-stop production requires changing some of the S88 rules, but not breaking the basic model. For purposes of this paper the extended rule set is identified as **NS88**. This is a model that can be applied where product moves in discrete elements, or as a continuous flow, but where all of the product may never be in a single unit at the same time.

The goal of **NS88** is to maintain the powerful concept of separation of product definition (in recipes) from intrinsic equipment capabilities. This allows changes in products without requiring changes to equipment control programs. **NS88** must also address the ability to have multiple products in the same process cell at the same time.

NS88 Rules

A unit is only assigned to one batch at a time.

- A unit completes it's main processing phase when the last element of the batch reaches the front of the unit.
- A unit keeps controls of the old batch as it moves through the unit using to the old batch's processing requirements.
- A unit keeps track of the last element of the old batch as it moves through the unit.
- A unit sends an end-of-batch to the downstream unit when the first element of the new batch reaches the end of the unit.

Figure 2 - NS88 Rules

The key change from S88 for **NS88** is a change to rule that a unit only contains one batch at a time –to– a unit is only assigned to one batch at a time.

There are also specific rules that equipment phases must follow. In Figure 1 each box represents a unit, but they are small units compared to the units in a typical batch system. These units however typically perform only one or a small number of process actions. For example a unit may "wet" a product, apply a coating to a product, insert components into a product, or mix multiple product streams. Typically there can be one main "operational" phase for each unit, such as "Wet", "Coat", "Insert (component)", or "Mix".

The main operational phase should include the following rules:

1. The main operation phases must complete when the last element of the batch enters the unit. The next product to follow is designated as the new batch

2. Each unit or equipment module must continue to process the old batch still in the unit and keep track of where the batch boundary is within the unit.
3. Optionally each unit or equipment module may send an end-of-batch signal to its downstream unit when the last element of the old batch leaves the unit.

Applying NS88

The following example illustrates production using the NS88 rules defined above. Figure 3 illustrates a single stream production line with two units. FILL #1 fills the product with material. COAT #1 coats the product with a material. Each unit has a main processing phase, FILL #1 has an equipment phase "Fill", COAT #1 has an equipment phase "Coat". These phases have parameters which specify which material to use in their process.

The units include the conveyors section downstream of the main processing unit. The conveyors run from FILL #1 to COAT #1, with the assumption that there is something downstream of COAT #1 to catch and store the product. More complex conveyor systems are discussed later.

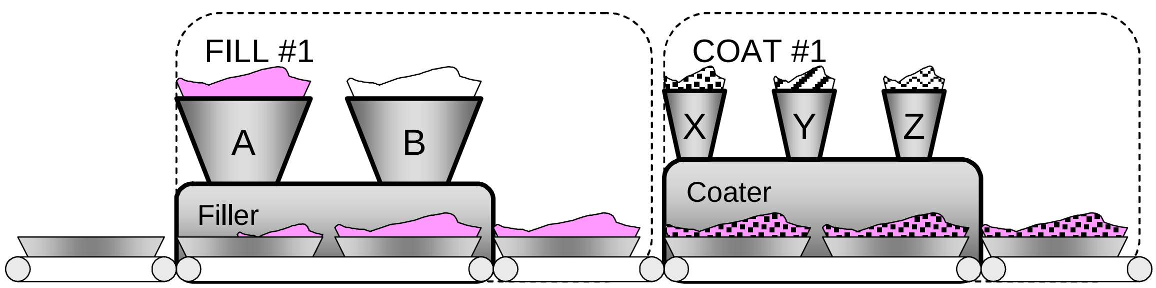

Figure 3 - Sample Non Stop Production Line

Figure 4 illustrates a sample recipe for this production line. This is a collapsed recipe with phases within unit procedures and no operations. Notice that there is no unit-to-unit transfer in this recipe. Using the **NS88** model, unit to unit transfers are not required between continuous units. This means that **NS88** recipes are simpler than S88 recipes because they are constrained by the movement allowed by the physical equipment. This is a very simple example, but it illustrates how the **NS88** rules for unit assignment and phase execution allow for a non-stop switch of product in continuous production.

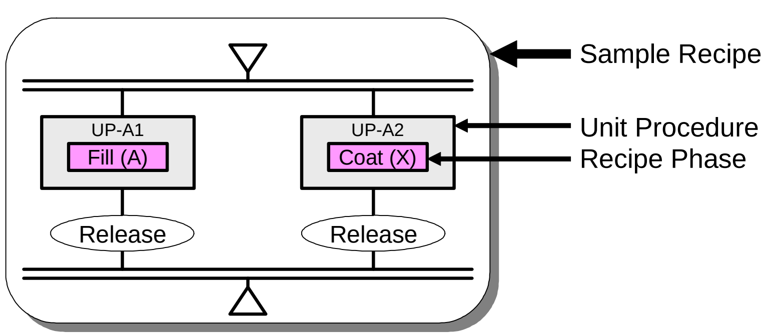

Figure 4 - Sample Recipe for a Non Stop Process Cell

Batch B2 Starting Fill

The full example is too complex for this paper, but a look at system in the middle of a unit switch over illustrates the application of the rules. The situation is:

- The first unit of Batch B2 has entered FILL #1.
- U1 is assigned to B2, but the unit code is still keeping track of B1's location so it knows when B1 leaves the unit.
- FILL #1 continues to fill the old batch with product "A", but is also filling the new batch with product "B".
- COAT #1 is still assigned to Batch B1.

The state of the system should be visible outside the batch system in an HMI or SCADA system, where FILL #1 would be coded to indicate it is assigned to Batch B2, but still has not yet cleared Batch B1.

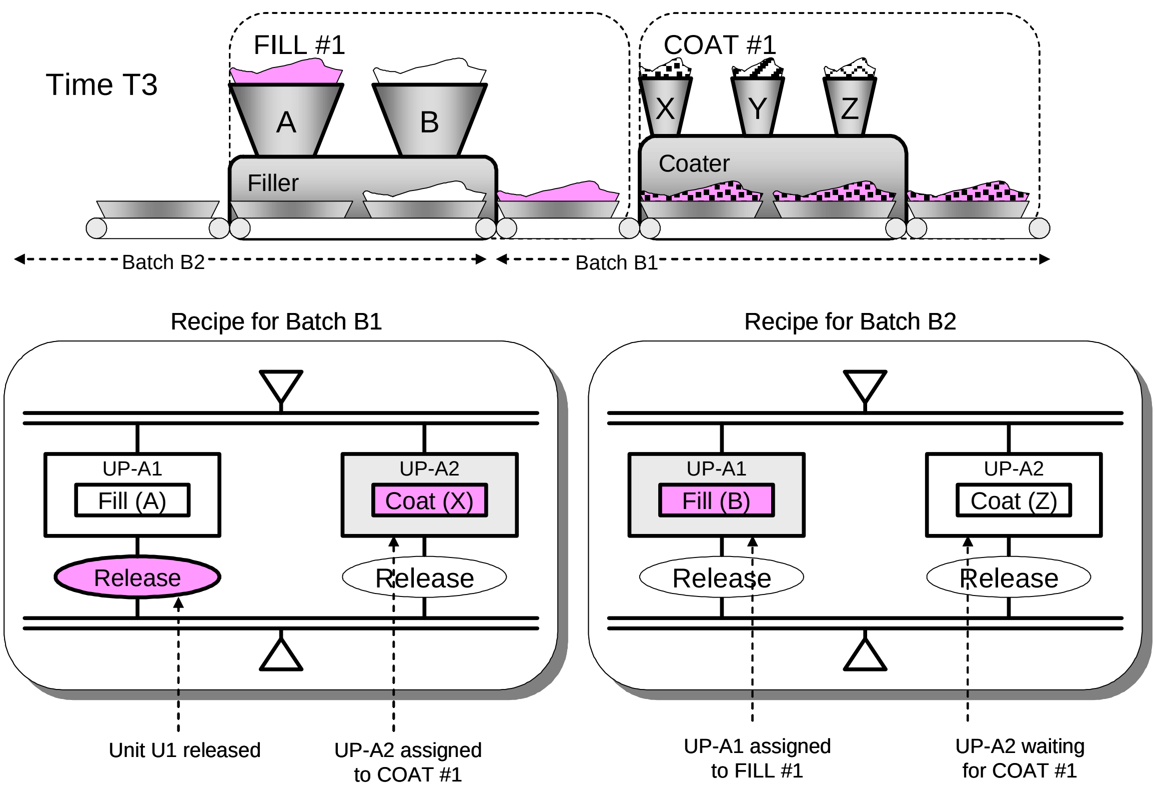

Figure 5 - Time T3 Product Switchover in FILL #1

Generating the Right Batch Record

In the normal S88 model the batch record contains all of the actions performed on a batch. There is only one batch at a time in a unit, the phases in a unit are specifically assigned to a single batch, and the batch log can be organized by phases. In **NS88** there are times where the unit contains more than one batch, and the equipment phase for a batch completes before the batch completely leaves the unit.

In cases where complete information about a batch must be defined in a single batch record the following method can be used.

1. Create reporting units that match the processing units.
2. The reporting units contain phases that follow the rules:
    a. The report unit phases must complete when the last element of the batch leaves the unit.
    b. The report unit phases report on all elements of the batch processed through the unit. The report unit phases must coordinate with the processing unit's operational phase to track information about the new batch through the unit.

NS88 Rules

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- A unit keeps track of the last element of the old batch as it moves through the unit.
- A unit sends an end-of-batch to the downstream unit when the first element of the new batch reaches the end of the unit.
- Create reporting units that match the processing units.
    - The reporting units phases complete when the last element of the batch leaves the unit.
    - The report phase reports on all elements of the batch processed through the unit.
    - The report unit's report phase must coordinate with the processing unit's operational phase to track information about the new batch through the unit.

Figure 6 - NS88 Rules with Reporting

Figure 7 illustrates the reporting method. In the previously defined example two new units would be created, FILL #R1 and COAT #R1. These units would have report phases that report on the batch still in the unit. From the batch execution system they are units assigned and released the same as the processing units. The recipe contains extra unit procedures for the reporting units.

Figure 7 illustrates the situation at time T3 in the example. In this case the "Report" phase in reporting FILL #R1 has not yet completed because the last of the batch has not yet left FILL #1. In the batch log for Batch B1 it would contain the reported information on all elements of Batch B1 in FILL #1.

When the last element of Batch B1 leaves FILL #1, then the FILL #R1 report phase can report the final information and then complete. FILL #R1 is released and can then be assigned to Batch B2.

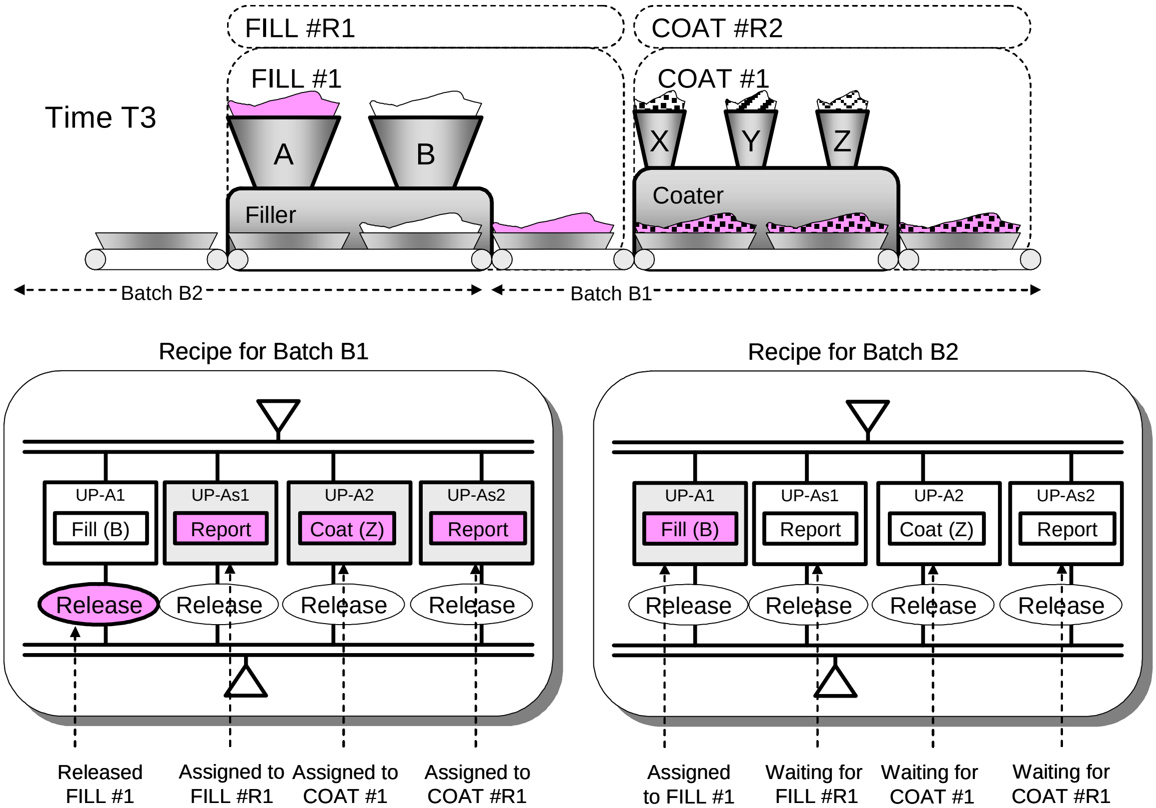

Figure 7 – Using Reporting Units to Report on a Batch

This method doubles the number of units within a process cell, and may double the number of phases, since the process phase (ie: Fill) can not return a report. In an S88 system the Fill phase may have two parameters that specify the material to fill and the amount to fill. The phase would also have a report parameter that is returned by the phase with the amount of material actually filled. In the NS88 model the Fill phase would not have a report parameter, and a "Report" phase would return the actual number of product elements filled.

Other Special Rules

The same model can be applied to starting up and shutting down the production line or process cell. Recipes can be used to sequence equipment startup, usually a requirement due to electrical load considerations.

Switching conveyor systems can also be handled using the same set of rules. For example a switching conveyor system would be defined as a unit. It would have a main operational phase which directs its material flow down the proper path, but would also control the previous batch down its path until it leaves the conveyor system.

Generally a production line is designed with some units that can buffer to handle temporary stops of equipment, such as that shown in Figure 8 in a continuous filling process. In this case the HOLD rule is applied when a hold signal is sent from a downstream to an upstream unit. This can be a peer-to-peer communication or it could be handled through a batch execution system.

The high speed conveyor system could either be a unit (when the HOLD signal goes through a batch system) or an Equipment Module (when the HOLD signal speed requires direct communication to the upstream and downstream phases).

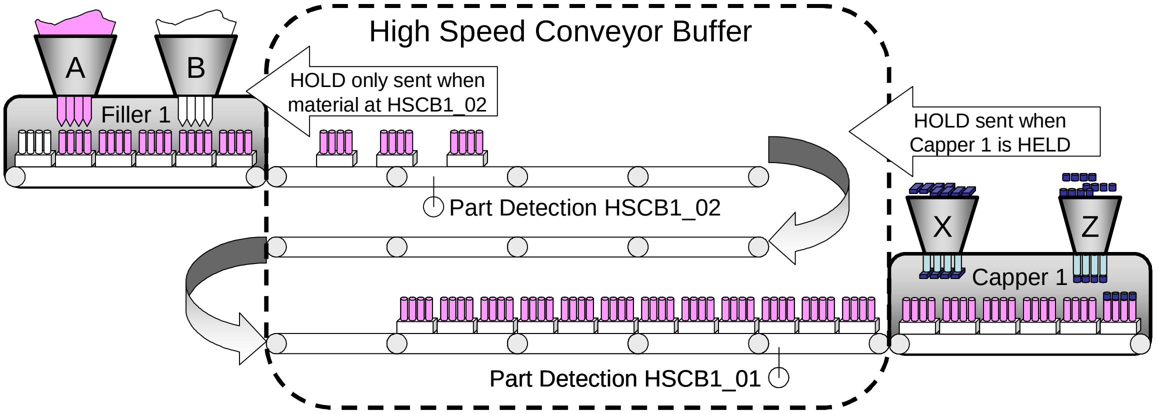

Figure 8 - Buffering in a Discrete Process

NS88 could use a modified state model, such as the one illustrated in Figure 9 Each unit and/or equipment module may have a different state model, but the following is typical example of an **NS88** unit, workcell, or shared equipment module. This model is derived from the OMAC state model and includes extra states for product switchover used by **NS88**.

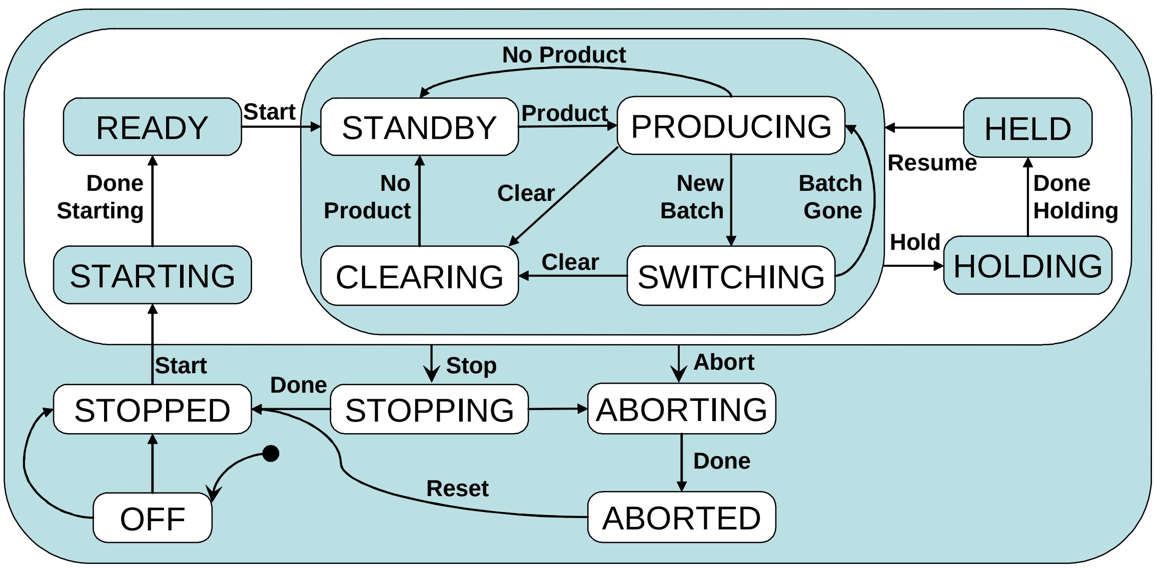

Figure 9 - Example of a Typical Equipment State Model

Equipment states are generally not the same for all pieces of equipment and that the exact functions to be performed in each state will change based on the manufacturing process and equipment capabilities. Table 1 lists some example equipment state definitions.

Table 1 - Equipment State Definitions

Equipment State	Description
OFF	The equipment is powered up, but is not yet ready to be operated. Note: It may be performing initial self tests and power up logic.
STOPPED	The equipment is ready to be started, is not performing its basic processing function, and equipment is not processing material.
STARTING	The equipment has been commanded to start and is in the process of starting equipment, but the equipment has not yet been commanded to process material.
READY	The equipment has finished starting and is ready for operation.
STANDBY	The equipment is waiting for material to process.
PRODUCING	The equipment is performing its basic processing function on one batch.
SWITCHING	The equipment is finishing processing of a batch and is starting processing of a new batch.
CLEARING	The equipment is finishing processing of a batch and no new batch is present.
HOLDING	The equipment has been commanded to hold and stop processing the batch, and is performing the actions to go to the HELD state.
HELD	The equipment is not processing the batch, and has sent a HOLD to its upstream equipment.
STOPPING	The equipment has been commanded to stop processing material and is performing actions to clear the material.
ABORTING	The equipment is not performing its basic processing function but material is clearing the equipment
ABORTED	The equipment is not ready to be started, is not performing its basic processing function, and equipment is not processing material.

Summary

The ISA 88 model can be effectively applied to non batch systems, and in particular to non stop continuous and discrete production systems with only slight modifications. The modified rules, identified as **NS88**, can be applied to a wide range of problems, and allow exiting batch products to be effectively used in non batch problems. **NS88** changes the "one-batch-per-unit" rule of ISA 88 to a "one-batch-assigned-to-a-unit" rule. **NS88** then provides an underlying pattern for the organization and state models for equipment modules (programmed code) and for unit to unit communications. NS88 has been verified in a large continuous product flow system with stringent non stop production requirements. In addition the **NS88** architecture was retrofitted onto an existing physical process with minimal disruption and changes to the underlying physical equipment.