3 Sequential Control

A control system in which the individual steps are processed in a predetermined order, progression from one sequence step to the next being dependent on defined conditions being satisfied. Such a system may be time-dependent, in which the step transition conditions are functions of time only; on external-event dependent, where the conditions are functions of Input signals or combinations of these conditions.

Object has finite numbers of states: lift, Clean-in-Place (CIP) processes (is a method of cleaning the interior surfaces of pipes, vessels, process equipment, filters and associated fittings, without disassembly), assembly line process, conveyor systems, robots, power protection systems, motor starting and control.

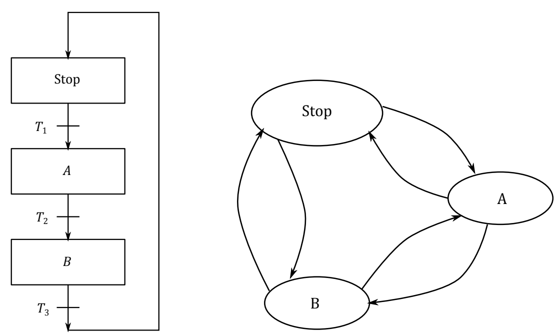


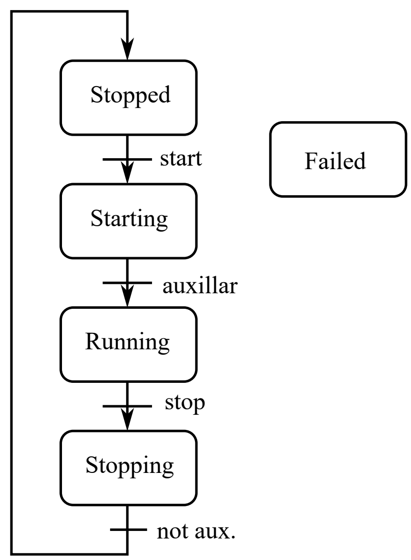
Figure 1.1: State and Data-flow diagrams

State diagram: states (initial state), transactions, conditions.
Can be presented as table, graph, Petri net.

Table 1.1: Comparison of the Control Techniques

Process control	Sequential
Feedback is continuous.	Status I/O typically bi-level in nature.
Controller could be implemented with analog or digital control methods.	ON-OFF control.

State based control - states are fixed and clear transactions.



Possible states of the controlled process/ equipment

- Final states: stopped, running
- Transition states: starting, stopping
- Failure states
- Intermediate states: waiting, maintenance, cleaning, loading, etc.

3.1 Structure

Handler - the execution engine for a Sequential Control Module (SCM). There are Main handlers and Exception handlers.

Step block - executes output expressions that change process parameters and/or provide instructions to the operator.

Transition block - waits for specific process conditions to be true. When the logical statement formed by a transition's conditions and logic gates is true, the SCM executes the next step or synchronization block.

Synchronization block - enables the SCM to execute parallel paths contained within the handler.

Structure of the program - steps: A, B, C. Each state is either active or passive. Only one state is active at a time. The state machine always starts in a particular state defined as the initial state, and it ends (stops) after the final state. Special symbols or colors may be used for the initial state and the final state [1].

If no interrupt or abnormal conditions occur, a handler executes transitions, steps, and phases in sequential order until reaching the end of the module's program where the module is either completed or returned to start. Execution can be interrupted by predetermined conditions that can interrupt, stop, hold, or abort the SCM.

Every SCM must have at least one main handler, but it can have multiple main handlers and optional exception handlers. While only one handler can be actively executing, exception handlers

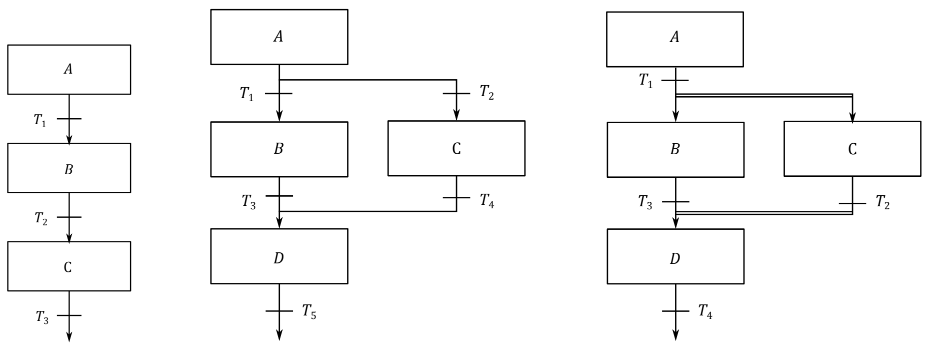


Figure 1.2: Sequence types: Sequence, Choice and Parallel actions

can be waiting for specified process conditions. When the specified process condition occurs, the Main Handler's process actions cease execution and the exception handler (Abort, Stop, Hold, and Interrupt) begins its ordered set of process actions (see Fig. 1.3).

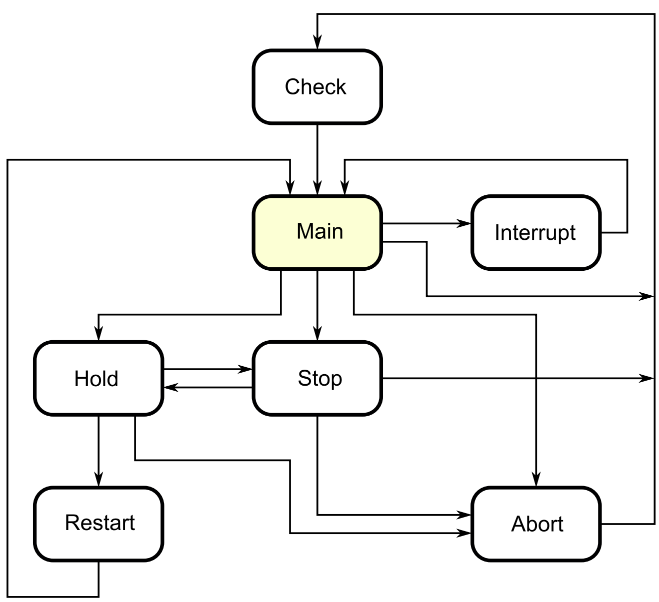


Figure 1.3: Configurable Handlers categories

A Handler must have exactly one Invoke Transition which allows to specify logical conditions for invocation of the handler and specifies the first step of the handler.

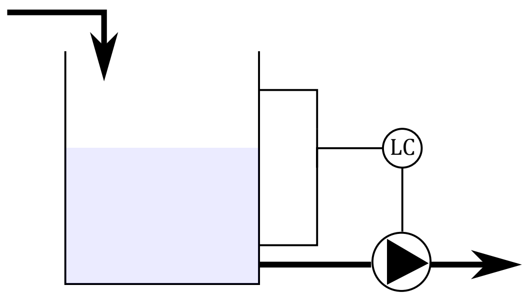
Handlers are prioritized from Main to Abort. Main is the lowest priority; Abort has the highest priority. If the Main handler is active and the Hold conditions become true, the Hold handler becomes the active handler. If at the same instance, conditions for the Abort handler become true, the Abort handler becomes the active handler.

Main Handler contains the primary sequential activities of the process. Multiple Main handlers may be configured, but only one will be selected for execution at any given time.

Check Handler is a normal exception handler which can be configured to initialize process equipment and/or reset values in order to setup and verify the base conditions required for the SCM to execute properly. No other handler is enabled when the Check Handler is executing.

Stop Handler is an abnormal exception handler that preempts the activity of the Main, Interrupt, Restart, or Hold. Stop Handler is designed to guide process to fail-safe state. [1].

Example 1 *Two positional level control*



Possible states:

- *Final states: stopped, running*
- *Transition states: starting, stopping*

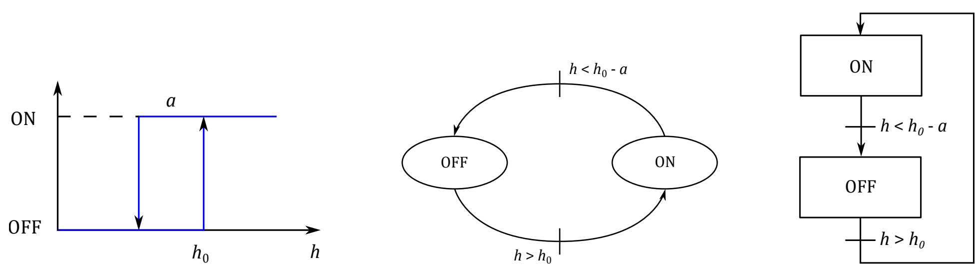


Figure 1.4: Pump On-OFF Control

Example 2 *Two positional level control with additional pump*

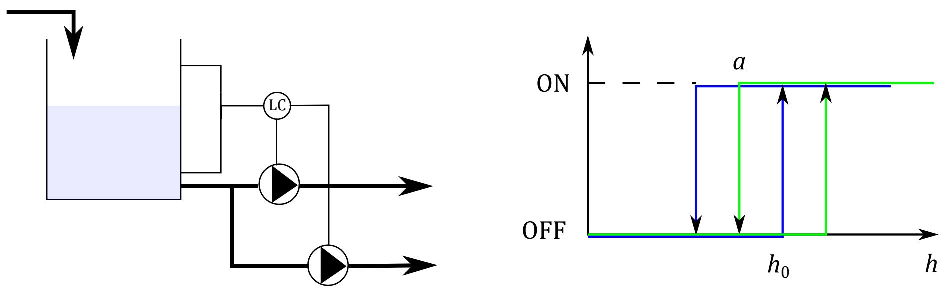


Figure 1.5: Two pumps control

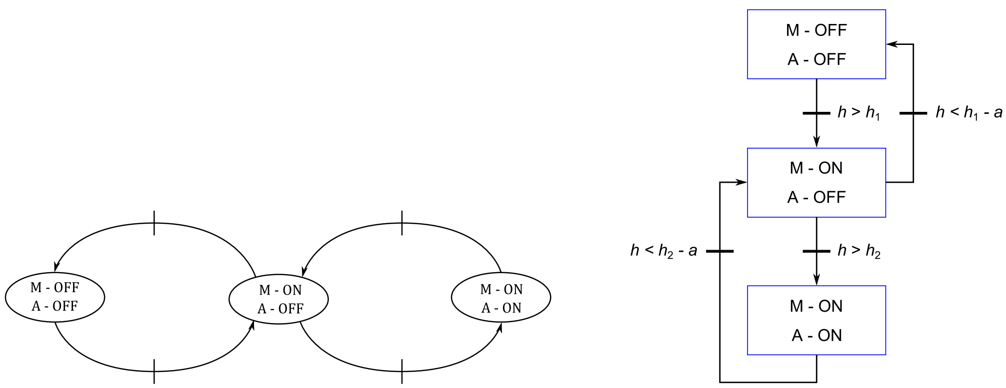


Figure 1.6: Control diagrams

4 Batch Control

Produce: with the required quantity, quality, safely, within a short period, min. pollution, etc.

Production is either continuous (electricity), discrete (car), or batch.

Earlier any production took place by portions and was a handmade

- brewing /4000 years old!/
- cooking
- (gun)powder, steel, soap, etc.

Modern examples of batch processes are

- washing machine work, concrete production, bread making
- varnishes, paints, biotechnology, pharmaceutical

Each process has a beginning, end (start, stop) and a life-cycle.

Batch processes consists of a discontinuous flow of raw and processed materials. The raw materials are the ingredients; each one is typically introduced sequentially into the process in a prescribed order and in a prescribed amount.

The batch production allows you to:

1. Change the production number, characteristics, qualities,
2. Process can be monitored, studied, corrected, repeated, etc.

Features of the batch processes:

- The volume is limited and varies;
- Loading components are kept with ratio A:B:C;
- Controlled from beginning to the end, changes are large, complex;
- Process dynamics depends on the quantity, components, here is no equilibrium point ($SP \neq const$), limitations of signals, time constants can change (up to $\times 10$), nonlinearity;
- Control of the completion (quality or composition of the product);
- Preparation errors can cause damage of the product or devices.

Batch control projects have traditionally been among the most difficult and complex to implement. Typically, batch control projects span over a wider scope of functionality than that required for either continuous or discrete manufacturing processes.

With batch processes a certain amount of product is produced:

- Specified material (recipe)
- Fixed sequence of operations (procedure)
- with one ore several devices

Equipment control design should be understood by all parts (management, technologists, staff, etc.).

Batch processing has its own standards

- ISA standard S88
- IEC61512

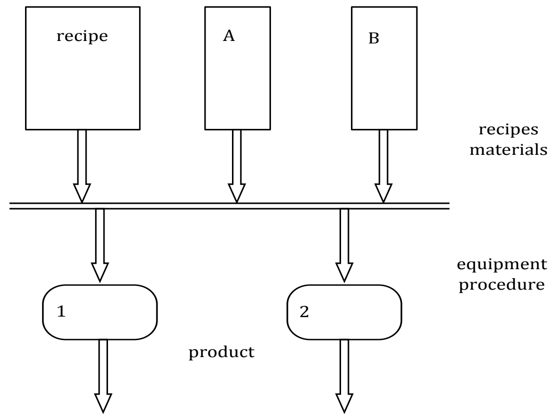


Figure 1.7: Batch process

Recipes	choice of the product	"What"
Processes	choice of the procedure	"How"
Equipment	choice of the devices	"Using what"

- The product is separated from the devices.
- Various products manufactured on the same equipment.
- Changes in the product does not affect the other products.

Recipe—necessary set of information that uniquely defines the production requirements for a specific product. Types of the recipe are: General, Site, Master and Control.

A recipe contains administrative information, formula information, requirements on the equipment needed, and the procedure that defines how the recipe should be produced. The procedure is organized according to the procedural control model .

4.1 Physical Model

Asset Hierarchy is a concept in Enterprise Model to define the containment-based hierarchical model of equipment entities and unit equipment.

Master recipe—a type of recipe that accounts for equipment capabilities and may include process cell specific information.

Unit—a collection of associated control/equipment modules in which major processing activities can be conducted.

Units are supposed to to operate on only one batch at a time. And those operate relatively independently of one another.

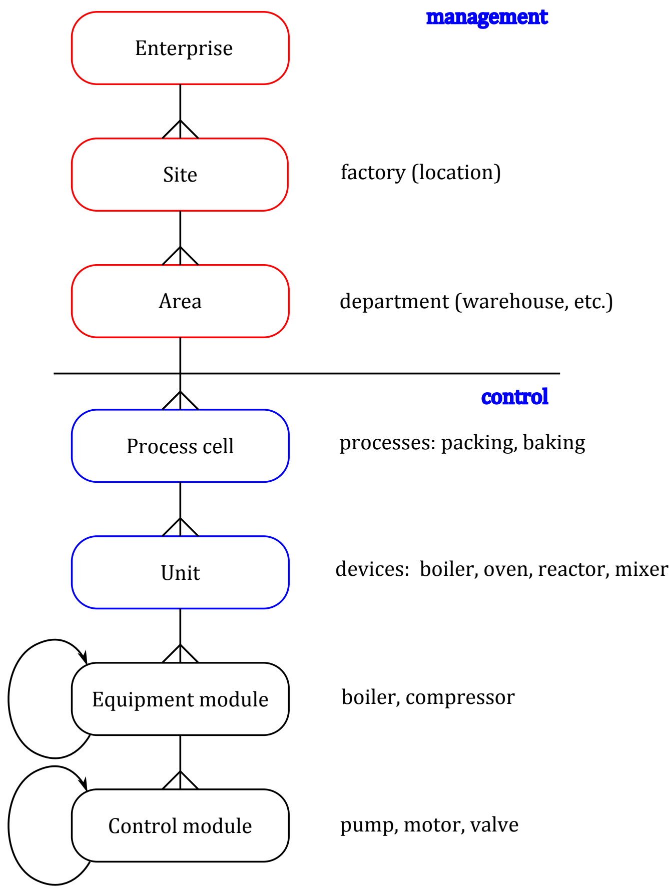
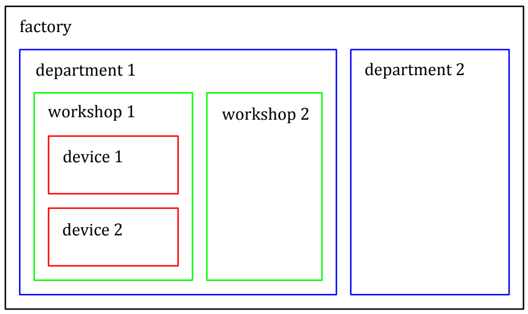
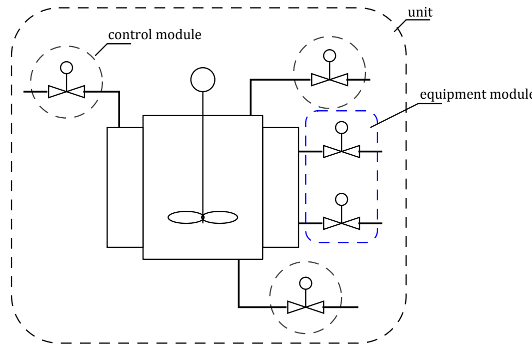


Figure 1.8: Physical Model

Physical Model—assets. A model representing the Physical Equipment upon which the control strategies are executed. This model defined to the level of granularity needed to support aspects of Modular Batch Automation that support the definition of control strategies at a logical functional level for subsequent execution against the defined Assets.





Process Model

Process Model—describes actions where the product changes.

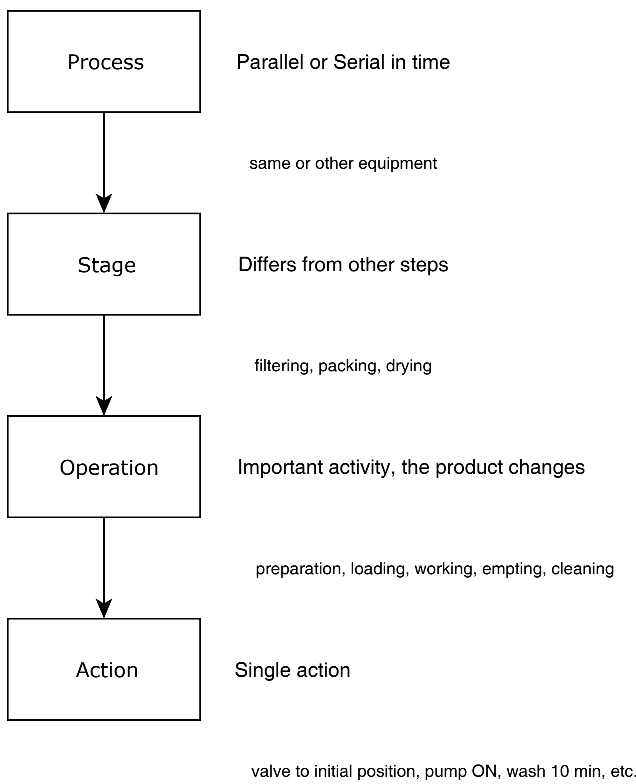


Figure 1.9: Process Model

In the process model, the procedure for making a product does not consider the actual equipment for performing the different process steps.

Control Model or Procedural Control

Procedural Control—Control that directs equipment-oriented actions to take place in an ordered sequence to carry out some process-oriented task.

There are four procedural elements in the procedural control model: procedure, unit procedure, operation, and phase. They are a means for splitting a complex problem into reusable modules with increasing amounts of detail [2].

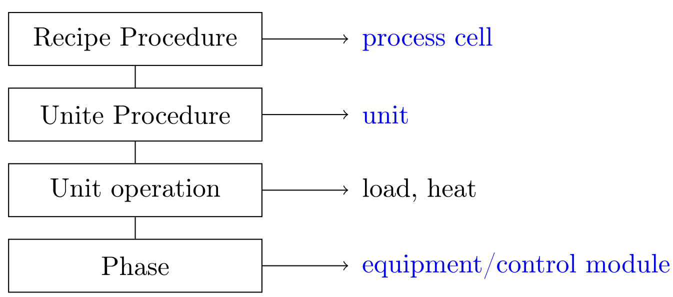


Figure 1.10: Recipe Model Hierarchy

Equipment unit procedure

Module (unit) work is described by some operating state, at time instance unit has some state.

Recipe

The layered recipe function lets you build recipes in layers to support the S88 recipe hierarchy shown in the previous Fig. 1.10. In this hierarchy, a higher level recipe can control its underlying recipe(s). Recipes at each layer are implemented as a modular function block. Recipe Control Module (RCM) blocks can represent Procedures, Unit Procedures, and Operations.

Sequential Control Module (SCM) blocks can represent Phases.Phase blocks allow to link layers together to form layered recipes (see Fig. 1.13). Phases are implemented as SCMs, which coordinate device control.

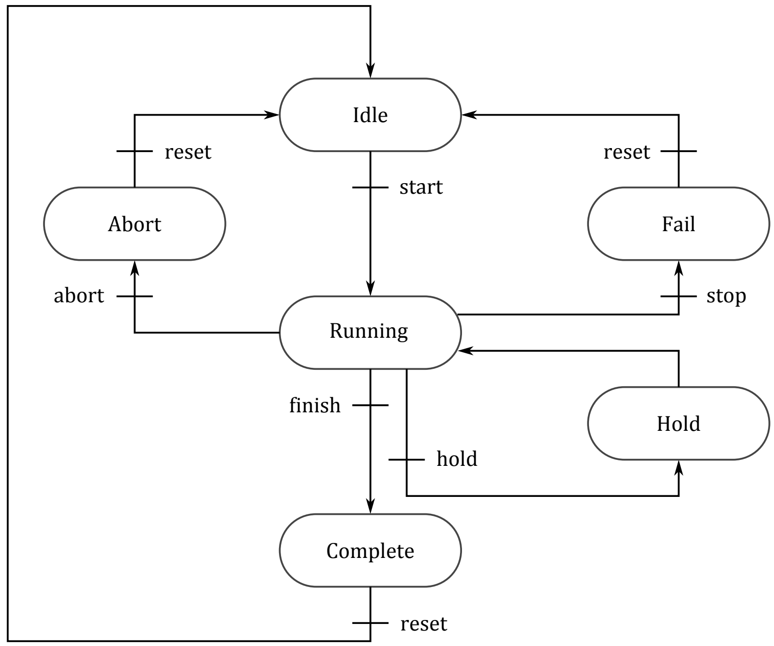


Figure 1.11: Equipment unit procedure

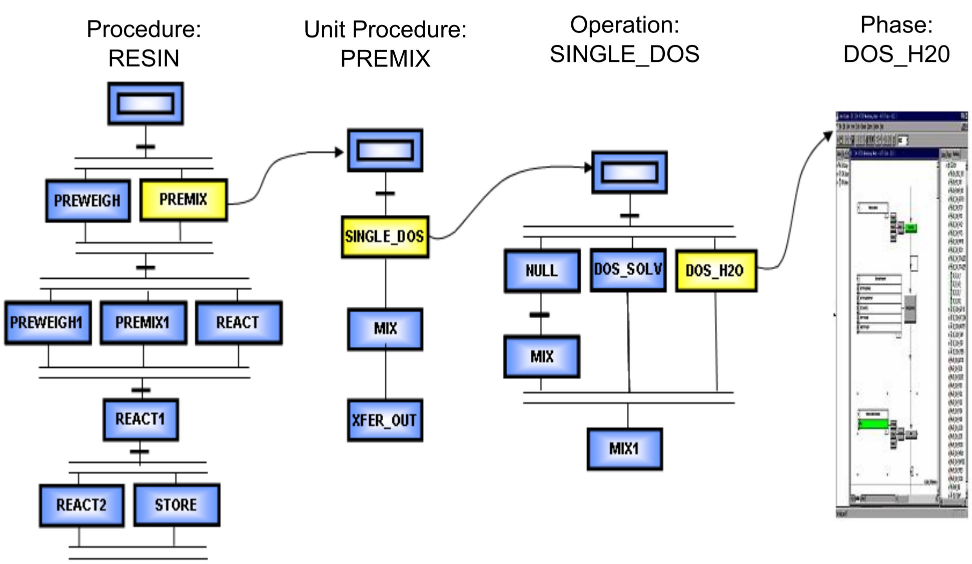


Figure 1.13: S88 recipe hierarchy

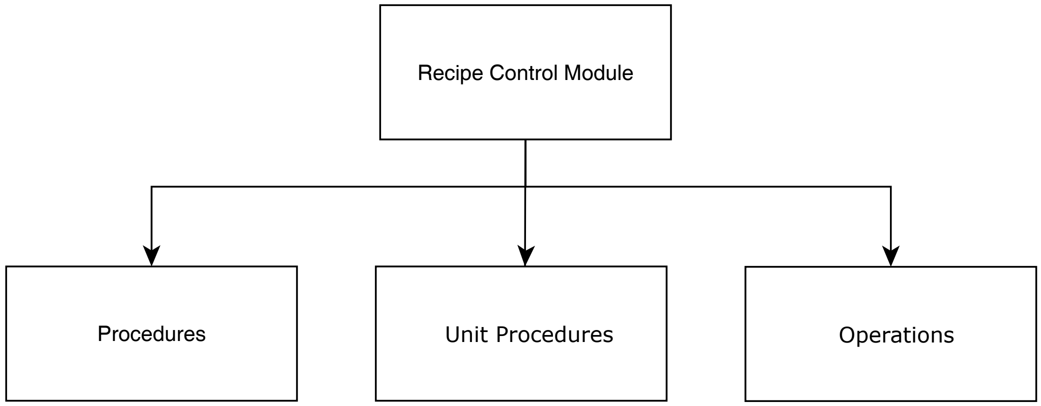


Figure 1.12: RCM

The Recipe Control Model (RCM) runs procedural operations that initiate the execution of one or more SCM or RCM in series, parallel, or combination of both.

The RCMs and SCMs at each layer manage their own execution. At run time, the upper level module commands its child (children) through Phase block(s). Phase block monitors the execution of its linked RCM/SCM and projects the key parameters, State, Execution Status, Mode, and Mode Attribute to the parent recipe.

Unit Control Module

The Unit Control Module (UCM) is a container that represents a piece of or logical grouping of physical equipment.

Table 1.2: Comparison of Unit Control Module and Control Module

	UCM	CM
Manages resources arbitration	+	if configured
Has associated RMCs	+	-
Represents	equipment	device
Contains executable basic function blocks	-	+
Monitors SCM's state	-	+

The UCM Identifies the current running RCM. Multiple RCMs can be queued to a single UCM, but only one RCM can run against an UCM at a time. UCM does not have a containment relationship with the RCMs that are associated with it.

The UCM maintains an arbitration list that holds the tag names of all the RCMs that are

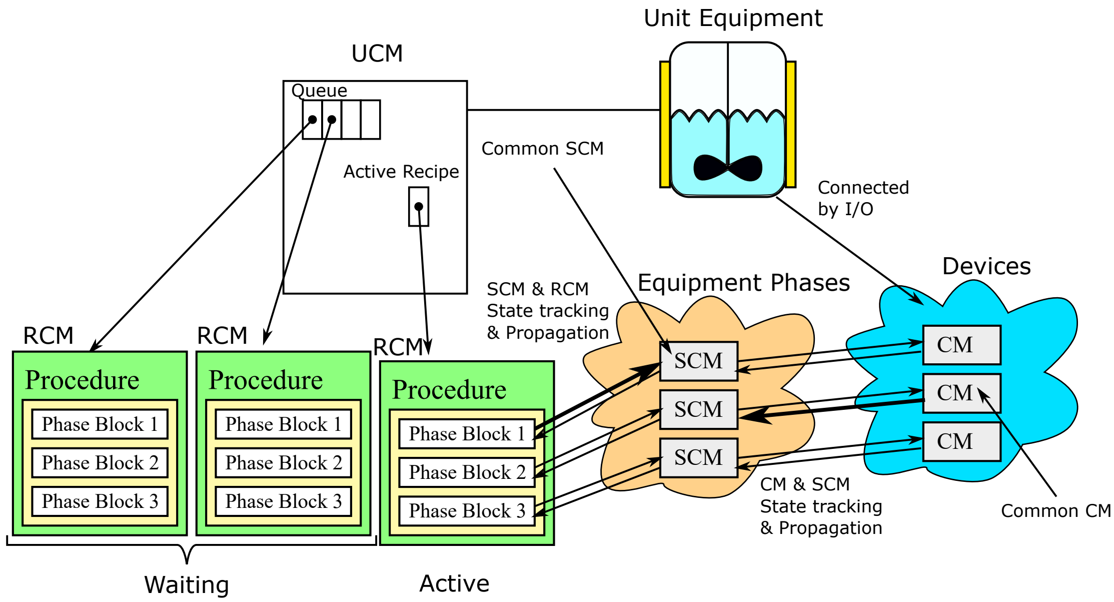


Figure 1.14: Relationship between UCM, Equipment, and RCM

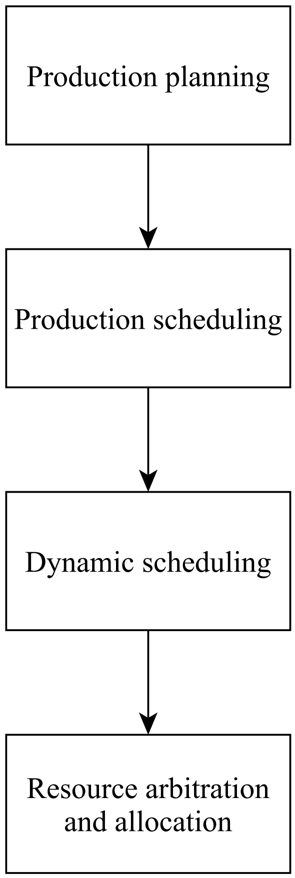
currently waiting for the UCM for their procedure execution. When the current RCM is completed, the first one on the list will be started automatically (See Fig. 1.14).

A system without resource conflicts (all requesters can get their resources immediately all the time) will work the same all the time (no-conflict system).

A system with at least one case of multiple conflicts for at least one resource may exhibit a different behavior in the same situation, depending on the size of the queue of the resource, where the multiple conflicts occur.

A batch process is neither continuous nor discrete, yet it has characteristics from both. A batch cell can be made highly flexible, both with respect to the number of different products it can produce and with respect to the structure of the plant. The multi-product, network-structured batch cell is the most flexible but also the most difficult type of plant to control. The recent batch control standard ISA - S88.01, formally defines the terminology, models and functionality of batch control systems [3].

In Batch Control systems the software is usually structured according to the physical model. Thus devices like valves, motors, PID controllers will become Control Modules. These will in turn be controlled by equipment modules, which in turn belong to units (although some equipment modules could be stand-alone). Usually this will be achieved by structuring the software into a hierarchical folder structure. In terms of writing functional requirements and design specifications, those documents would be structured using the same idea: Divide the physical plant into units, equipment modules and control modules. The equipment modules would be further divided into phases which each have parameters that determine their behavior.



At the Production Planning level, scheduling is used to assign product orders to the various manufacturing plants. At this planning level, the horizon may be measured in weeks or month.

The order is sent to the Production Scheduling system in a plant. Production demands are checked and it is determined how much raw material that needs to be ordered. A master recipe is created. At the production scheduler is run once a day or once a week.

At the Dynamic Scheduling level, it is necessary that the schedule more closely approximates real-time. A detailed schedule based on the specific resources and requirements of the batch production system is generated. At the dynamic scheduling level horizon is measured in shifts, hours or minutes.

The Resource Arbitration System resource arbitration system prevents a piece of equipment from being used by more than one user at a time. The resource arbitration system comes into play when it is necessary to decide which product is the most deserving of access to a shared resource that is being allocated by two resources at the same time.

Different scheduling techniques exist; linear programming, material requirement planning, simulation, expert systems. However, most batch plants are still scheduled using human made schedules [3].

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[1] Honeywell Process Solutions, *Sequential Control: User's Guide*, 2014.

[2] B. Hawkins. (2012) Organizing batch process control. [Accessed: April, 2018]. [Online]. Available: https://www.isa.org/standards-and-publications/isa-publications/intech-magazine/2012/june/automation-basics-organizing-batch-process-control/

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