Batch Management and Control

Ashutosh Kshirsagar
Title – Global Process Technical consultant
Date – 11th February 2015
Manufacturing Processes...

- Continuous
- Discrete
- Batch
Continuous Processes…

- Typically are used in plants which manufacture a small variety of products but in very large quantities.

- Process changes are very few and plant operates at the steady state for a very long duration.

- Process operations are mainly regulatory in nature with some amount of interlocking and sequencing, especially during plant startup and shutdown.

- Plant consumes raw material in a continuous manner and produces the output product in a continuous manner.

- Input raw material loose their individual identity in the manufacturing process.

- For example Urea, Petrochemicals, Glycol, Sugar etc. are manufactured in large quantities in continuous process plants.
Discrete Processes...

- Typically are used in plants which manufacture discrete products like a car in an assembly line.

- Process calls for a variety of actions like timing, counting, sequencing, interlocking, material handling etc. at different stages of the manufacturing process.

- No manufacturing process variation expected after the start of the manufacturing activity and follows a fixed and well defined sequence of operation.

- Plant consumes raw material in lots and produces the output product in lots.

- Input raw material retain their individual identity in the manufacturing process even in the final finished product.

- For example, cars, trucks, incandescent lamps, cell phones etc. are manufactured through discrete processes.
Batch Processes...

- Typically are used in plants which manufacture large variety of products but in relatively small quantities

- Process calls for a variety of actions like timing, counting, sequencing, interlocking, material handling, loop control, advanced regulatory controls, coordinated control, common resources handling at different stages of batch

- Process flow can get changed as the batch progresses and may not always follow a very well defined path, based on the prevailing process conditions

- Plant consumes raw material in lots and produces the output product in lots

- Input raw material do not retain their individual identity in the manufacturing process

- Differing process sequences can be carried out on the same set of physical equipment to produce different products

- For example, Soaps, Detergents, Paints, Bulk drugs, Inks, Agro-chemicals etc. are manufactured through batch processes
These processes show all the characteristics of Continuous processes and discrete processes at different stages of operations apart from its own unique batch like nature.

For example during the charging of two liquids in ratio mode to a reactor…. It looks like a continuous process with emphasis on regulatory control at this stage

When it requires an operation of a series of valves and pumps in a sequential manner to re-circulate the reactor contents for homogenization for a certain period of time… it looks like a discrete process… with timing, sequential and interlocking operations at this stage
Batch Processes range from simple to very complex...

- Single Reactor, Single product
- Multiple Reactor, Single product
- Single Reactor, Multiple Products
- Multiple Reactors, Multiple products with fixed equipment grouping and material routes
- Multiple Reactors, Multiple products with dynamic equipment grouping and material routes
**System Definition:**
Same process operations in the same sequence using unchanging parameter values.

**Typical Applications:**
Repetitive sequencing in all industries. CIP, catalyst regeneration, Continuous processes startup/shutdown, material transfer.

Typically single product plants.

**Typical Characteristics:**
The sequencing of operations in such plants may not be very complex but the process control actions may be quite complex.
Multiple products / grades - Fixed Sequencing Variable Formula parameters

System Definition:
Fixed sequencing of operations, but multiple sets of parameter values that will be changed based on product requirements

Typical Applications:
Many Batching applications such as formulations. Small Food and Beverage, Different grades of same chemical product manufacturing

Typical Characteristics:
The sequencing of operations in such plants may not be very complex but the process control actions may range from simple to very complex
Multiple products, multiple sequences & parameter sets, single reaction vessel or vessel train, fixed path

**System Definition:**
Single processing vessel or a vessel train with multiple processing sequences with multiple parameter sets and processing requirements that are changed often.

**Typical Applications:**
Food processing applications, Pharma and Specialty chemicals, Soaps, Detergents, Lube Oils, Paints, Inks.

**Typical Characteristics:**
The sequencing of operations in such plants can be very complex along with the process control actions as well as inter unit co-ordination during material transfers, common path and equipment sharing also becomes very important.
Multiple products, multiple sequences & parameter sets, multiple reactors & dynamic equipment groups

System Definition:
Highly interconnected plant simultaneously running multiple recipes with multiple sequencing requirements, variable process parameters, with processing equipment grouping defined dynamically as per the prevailing process conditions

Typical Applications:
Food, Beverage, FMCG, Specialty Chemical, and Life Science processes. Paints, Lube Oil Blending

Typical Characteristics:
The sequencing of operations in such plants can be very complex along with the process control actions as well as inter unit co-ordination during material transfers, common path and equipment sharing also becomes very important.
Batch Processes - Production challenges

- Assure product quality and consistency
- Integration of Automation system with Business systems
- Fast product change-over
- Scalable batch sizes to suit production requirements
- Authentic Batch reports and a strong reporting functionality
- Ensure equipment utilization at highest level
- Manual and automatic equipment coordination
- Optimized batch cycle times
- Manufacturing different products on different equipment simultaneously
- Facility to modify operation sequences ‘online’ for handling QC or other unforeseen process issues
Batch Processes – Control System design imposed limitations

- Unable to handle multiple products with differing process sequences
- No standardization in the design of graphical user interface
- No proper mechanisms to handle common process resources
- No proper mechanism to handle process faults & recovery strategies
- Process engineers cannot design or modify process sequences on their own independently
- Inefficiency in scheduling of equipment leads to sub-optimal plant efficiency
- Inability in achieving designed batch cycle times
- No mechanism for modification of process sequences for ongoing batches
- Re-validation of logic is required each time after creation/modification of a process sequence
Sensing the underlying structures and patterns in batch manufacturing plants

Despite of the differing nature of the physical processes, the differing chemistry of the processes, the differences in the plant equipment, there is still quite some similarity in the way the processes take place, the way they are handled as well as similarity in the way the physical equipment are operated and handled.

In order to design robust, flexible and user friendly batch control systems, it is precisely these similarities that have to be sensed, represented in a structured manner and properly reflected in the control system design. This is the key to design flexible manufacturing systems.

The ISA-88 standard is all about facilitating the above.
A batch facility has an inherent **STRUCTURE** which can be accounted for in the automation system.

This inherent structure is divided into **TWO** main components:

- The **EQUIPMENT** in the plant
- The operating **PROCEDURES**
ISA-88: Making Order Out Of Chaos

- ISA-88 standard for batch processes gives us a standardized set of terminology and methods.
- A common language for the design, operation and supervision of batching systems.

- The terms:
  - Process Model: high-level flow sheet of process
  - Equipment (Physical) Model: the ‘pots and pans’
  - Procedural Model: the sequence of operations
  - Recipe: the quantity of ingredients (formulation) combined with the Procedure

- Separates the recipe from the equipment
  - Change sequences without changing controller programs
ISA-88: Making Order Out Of Chaos
Applying the ‘Equipment’ Model to the plant
ISA-88: Making Order Out Of Chaos
Modeling the plant - The ‘Site’

Diagram showing the process flow with the 'Site' in the middle, connected to packaging stations.
ISA-88: Making Order Out Of Chaos
Modeling the plant - The ‘Areas’
ISA-88: Making Order Out Of Chaos
Modeling the plant - The ‘Process Cells’
ISA-88: Making Order Out Of Chaos
Modeling the plant - The ‘Units’
ISA-88: Making Order Out Of Chaos
Modeling the plant - The Control Elements
ISA-88: Making Order Out Of Chaos
A hierarchical view of the ‘Equipment’ model
ISA-88: Making Order Out Of Chaos
Applying the ‘Procedure’ Model to the plant
ISA-88: Making Order Out Of Chaos
A hierarchical view of the ‘Procedure’ model

Recipe Procedure → Unit Procedures → Operations → Recipe Phases → Equipment Phases → Control Module logic

Recipe Phases:
- Manufacture
- Polymerize
- Recover
- Dry
- Charge
- React
- Prepare
- Add A
- Add B
- Heat
- Soak

Equipment Phases:
- XV 101
- XV 102
- PM 101
ISA-88: Making Order Out Of Chaos A combined view of ‘Equipment’ & ‘Procedure’ models
ISA-88: Making Order Out Of Chaos - Equipment Phases - The work horses of any batch process

These actions are the basic building blocks of process and any high level batch process sequence can be built up using these blocks only.

The internal operating sequence of these actions remains the same irrespective of their position/step in the main sequence.

These rectangles represent all possible independent minor processing actions that are possible on this unit.

These actions are completely self contained and do not require to cross the boundaries of the rectangle for their execution.
ISA-88: Making Order Out Of Chaos - Differing Sequences but same set of Equipment phases

Three different batch sequences but with same set of Equipment modules & phases
Recipe

- Equipment Requirements
- Header
- Procedure
- Formula
- Other Information
ISA-88: Making Order Out Of Chaos
Recipe Structure- The manufacturing roadmap

This form helps the user to define all the information required to manufacture a product, like
- Product Name
- Ingredients used
- Ingredient Qty.
- Process Sequence

Map the basic process building blocks as ICONS in the sequence chart actions bar

Select the required ingredients from the master list & specify their quantities

Specify the product name for which this recipe is being designed for
Specify the number of steps required to complete the sequence.

Select the process Phases that are required to be executed per step for each of the steps.

Specify that Process Sequence definition is to be done in this part of configuration.
ISA-88: Making Order Out Of Chaos
Phase operation parameter definition

Select a phase & program the process parameters relating to the activity performed in that phase, for each of the configured phases.

Specify that process parameters relating to each of the configured Phases is to be defined in this part of configuration.
ISA-88: Making Order Out Of Chaos
Create and store a library of pre-defined recipes

Recipe gets added to the master list

Recipe definition & flexible manufacturing can be as easy as this...

“Save” the recipe into the master list.

You can create a library of ready made product recipes which can be just selected and run during actual manufacturing.

Save the recipe
So, all the process blocks are analyzed from various angles to capture the operations of the different equipment modes required. These requirements are documented and implemented in a modular fashion.

While each of the Equipment phase performs a very different process activity, there is still a strong similarity in their modes of operation which can be captured with the help of this model.

### Procedural States

<table>
<thead>
<tr>
<th>State</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Idle</td>
<td>The procedural element is waiting for a START command that will cause a transition to the RUNNING state.</td>
</tr>
</tbody>
</table>
### ISA-88: Making Order Out Of Chaos

Traditional method for Phase definition

<table>
<thead>
<tr>
<th>Equipment Phase</th>
<th>Control Step</th>
<th>Control Action</th>
<th>Comments</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Initialize</strong></td>
<td>Put ingredient B ratio controller in MANUAL mode and set output to zero</td>
<td>Rat io control algorithm</td>
<td>Check existing control module control activity for ingredient B feed control to see if the necessary equipment and control actions are available</td>
</tr>
<tr>
<td></td>
<td>Start jacket circulation pump AND set reactor temperature controller to SEC/ AUTO mode with a setpoint of 200°F</td>
<td>Cascade control algorithm</td>
<td>Check existing control module control activity for R602 reactor temperature control to see if the necessary equipment and control actions are available</td>
</tr>
<tr>
<td><strong>Add ingredient A</strong></td>
<td>Initialize (reset ingredient A flow totalizer accumulated value to zero and preset value to 30,000 #)</td>
<td>Flow totalizer algorithm with preset</td>
<td>Check existing control module control activity for ingredient A feed to see if the necessary equipment and control actions are available</td>
</tr>
<tr>
<td></td>
<td>Open ingredient A charge valve and verify its opening</td>
<td>Automatic block valve driver algorithm</td>
<td>Verify equipment and control actions are available</td>
</tr>
<tr>
<td></td>
<td>Start ingredient A at orage tank pump</td>
<td>Pump driver algorithm</td>
<td>Verify equipment and control actions are available</td>
</tr>
<tr>
<td></td>
<td>When 4000 # of ingredient A has been charged, start the agitator</td>
<td>Agitator driver algorithm</td>
<td>Verify equipment and control actions are available</td>
</tr>
<tr>
<td></td>
<td>When amount of A charged equals 28500 #, close ingredient A charge valve to the dribble position</td>
<td>Valve driver algorithm with at least two output states, fully open and open to dribble setting</td>
<td>Check the actuating element to make sure that it has two output states, check control action to see if can implement dribble shut-off</td>
</tr>
<tr>
<td></td>
<td>When amount of A charged equals 30,000 #, fully close ingredient A charge valve AND stop storage tank pump</td>
<td>Previously defined</td>
<td></td>
</tr>
</tbody>
</table>
A process oriented framework for capturing, documenting and structured implementation of Phase Logic in an ISA-88 environment

Ashutosh Kshirsagar
Rockwell Automation
Set of sheets to define the requirements of each ISA-88 phase state in an unambiguous format
ISA-88: Making Order Out Of Chaos
‘Running’ state definition

<table>
<thead>
<tr>
<th>LOGIC MODULES</th>
<th>CONTROL MODULES</th>
<th>STEP TRANSITION</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>2</td>
<td>2</td>
<td>2</td>
</tr>
<tr>
<td>3</td>
<td>3</td>
<td>3</td>
</tr>
<tr>
<td>4</td>
<td>4</td>
<td>4</td>
</tr>
<tr>
<td>5</td>
<td>5</td>
<td>5</td>
</tr>
<tr>
<td>6</td>
<td>6</td>
<td>6</td>
</tr>
</tbody>
</table>

Define the Control Modules required
Specify process conditions to be true to go to next step
Define if step transition to be disabled till all control modules reach their commanded state

Define the Logic action Modules required
Specify steps where Logic Modules execute with binary 1/0 attributes
Specify steps where Control Modules execute with binary 1/0 attributes
ISA-88: Making Order Out Of Chaos... Standardized Phase faceplate for phase Monitoring and control

This field shows the ‘State’ of the Phase

These fields show the Current Step number & total number of steps in the phase

These are the control and command keys to help the operator to intervene into the process

This field shows the name of the Phase

This field shows the mode of operation of the phase Phase

This field shows the transition condition to be satisfied to go to the next step
ISA-88: Making Order Out Of Chaos
This is how a ISA-88 based design looks like

- Recipe Procedure
- Unit Procedures
- Equipment Phases
- Control Module Basic control logic

This is how the a typical actual implementation of Procedure model looks like
ISA-88: Making Order Out Of Chaos

Equipment Phase sequencing - other schemes

- Controller Batch Sequencer
- PC Batch Sequencer
- Controller state Logic
- Controller SFC Sequencer

Various different methods for implementation of Unit Procedures

Copyright © 2012 Rockwell Automation, Inc. All rights reserved.
A typical Batch application for a FMCG industry
A typical Batch application for a FMCG industry

### Recipe Creation

#### Weighing

<table>
<thead>
<tr>
<th>COMP</th>
<th>REQ</th>
<th>TOT. QTY</th>
<th>FN QTY</th>
<th>FNPQ QTY</th>
<th>TIME OUT</th>
</tr>
</thead>
<tbody>
<tr>
<td>A/B</td>
<td></td>
<td>750.00</td>
<td>50.00</td>
<td>25.00</td>
<td>10.00</td>
</tr>
<tr>
<td>C/D</td>
<td></td>
<td>250.00</td>
<td>25.00</td>
<td>10.00</td>
<td>10.00</td>
</tr>
<tr>
<td>E</td>
<td></td>
<td>6.00</td>
<td>2.00</td>
<td>1.00</td>
<td>5.00</td>
</tr>
<tr>
<td>F</td>
<td></td>
<td>1.90</td>
<td>0.50</td>
<td>0.10</td>
<td>5.00</td>
</tr>
<tr>
<td>G</td>
<td></td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
</tr>
<tr>
<td>H</td>
<td></td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
</tr>
<tr>
<td>SLDA</td>
<td></td>
<td>0.00</td>
<td>NA</td>
<td>NA</td>
<td>0.00</td>
</tr>
<tr>
<td>PWDA</td>
<td></td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
</tr>
<tr>
<td>PWDB</td>
<td></td>
<td>10.00</td>
<td>3.00</td>
<td>1.00</td>
<td>5.00</td>
</tr>
<tr>
<td>PWD</td>
<td></td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
</tr>
</tbody>
</table>

#### Discharge Sequence

<table>
<thead>
<tr>
<th>STP</th>
<th>A / B</th>
<th>C / D</th>
<th>E</th>
<th>F</th>
<th>G</th>
<th>H</th>
<th>SWH</th>
<th>FD</th>
<th>VD</th>
<th>BLW</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>3</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>4</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>5</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>6</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>7</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>8</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>9</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>10</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

### Product: Rexona

- **Excel**: checked
- **Operator**: checked
- **Excel Workbook Name**: NIL
- **Excel Sheet Name**: NIL

- **Configure Operations**: checked
- **Configure Parameters**: unchecked

- **Save Recipe**

---

**Note:** The screenshot contains a control system interface for recipe creation and discharge sequence management in a Batch application for a FMCG industry. The interface includes fields for weighing components, discharge steps, product name, and configuration options.
A typical Batch application for a Multi-Product Chemical Process plant
A typical Batch application for a Multi-Product Chemical Process plant
A typical Batch application for a complex single product Chemical Process plant
A typical Batch application for a complex single product Chemical Process plant

STATE LOGIC DIAGRAM FOR M22
A typical Batch application for Multi-product Lube Oil / Paints / Inks process plant
A typical Batch application for Multi-product Lube Oil / Paints / Inks process plant

<table>
<thead>
<tr>
<th>SN</th>
<th>COMMAND</th>
<th>INGRD</th>
<th>SP1</th>
<th>SP2</th>
<th>SN</th>
<th>COMMAND</th>
<th>INGRD</th>
<th>SP1</th>
<th>SP2</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Halt</td>
<td></td>
<td></td>
<td></td>
<td>16</td>
<td>QC Check</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>Dose Base Oil 001A</td>
<td>90.0000</td>
<td></td>
<td></td>
<td>17</td>
<td>Man Dose 015A</td>
<td>100.0000</td>
<td></td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>Dose Base Oil 034A</td>
<td>100.0000</td>
<td></td>
<td></td>
<td>18</td>
<td>Man Dose 022A</td>
<td>100.0000</td>
<td></td>
<td></td>
</tr>
<tr>
<td>4</td>
<td>Agitator ON</td>
<td></td>
<td></td>
<td></td>
<td>19</td>
<td>Control Temp</td>
<td></td>
<td>55.0000</td>
<td>68.0000</td>
</tr>
<tr>
<td>5</td>
<td>Heat ON</td>
<td></td>
<td>50.0000</td>
<td></td>
<td>20</td>
<td>Recirculation</td>
<td></td>
<td>15.0000</td>
<td></td>
</tr>
<tr>
<td>6</td>
<td>Time Delay</td>
<td></td>
<td>10.0000</td>
<td></td>
<td>21</td>
<td>QC Check</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>7</td>
<td>QC Check</td>
<td></td>
<td></td>
<td></td>
<td>22</td>
<td>Discharge</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>8</td>
<td>Dose Base Oil 035A</td>
<td>100.0000</td>
<td></td>
<td></td>
<td>23</td>
<td>Heat OFF</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>9</td>
<td>Recirculation</td>
<td></td>
<td>10.0000</td>
<td></td>
<td>24</td>
<td>Agitator OFF</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>10</td>
<td>Receive Premix</td>
<td></td>
<td>100.0000</td>
<td></td>
<td>25</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>11</td>
<td>Time Delay</td>
<td></td>
<td>2.0000</td>
<td></td>
<td>26</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>12</td>
<td>Dose Bulk Additv 0106</td>
<td>100.0000</td>
<td></td>
<td></td>
<td>27</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>13</td>
<td>Time Delay</td>
<td></td>
<td>5.0000</td>
<td></td>
<td>28</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>14</td>
<td>Dose Bulk Additv 0152</td>
<td>80.0000</td>
<td></td>
<td></td>
<td>29</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>15</td>
<td>Time Delay</td>
<td></td>
<td>2.0000</td>
<td></td>
<td>30</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**Recipe Creation**

**Product Code:** A123  **Formula:** 1  **Family:** F-1  **Recipe:** 1  **Designer:** [Name]  **Design Date:** 6/23/2008

**Recipe Description:** Hi speed Oil

**Recipe Type:** BLENDER+PREMIX

**Recipe Being Created For:** BLENDER  PREMIX  DYE

**Total Steps:** 24  **Selected Ingredient Cumulative:** 100.0000

**Clear Step**  **Insert Step**  **Delete Step**  **Copy Step**  **Paste Step**  **Validate**  **Clear Error**  **Clear % Error**  **Spare**  **Print**
Thank you for participating!

Your feedback is valuable!
Please complete the session survey.

E-Mail us – indiamarketing@ra.rockwell.com