Presented at the
World Batch Forum
European Conference
October, 2000

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The Zones of Batch Manufacturing and Their Impact Upon Automation

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KEY WORDS

S88.01 Models, Zones, Usability, Unit Modes, Residency, Automation, Basic Control, Equipment Phase, Equipment Module, Equipment Centric, Procedure Centric

ABSTRACT

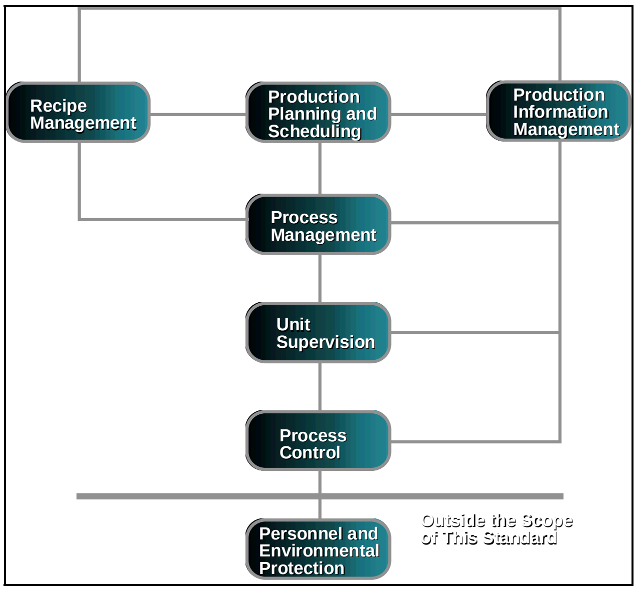
All of the components, and the zones in which they reside, that comprise the scope and magnitude of batch manufacturing have always been a challenge to fully comprehend at a single instant. When attempting to automate these components one must understand the unique requirements of the zone in which the component resides, as well as the touch points and interactions between the different S88.01 models. The approaches used to modularize and automate these touch points and interactions have a great impact upon the "usability" of the automation. The concepts of "Unit Modes", Equipment Module and Phase "residency" are key to a usable automated batch manufacturing application. This paper explores the zones of batch manufacturing and an approach to automate the touch points and interactions of the S88.01 models that provides a very usable application.

INTRODUCTION

Batch Manufacturing has been with us since the start of recorded history, as demonstrated by ancient recipes for the manufacturing of a malt-based beverage. It can be confusing and difficult to understand the many facets of this challenging method of manufacturing, although we realize its benefits. With the acceptance of the S88.01 Standard on Batch Models and Terminology (the

Rosette Stone for the world of batch), we at last have a tool to help us better communicate about batch manufacturing. It is not perfect yet, but it is very, very good.

This form of making products has been successfully used for millenniums without automation. In our efforts to bring automation into this area we are faced with many challenges, not only in how to do it, but in convincing Manufacturing of the benefits of changing from their tried-and-true techniques to something new. The desired-end result of any automated system can have a radical impact upon the design of its application. One of the most influential factors is whether the focus of Manufacturing is on the procedure or on the physical process. This is a Manufacturing decision and does not belong to the engineers who design and construct the systems and applications.



Activity Model Fig. 1

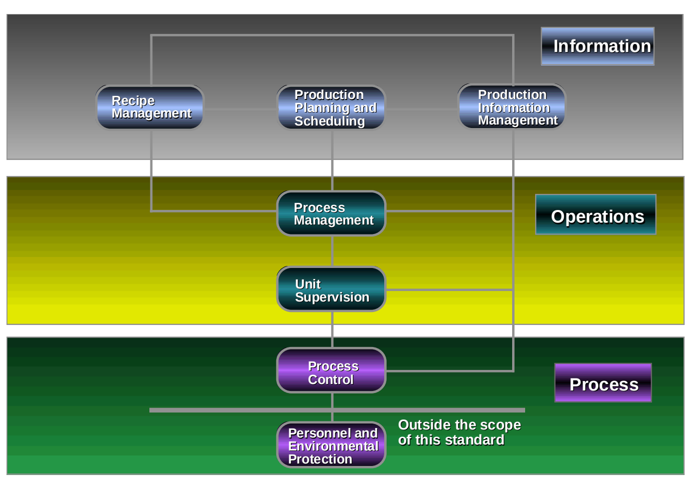
Batch Manufacturing Activities and their distinct Zones

Whether manual or automated, S88.01 identifies the activities and physical structures of our batch processes. As this standard has been applied, it has become clear why batch manufacturing has always been such a challenge to automate. By using the S88.01 activity model, (Fig. 1) we have been able to identify three separate "zones" across which our batch system must span. These zones range from the factory floor instruments and physical equipment to mainframe computers, with much in-between. Each zone has unique requirements and brings its own unique values.

Manufacturing has always viewed this form of making products as a seamless "whole" and quite simple. When approaching it from an automation viewpoint, it is best to treat it as three separately grouped functions (see Fig. 2), and to give it the respect its true complexity demands.

These zones are:

Process - This zone consists of the Physical Process and its control. This control can be 100% manual or almost totally automated. To automate the physical manufacturing process totally, so that human involvement is not required,



Three Zones Fig. 2

is a daunting task and may not be attainable in the near future. The focus of this zone is tactical and its mission is to carry out the directives necessary to make product of acceptable quality at acceptable rates. There are two engineering disciplines required here: Process Control and Process Manufacturing. This often leads to "turf-wars" and can be a real challenge to manage. The time horizon here is micro-seconds to minutes.

Operations - This middle zone is where the physical process world collides with the non-physical world of data management in the form of procedures and recipes. The people in this zone must have their feet firmly planted in the zones on either side. The activities here can be managed totally with paper and personal communication. Great benefits can be realized within this zone when successful automation occurs. There are two focuses here, tactical and strategic. There are also several missions. One is to manage the processes that make up the physical plant and see that the directives of the recipes are successfully implemented through the execution of the procedural elements of the unit recipe. The recipe phase maps to an Equipment Phase and is the process that moves across the boundary between the operations zone and the process zone. Here also is where the data that is required by the upper layers is gathered and made available for use. The single engineering discipline required here is often referred to as Automation Engineering. To be successful, these engineers must be knowledgeable of all of the zones. The time horizon of this zone is seconds to hours.

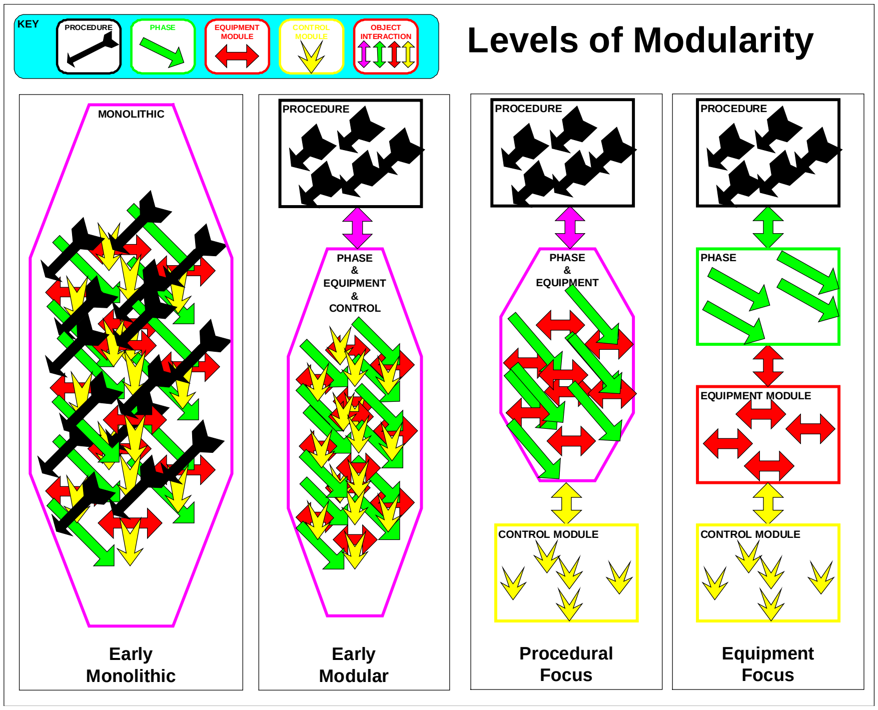
Information - While this is viewed as the "top" zone, it is not necessarily agreed to that it is the most important. However, when dealing with the computer scientist who manages this zone, one must learn never to tell them that without the lower layers they would have no information to manage. This zone is almost totally strategic in nature and is very important to the overall success of batch manufacturing. The time horizon here is minutes to months.

These are the three zones in which batch manufacturing occurs. Not only are there the three zones but there are also the transition boundaries between the zones which must be successfully negotiated. The successful automation of these zones allows us to increase productivity of our systems and the quality of our products. Detailed understanding of the unique needs of each zone, as well as how to move across the boundaries between them, increases the probability of successful automation.

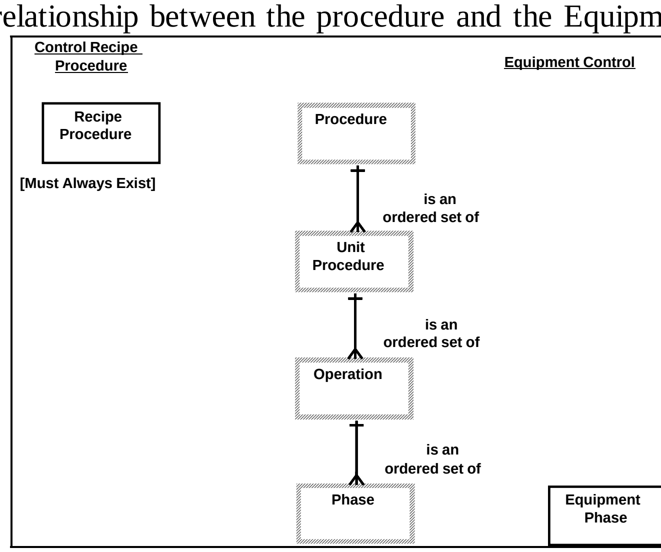
The Physical Process, Levels of Process Automation and Divisions of Function

Before the advent of S88.01, systems were “automated” using many different approaches from totally monolithic in which the different functions were interlaced in very large applications to totally modular systems, where all of the different functions were separated and everything in-between. (See Fig. 3.) Some of these older approaches were very close to the recommended modularization concepts of S88.01 with only the terms being different. For those that did separate the functions, the level of modularization was often driven by the approach to manufacturing that was taken, either Procedure Centric or Equipment Centric.

In Equipment Centric systems the focus of Manufacturing is primarily directed to the operation of the physical equipment with the procedure used as an aid to direct the equipment in the making of product. These types of systems are generally highly automated and will make several batches of product in campaigns with the procedures and Equipment Phases having been designed to operate with a minimum of operator interaction. On the other hand the physical elements of this form of manufacturing generally involves many people that will be frequently interacting with the equipment as it is used to make product. When things do not go according to plan and an operator must become involved, they are permitted to take whatever independent action they deem necessary to resolve the issue. The preferred point of interaction is with the equipment and not the procedure or the Equipment Phase. In Equipment Centric Systems, the Equipment Phase is used to replace the thought process that the operator uses if everything is working as designed. It provides instructions to elements lower in the architecture which will execute the "Basic Control" and carry out the process functions. Fig. 4 shows the lowest level relationship between the procedure and the Equipment Phase as defined by S88.01. It is possible for the operators to "disconnect" the Equipment Phase and command the "Basic Control" of the process function that is part of the Equipment Module or take total control at the Control Module level and perform the process function without the aid of the Equipment Module logic. When the operators have taken the required actions, control can be returned to the procedure and Equipment Phases which will resume at the proper point in the recipe. The simplistic example shown in Appendix A represents an Equipment Centric implementation. In this example, the procedural functions of the

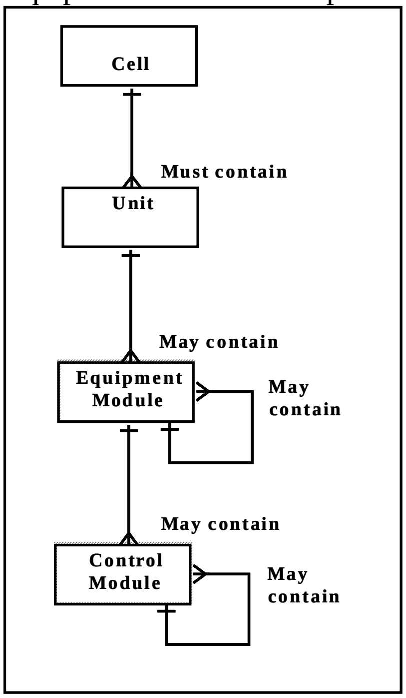


Levels of Modularity Fig. 3



Procedure to Equipment Phase Fig. 4

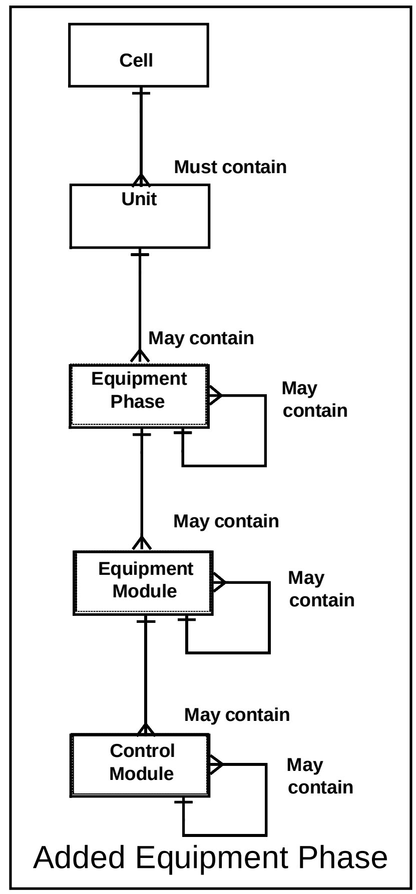
Equipment Phase are separated from the physical functions of the Equipment Modules with operators capable of taking control at any level.



Physical Model Fig. 5

In Equipment Centric systems, the separation between the Equipment Phase and the Equipment Module is total, with the Equipment Phase providing logical procedural functions that would be generally performed by the operators. The Equipment Modules are commanded by the higher level components (which include operators) and cause the physical process functions to be executed. The separation adds some increased complexity of interaction between the different components but provides many more options for the operators in the event of a system upset. The operators can also effectively direct the system to make product without the need of an automated procedure by directing the Equipment Modules through the required steps.

The lower levels of the S88.01 Physical Model refers to Process Cells, Units, Equipment Modules and Control Module. (See Fig. 5). In this model there is no reference to the Equipment Phase. Many assume that the Equipment Phase exists as part of an Equipment rather than an independent entity within the Unit. The S88.01 standard allows a large amount of user discretion as to how much automation occurs in each entity in the physical model and how the levels collapse or expand. With the modification to the physical model demonstrated in Fig. 6, it does become more understandable that it is possible to have this level of modularity.



Modified Physical Model Fig.6

In Procedure Centric manufacturing systems the operators generally aren't expected to take independent actions outside of the procedure and the directions of the Equipment Phase. If things do not go according to plan, the preferred point of interaction is with the procedures and the Equipment Phases. Only as a last resort does the operator take control of the process, and then it is at the control module level. This quite often leads to an automation implementation in which the Equipment Phase logic and Equipment Module Basic Control logic are combined into one entity, thus intermixing the procedural part of the Equipment Phase with the Basic physical control of the Equipment Module (as demonstrated in the simplistic example shown in Appendix B).

The Equipment Centric approach does require another layer to be added to the physical model for the Equipment Phase. (See Fig. 6). Many would argue that this is just another Equipment Module rather than a new entity called an Equipment Phase. While the standard does support this interpretation of Equipment Phases commanding Equipment Modules lower in the architecture, unless it is explicitly spelled out very few in the industry are open to this type of interpretation.

Unit Modes

Units within an Equipment Centric system generally have modes associated with them. The S88.01 standard has, as an example, three modes for the procedural elements as “Automatic, Semi-Automatic and Manual” with equipment entities having two modes as “Automatic and Manual”. While not explicitly prohibiting other modes of operation, the possibility of a Unit having a mode is not explicitly addressed. Example modes of a Unit in an Equipment Centric system are:

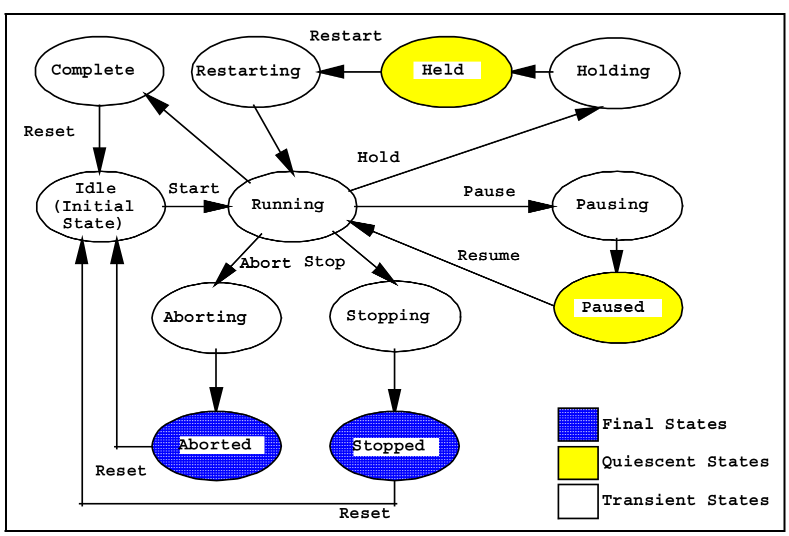
Unit Automatic - In this mode the procedure and Equipment Phases are in control of all activity within the unit. The procedure still has its own modes which control its actions. The procedure evaluates the recipe and provides instructions to the lower level elements through its interaction with the Equipment Phase.

Unit Semi-Auto - In this mode the procedure will stop processing any new instructions from the recipe. It will continue to carry out whatever was active before the Unit Semi-Auto mode became active. All Equipment Modules go to their designed safe state (paused if necessary) and no longer accept new instructions from Equipment Phases. Equipment Phases continue to monitor (and may react to) the state of the process, but do not command the lower level elements. The Equipment Modules are available to receive commands from operators. Generally, Control Modules will still only accept instructions from the Equipment Modules.

Unit Manual - In this mode the Control Modules all go to their designed safe state. The Control Modules no longer accept direct commands from the higher level elements and are available to receive commands from operators.

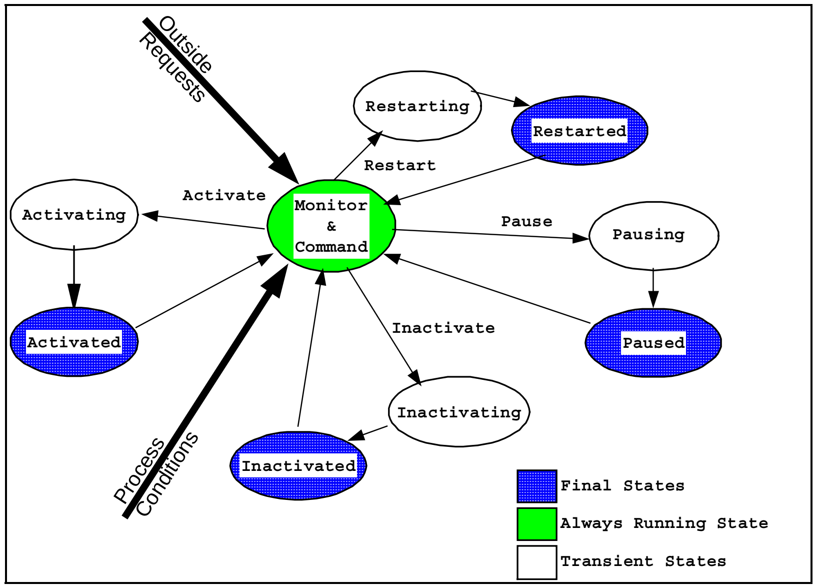
States

Another difference that exists between Procedure Centric and Equipment Centric systems are the “States” that exist with the different physical elements. The S88.01 standard has as an example the state diagram shown in Fig. 7. The standard uses this



S88.01 State Diagram Fig. 7

as an example and applies it to procedures and equipment entities. This works well for procedures and Equipment Phases which are discontinuous in nature and are truly idle most of the time waiting for the procedure to start them. In an Equipment Centric application many of the Equipment Modules have a need to be in some form of active state providing Basic Control all of the time. They will continuously monitor the process and will react to conditions as necessary and will accept commands from outside entities.(See Fig. 8)



Equipment Centric Equipment Module States Fig. 8

Advantages and Disadvantages

As with anything, there are pros and cons with Equipment Centric applications that must be weighed. Some will view the pros and cons in reverse depending upon their stance. What is a benefit to one, may be a detriment to another. This is why we have the multiple focuses on manufacturing techniques, no one solution meets everyone needs. Following are some views on Equipment Centric systems.

Enhanced Manual Operations - With the separation of the physical equipment operation from the logical operations of the Equipment Phase, almost all operators can quickly access the process actions in times of need and keep the process running. This requires that the operators have an accurate understanding of how the process should behave under all conditions. On any given shift, only one or two operators will have the skills necessary to effectively interact with the Procedure or the Equipment Phase, while there will be many operators that will be able to interact with the physical process through the Equipment Modules. In equipment centric systems everyone in manufacturing must know the equipment operations and what is required to carry them out. Only a few require the substantial extra training to be able to operate the automated Procedure Manager and Equipment Phases. This does mean that Manufacturing has faith in the ability and judgment of their operational work force. Also, in the event that an Equipment Phase has a “logic flaw”, Manufacturing operations must not be inhibited while the right resources are brought to bear on the issue. With the rate of change in some industries, this is a common occurrence and interruptions are not acceptable to Manufacturing.

Simpler Equipment Phases - With the ability to rely upon the operators to react to unforeseen or very rare abnormal conditions, the Equipment Phase does not have to be designed to react to all possible process conditions, just the ones that are generally expected. This allows for simpler designs. The fact that operator interaction with the Equipment Phase is rare enables the design to be even further simplified.

Expanded Engineering and Maintenance Resources - The number of people in the industry that are able to design, construct and support the Equipment Module functionality, as described for the Equipment Centric approach, is fairly large. The number of people in the industry with the capability to design and construct Equipment Phase level functionality which often intermixes elements of information management, and operational situations is much more limited. The people who can effectively intermix all of the different functional requirements in a single entity are a very rare commodity. With the separation of the Equipment Phase and the Equipment Module, those with the talents to do process automation can focus only on the physical operation of the equipment, while those with the talents to do procedural automation can focus on the Equipment Phase and the need to have the extremely rare individuals who can do it all is greatly reduced.

Added Complexity of Module Interaction - By separating the Equipment Phase and the Equipment Module an added layer of interaction is introduced. Depending upon the automation platforms, the burden of this layer will vary. Many of the tools that vendors supply for use with their automation platforms do not address this level of interaction. Almost all platforms in the industry can be used to perform this interaction, but some require much more effort on the part of the user than others. If it becomes too difficult, it may offset the other benefits.

In Conclusion

There are two distinct and different approaches to batch manufacturing. Equipment Centric and Procedural Centric. Each provides benefits for the customers it serves. The general industry supplying tools and techniques for use in batch automation has taken an approach in which the focus of control revolves around the procedure. While this is not explicitly dictated in the S88.01 standard, it is easy to see how it could be interpreted that way. This presents a challenge for companies whose manufacturing focus is on physical equipment in that they have to create many of the enabling tools that allow for effective automation. In the future as deeper understanding of these requirements becomes more widely understood there will be better tools.

Load Cell-Based Material Delivery Equipment Phase -

- Verify adequate amount of material to satisfy requirements - if not enough material inform operator and accept decision
- Acquire permission to utilize required common resources - if not available request assistance from operator
- Verify capacity of unit is adequate to receive material - if not inform operator.
- Request Tank Farm Equipment Module to set valve path for material and wait for successful path setup.
- Adjust amount of required material based on analytical information.
- Provide amount of required material to Material Delivery Equipment Module and request Delivery.
- Wait for delivery to complete.
- Evaluate the amount of material delivered against recipe tolerance - if outside of tolerance inform operator and wait for instructions
- Inform procedure manager of the completion of this operation.

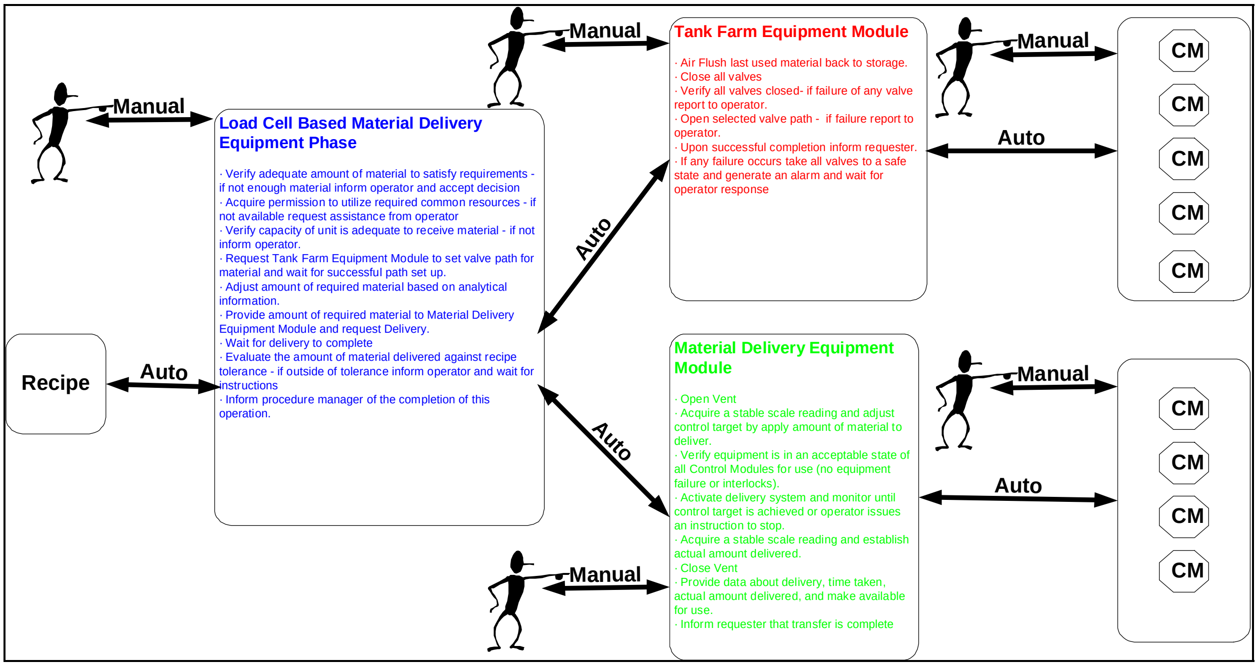
Tank Farm Equipment Module

- Air Flush last used material back to storage.
- Request all valves to close.
- Verify all valves closed - if failure of any valve report to operator.
- Open selected valve path - if failure report to operator.
- Upon successful completion inform requester.
- If any failure occurs take all valves to a safe state, generate an alarm and wait for operator response.

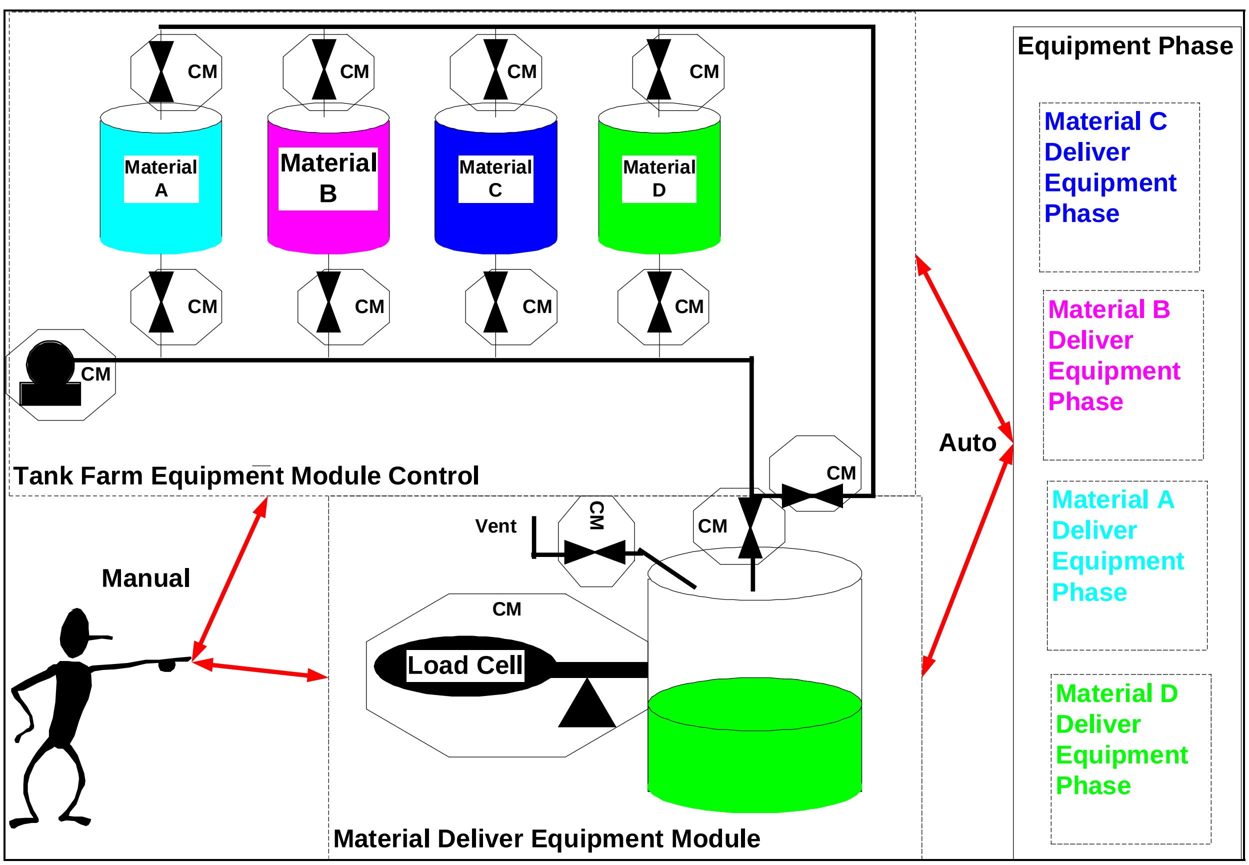
Material Delivery Equipment Module -

- Request Vent to Open.
- Acquire a stable scale reading and adjust control target by applying amount of material to deliver.
- Verify equipment is in an acceptable state of all Control Modules for use (no equipment failure or interlocks).
- Activate delivery system and monitor until control target is achieved or operator issues an instruction to stop.
- Acquire a stable scale reading and establish actual amount delivered.
- Request Vent to Close.
- Provide data about delivery, time taken, actual amount delivered, and make available for use.
- Inform requester that transfer is complete.

If any failure occurs take all valves to a safe state, generate an alarm and wait for operator response.



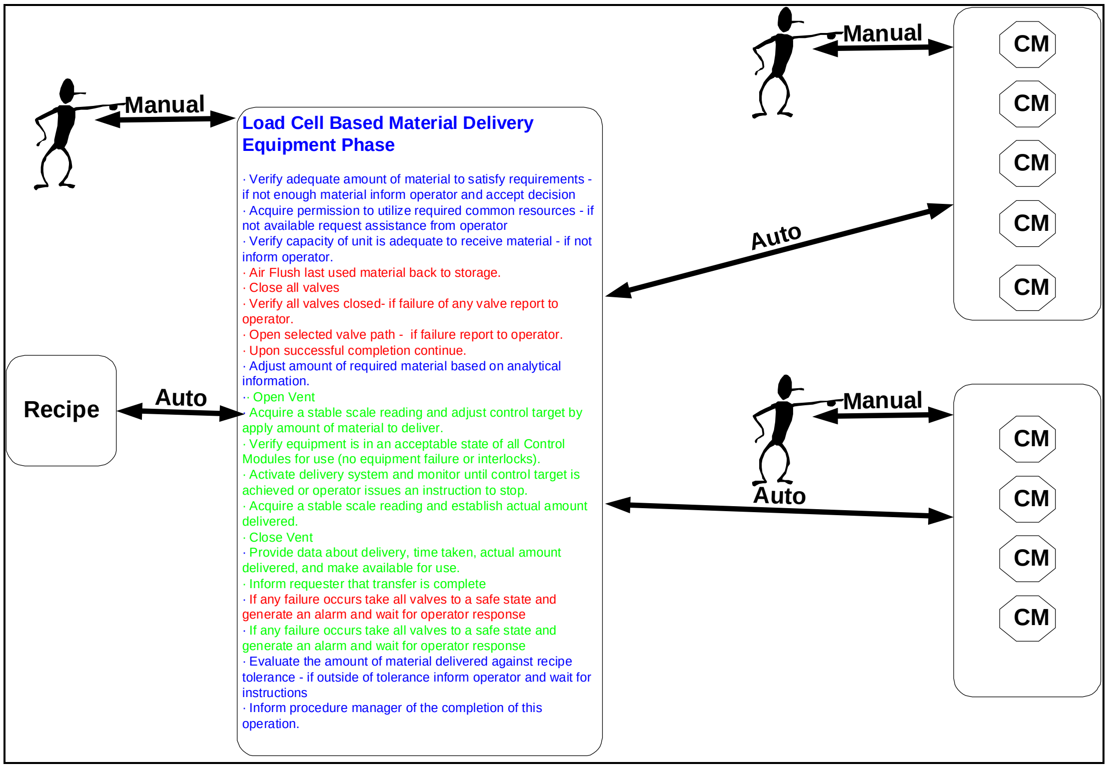
"Equipment Centric Process Control Entities" Fig.



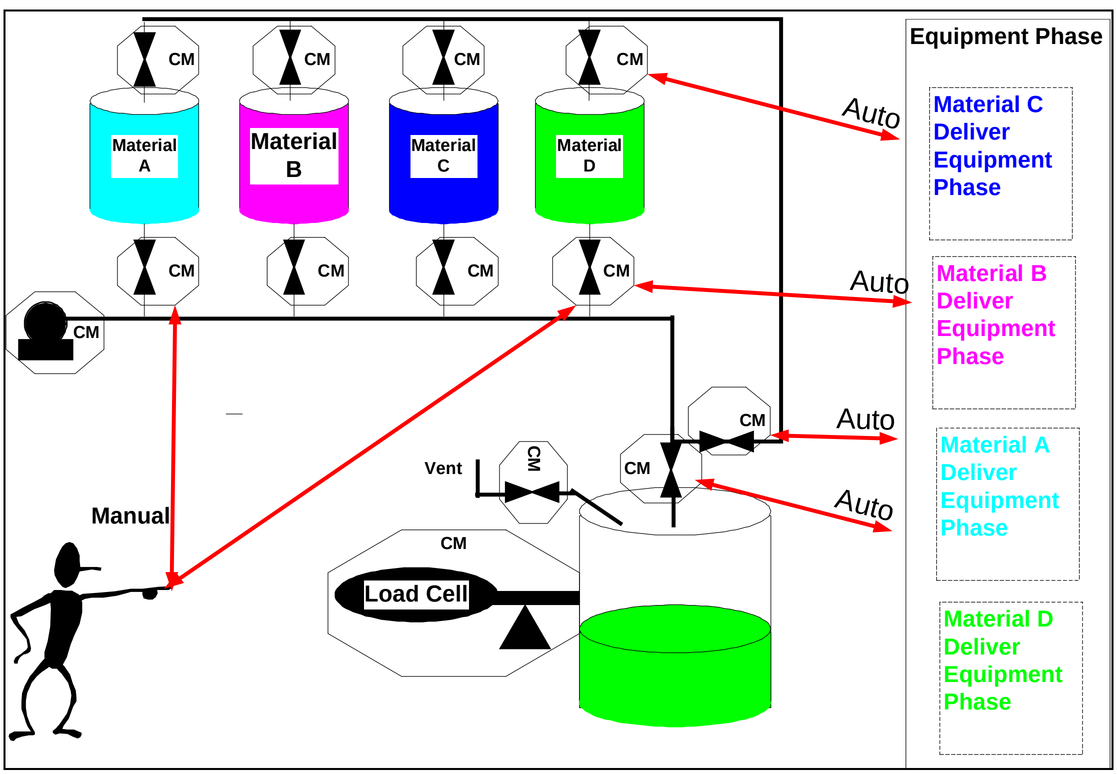
Simplified Equipment Centric Example Fig.

Load Cell Based Material Delivery Equipment Phase/Module -

- Verify adequate amount of material to satisfy requirements - if not enough material inform operator and accept decision
- Acquire permission to utilize required common resources - if not available request assistance from operator.
- Verify capacity of unit is adequate to receive material - if not inform operator.
- Air Flush last used material back to storage.
- Close all tank farm valves.
- Verify all valves closed - if failure of any valve report to operator.
- Open selected valve path - if failure report to operator.
- Upon successful completion continue.
- Adjust amount of required material based on analytical information.
- Open Vent.
- Acquire a stable scale reading and adjust control target by applying amount of material to deliver.
- Verify equipment is in an acceptable state for all Control Modules for use (no equipment failure or interlocks).
- Activate delivery system and monitor until control target is achieved or operator issues an instruction to stop.
- Acquire a stable scale reading and establish actual amount delivered.
- Close Vent.
- Provide data about delivery, time taken, actual amount delivered, and make available for use.
- Inform requester that transfer is complete
- If any tank farm failure occurs take all tank farm valves to a safe state and generate an alarm and wait for operator response
- If any feed failure occurs take all feed valves to a safe state and generate an alarm and wait for operator response.
- Evaluate the amount of material delivered against recipe tolerance - if outside of tolerance inform operator and wait for instructions.
- Inform procedure manager of the completion of this operation.



Procedure Centric Process Control Entities" Fig



Simplified Procedure Centric Example Fig.