Lecture 3

Batch Production Processes

Introduction

In a batch production process the product is made in batches or lots. Batch processing typically involves assembly-based processing using fluids and dry materials. 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. This is the recipe.

An example of a batch production process is seen in Figure 1. Examples of typical batch processes are; fine chemicals, biotechnology, beverage, and pharmaceutical.

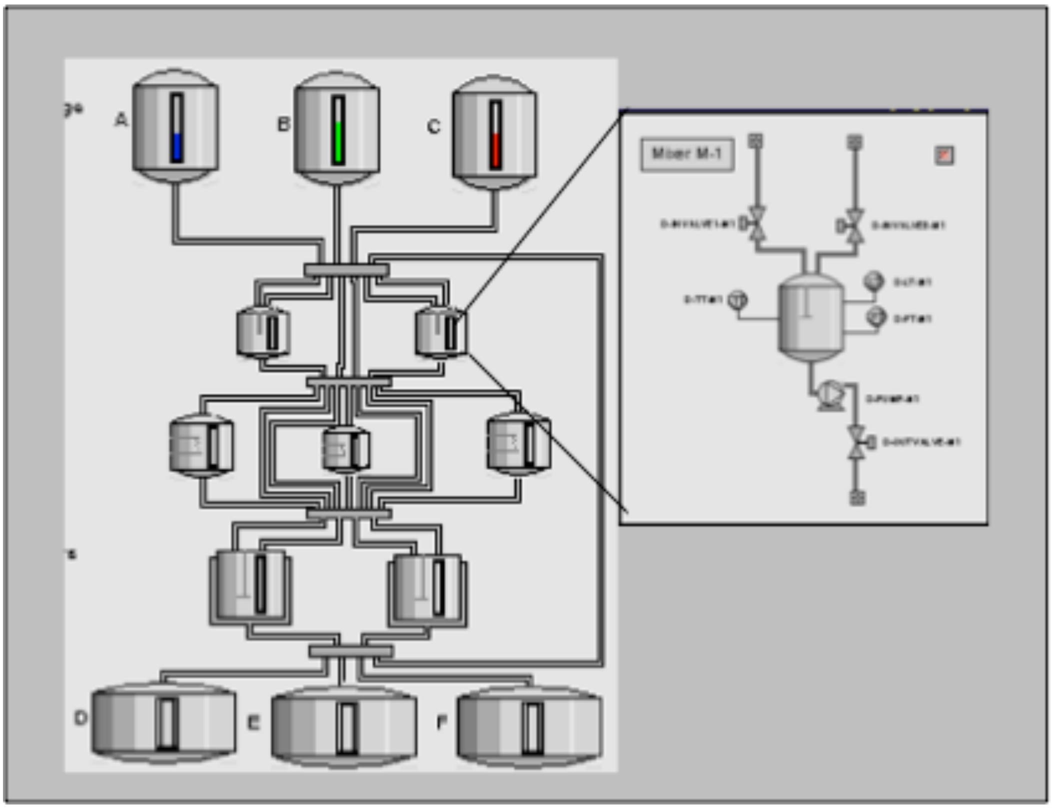

Figure 1: An example of a batch process.

There are a number of characteristics typical to batch processes:

- Production of products in batches
- Discontinuous flow of materials.
- Production run determined by time/end point.
- Production goes through steps of operations.
- Fluid and dry processing.

An example of a batch process taken from our daily life is the preparation of a cake. The work can be divided into three major tasks: preparation, baking, cooling and storing. The three tasks can be broken down into a sequence of sub-steps. The steps in each task should be done in a proper order to make a good cake. If not done in this way, the cake might not be very tasty and, as explained below, do not adhere to the formal definition of a batch process.

A formal definition of batch process is given by:
" A process is considered to be batch in nature if, due to physical structuring of the process equipment or due to other factors, the process consists of a sequences of one or more steps that must be performed in a defined order. The completion of this sequence of steps creates a finite quantity of finished product. If more of the product is to be created, the sequence must be repeated."

Another definition is given by:
"A batch process is a process that leads to the production of finite quantities of material by subjecting quantities of input materials to an ordered set of processing activities over a finite period of time using one or more pieces of equipment."

Control of Batch Processes

Continuous processes have been used to produce many products that were originally produced by batch processes. One reason for this is that batch processes have typically been labor intensive and experienced operators have been required to produce batch products with consistent quality. Since continuous plants were those that produced the largest volume of products this is where most of the research and development money were spent. However, increasing demands on flexibility and customer-driven production has led to an increased interest in batch processes. This is because batch processes are more economical for small scale production, as fewer pieces of process equipment are needed, and intermediate storage are not very expensive. Batch plants can also be made highly flexible, and thereby well suited for manufacturing of special products. For example, high quality malt whisky is produced in batch processes, whereas grain liquor, the basis for blended whisky, is produced in continuous processes.

There are also processes that are not easily amenable to continuous operations. Some examples are:

- Processes with feedstock and/or products that cannot be handled efficiently in a continuous fashion, such as solids and highly viscous materials.
- Processes in which the reactions are slow, requiring the reactants to be held in process vessels for a long time (e.g. fermentation of beer and wine).
- Processes in which only small quantities of products and/or different grades of the same product are required in limited quantities (e.g. dyestuff and specialty chemicals).
- Processes that need precise control of raw materials and production along with detailed historical documentation (e.g. drug manufacturing).

Typically, batch plants are used to manufacture a large number of products. Within each product a number of different grades often exist.

Batch processes can be classified by: (1) the number of products they can make and (2) the structure of the plant.

- A batch process can be single-product, multi-grade or multi-product. A single product batch plant produces the same product in each batch, e.g., a batch pulp digester. The same operations are performed on each batch and the same amount of raw materials is used. A multi-grade batch plant produces products that are similar but not identical. The same operations are performed on each batch but the quantities of raw materials and/or processing conditions such as, e.g., temperatures, may vary with each batch. The multi-product batch plant produces products utilizing different methods of production or control. The operations performed, the amount of raw materials and the processing conditions may vary with each batch.
- The basic types of batch structures are series (single-stream), parallel (multi-stream) and a combination of the two. A series structure is a group of units through which the batch passes sequentially. If the plant has several serial groups of units placed in parallel but without interaction the plant has a parallel structure. If interactions exist between the parallel branches, a series/parallel structure is achieved. Other names for the series, parallel and series/parallel structures are single-path, multi-path and network-structure.

The batch plant classification by product and by structure can be combined in a matrix to show the degree of difficulty in automating the various combinations. The single-product, single-path batch plant is the simplest, whereas the multi-product, network structure combination is the most demanding.

Control of Batch Processes

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 continuous and discrete processes, a reasonable level of automation can be attained merely by implementing basic regulatory or logic control. Batch operations typically require basic regulatory and logic control operating under sequential control; which in turn, is operating under basic recipe management in order to achieve process automation. The complexity of control within a process cell depends on the equipment available within the process cell, the interconnectivity among this equipment, the degree of freedom of movements of batches through this equipment, and the arbitration of the use of this equipment so that the equipment can be used most effectively.

The discussion about batch control systems and the progress in batch process control has been hampered by the lack of a standard terminology. In the last years, there have been three major initiatives with the aim to provide a common language. The first major effort was an outgrowth of a Purdue University workshop on batch control in the mid-1980s. The second was made by NAMUR. The third major effort is sponsored by the Standards and Practices division of ISA (International Society of Automation), the International Society for Measurement and Control. The standard is divided into two parts, Part1, called S88.01 deals with models, terminology and functionality. This part of the standard was approved by the main committee of ISA and ANSI in 1995. Part2 will deal with data structures and language guidelines. The ISA S88 standard has been accepted as an international IEC (International Electro-technical Commission) standard IEC 61512-1.

ISA88: a standard for Batch Control

The first part of the ISA S88 standard describes batch control from two different viewpoints: the process view and the equipment view see Figure 2. The process view is represented by the process model and is normally the view of the chemists. The equipment view is represented by the physical model and is normally the view of the product engineer or the process operator.

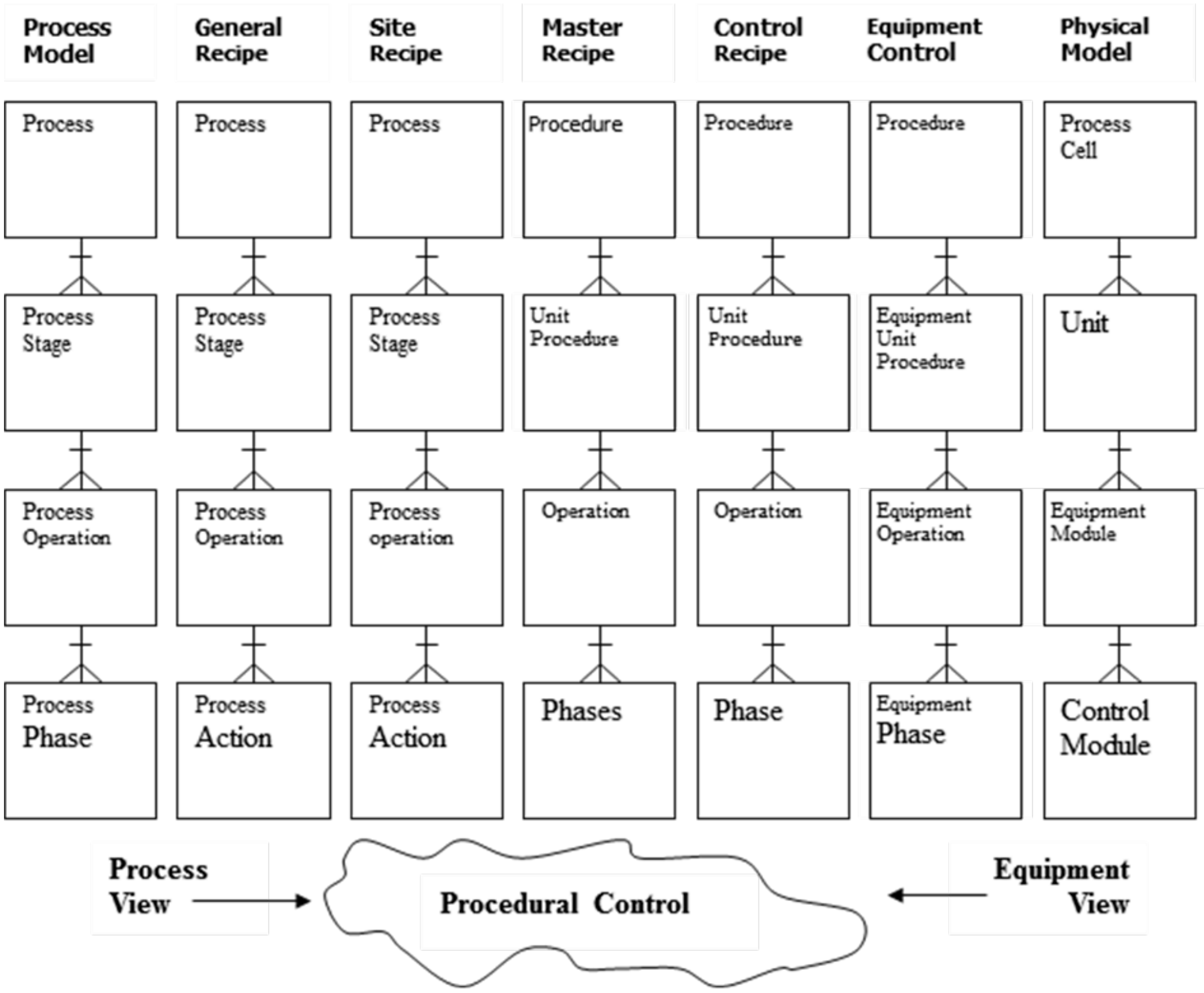

Figure 2: The process view and the equipment view

Process Model

A batch process can be hierarchically subdivided as shown in Figure 2 (left).

- The process consists of an ordered set, serial and/or parallel, of process stages. A process stage is a part of a process that usually operates independently from other process stages. It usually results in a planned sequence of chemical or physical changes in the material being processed. Typical process stages can be, e.g., drying or polymerizations.

- Each process stage consists of an ordered set of one or more process operations. Process operations describe major processing activities. It usually results in chemical or physical change in the material being processed. A typical process operation is, e.g., react.
- Each process operation can be subdivided into an ordered set of one or more process actions that carry out the processing required by the process operation. Process actions describe minor processing activities that are combined to make up a process operation, Typical process actions are, e.g., add reactant, and hold.

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

Physical Model

The physical model of S88 defines the hierarchical relationships between the physical assets involved in batch manufacturing. The model has seven levels, starting at the top with an enterprise, a site and an area. In Figure 2 (right) only the four lower levels are shown, with the following interpretation:

- A process cell contains one or more units.
- A unit can carry out one or more major processing activities such as react, crystallize or make a solution. Units operate relatively independently of each other. A unit is made up of equipment modules and control modules.
- An equipment module can carry out a finite number of minor processing activities like weighting and dosing. It combines all necessary physical processing and control equipment required to perform those activities. Physically, an equipment module may be made up of control modules and subordinate equipment modules. An equipment module may be part of a unit or may be a stand-alone equipment grouping within a process cell. It may be an exclusive use resource or a shared resource.
- A control module is typically a collection of sensors, actuators or controllers. Physically, a control module can be made up of other control modules.

Recipes

To actually manufacture a batch in a process cell the standard proposes a gradually refinement of the process model based on four recipe types; general recipe, site recipe, master recipe and control recipe. 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.

- General recipe: The general recipe is an enterprise level recipe that serves as a basis for the other recipes. The general recipe is created without specific knowledge of the process cell equipment that will be used to manufacture the product.
- Site recipe: The site recipe is specific to a particular site. The language in which it is written, the units of measurements, and the raw materials are adjusted to the site.
- Master recipe: The master recipe is targeted to a specific process cell. A master recipe is either derived from a general recipe or created as a stand-alone entity

by people that have all the information that otherwise would have been included in the general or the site recipe.

- Control recipe: The control recipe is originally a copy of the master recipe which has been completed and/or modified with scheduling, operational and equipment information. A control recipe can be viewed as an instantiation of a master recipe.

The four recipes are gradually refined to the stage where all necessary aspects for the execution of the recipe on a certain type of equipment are taken into account. The general and site recipes are equipment independent whereas the master and control recipes are equipment dependent. In order to distinguish between equipment independent and equipment dependent process steps different terminology is used. The terms Procedure, Unit Procedure, Operation, and Phase are introduced for the equipment dependent process steps, see Figure 2.

Procedural Control

The four recipe levels together with the equipment control constitute the link between the process model and the physical model, denoted procedural control, see Figure 3. Procedural control is characteristic for batch processes. It directs equipment-oriented actions to take place in an ordered sequence in order to carry out a process-oriented task.

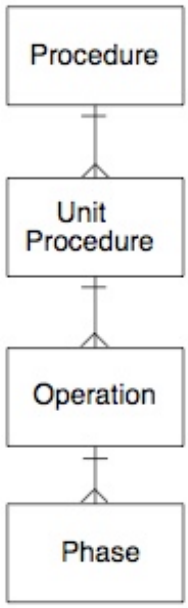

Figure 3: The four recipe levels

The procedural structure is hierarchical, see Figure 3. A procedure can gradually be broken down into smaller parts.

- The procedure is the highest level in the hierarchy and defines the strategy for accomplishing a major processing action such as making a batch. It is defined in terms of unit procedures, and/or operations, and/or phases. An example of a procedure is "Make a batch of product A".

- A unit procedure defines a set of related operations that causes a production sequence to take place within a unit. Examples of unit procedures are, e.g., polymerize, recover or dry. A unit procedure must be executed within a single unit process.
- An operation is a sequence of phases that defines a major processing sequence that takes the material being processed from one state to another. An operation usually involves a chemical or physical change. Examples of operations are, e.g., reaction and preparation.
- The smallest element that can accomplish a process oriented task is a phase. It defines a product independent processing sequence. A phase may be decomposed into steps and transitions according to Grafcet/SFC. Examples of phases are, e.g., add catalyst.

The IEC 1131-3 standard, which was published in 1993, specifies programming languages for controllers. This standard fills an important void since part1 of ISA-S88 does not specify languages for configuring the sequential and batch control functions. Many suppliers have however, already incorporated the IEC 1131-3 standard in their products.

Sequential Function Charts (SFC) are gaining acceptance for configuration of the procedural part of recipes. The main reasons for this are that SFC are graphical, easy to configure and easy to understand. SFC is also the basis for Procedural Function Charts (PFC), a graphical language for recipe representation presented in ISA88 Part2.

Equipment Control

The control recipe itself does not contain enough information to operate a process cell. On some level it must be linked to the process equipment control, i.e., the control actions that are associated with the different equipment objects. S88 offers large flexibility with respect to at which level the control recipe should reference the equipment control. It is also allowed to omit one or more of the levels in the procedural model. The situation is shown in Figure 4. The dashed levels could either be contained in the control recipe or in the equipment control.

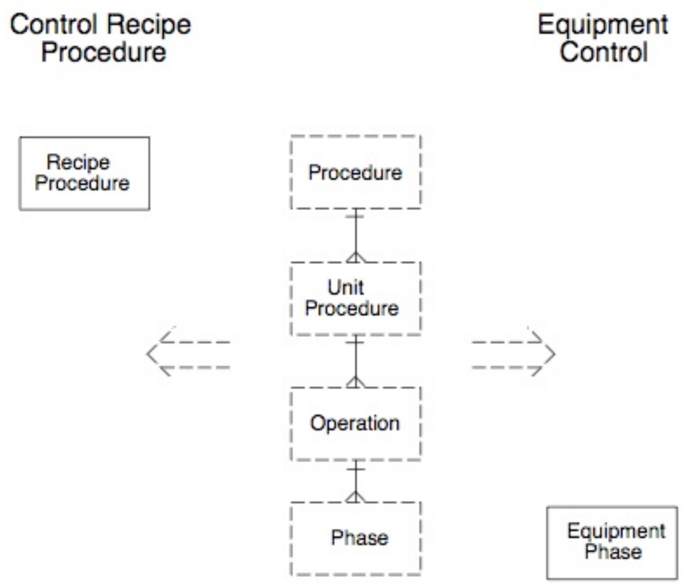

Figure 4: Recipe- equipment linking

Control Activity Model

To successfully manage batch production many control functions must be implemented. The control activity model shown in Figure 5, identifies the major batch control activities and the relationships amongst them. This model was outlined in S88, and provides an overall perspective on batch control.

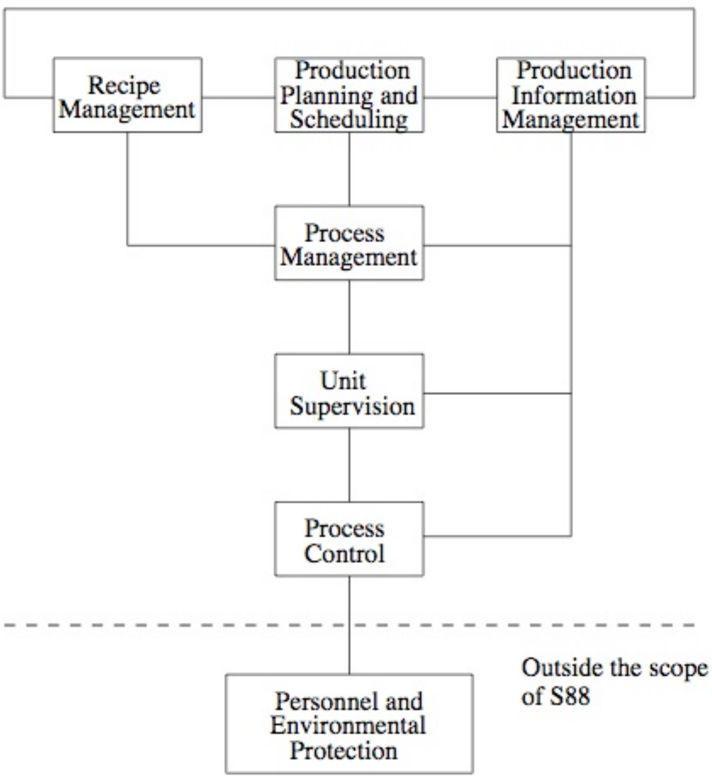

Figure 5: Control Activity Model

The control activities shown relate to real needs in a batch manufacturing environment.

- Recipe Management: The need to have control functions that can manage general, site, and master recipes implies a need for the recipe management control activity.
- Production Planning and Scheduling: Production of batches must occur within a planned time domain. Production planning and scheduling is the control activity where these control functions are implemented.
- Production Information Management: Various types of production information must be available and the collection and storage of batch histories is a necessity. The production information management control activity in the model covers these control functions.
- Process Management: Control recipes must be generated, batches must be initiated and supervised, unit activities require coordination and logs and reports must be generated. These control functions fall under the process management control activity.
- Unit Supervision: The need to allocate resources, to supervise the execution of operation and phases, and to coordinate activities taking place at the process control level are examples of control functions needed at the unit supervision control activity level.
- Process Control: The Process Control activity discusses control functions that deal directly with equipment actions.

Scheduling

Scheduling is a wide concept that can be broken down hierarchically, see Figure 6.

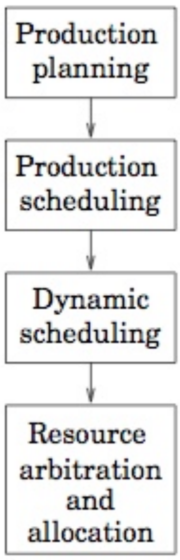

Figure 6: Scheduling hierarchy

At the highest 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. Here, the inventories are checked against the production demands and it is determined how much raw material that needs to be ordered. A master recipe is created. 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. Here, the horizon is measured in shifts, hours or minutes. A detailed schedule based on the specific resources and requirements of the batch production system is generated. The scheduling must be repeated if any activity is not completed in time (delayed, ahead of time). It may also be necessary to repeat the scheduling because of equipment malfunctions, lack of raw materials, etc. The dynamic scheduling level is sometimes referred to as detailed production scheduling,

The 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. The resource allocation system takes care of the allocation of resources. Here, a simple first-come-first-served algorithm is not always sufficient.

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

Industry Practice

Many different commercial batch control systems exist today. They are produced and utilized all around the world. Some examples are: FlexBatch from GSE Systems, OpenBatch from PID Incorporate, VisualBatch from Intellution, FoxBatch from Foxboro, InBatch from Wonderware, SattBatch from Alfa Laval Automation, Advant from ABB Industrial Systems, etc.

The batch control system suppliers are well aware of the ISA S88 batch control standard and their systems do, to greater or lesser extent, depending on the age of the system, comply with it. Even though the different systems have been developed at different independent companies they all have, from an operator point of view, a common look-and-feel. This is probably because of (or thanks to) the standard.

Summary

Industrial manufacturing and production processes can be classified as continuous, discrete or batch. Traditionally the areas of continuous and discrete processes have been the most research intensive areas. However, increased demands on production flexibility, small scale production and customer-driven production have led to an increased interest for batch processes and batch control. 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. The standard mentions the possibility to use Grafcet but only at the very lowest level of control. However, there is also a need for a common representation format, complying with the standard, at the recipe level.

Several different commercial batch control systems exist today. All suppliers are well aware of the ISA S88 standard. The recipes are structured according to the hierarchical procedural model. Steps and transitions are used for visualizing tasks and the changing of tasks. The recipe structure reminds of a Grafcet structure, however, no
formal links exists, the similarities have occurred by mere accident. Most commercial batch systems of today lack a user-friendly way of presenting the overall status of a plant, neither do the systems have an efficient way of handling the resource allocation.

In today's lecture the focus has been on Batch production Processes, see Figure 7.

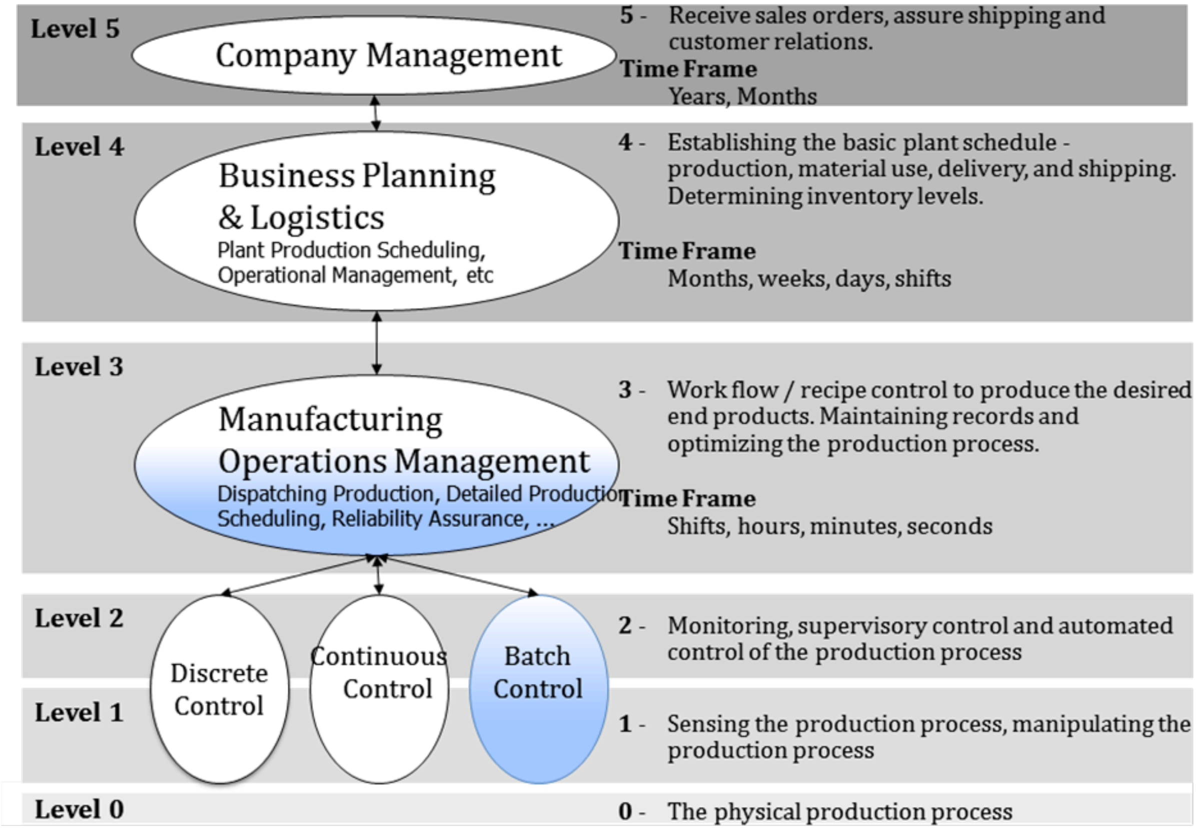

Figure 7: The batch production process

References

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