Cycle Time Reduction and Debottlenecking

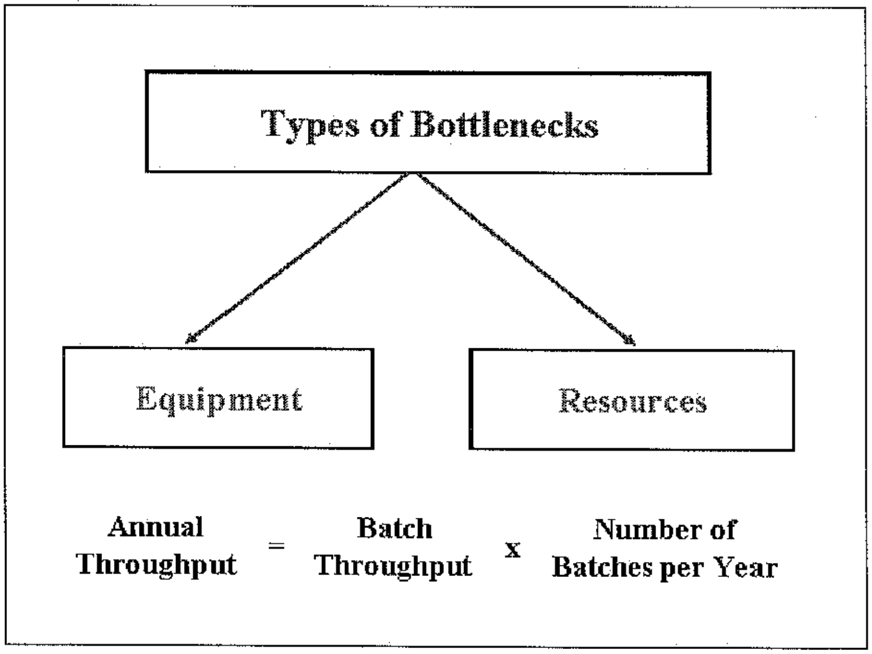
SuperPro Designer can be used to identify and eliminate bottlenecks that limit the production of integrated batch manufacturing facilities. The objective of Throughput Analysis and Debottlenecking is to enable the user to quickly and easily analyze the capacity and time utilization of each piece of equipment, and to identify opportunities for increasing throughput with the minimum possible capital investment.

The rest of this page highlights the capabilities of SuperPro on the subject. For more information, please visit the Literature page and download some of the pertinent papers and presentation documents. Also, you may visit the Consumer Goods page for a simple debottlenecking example related to formulation and packaging of consumer products.

Debottlenecking Theory

In a batch manufacturing facility, the annual throughput is equal to the batch throughput times the number of batches that can be processed per year. Consequently, we can increase the annual plant throughput by increasing either the batch throughput (size) or the number of batches per year or both. As we attempt to do that, we run into bottlenecks that are either equipment-related or resource-related. Resources include demand for utilities, labor, and raw materials.

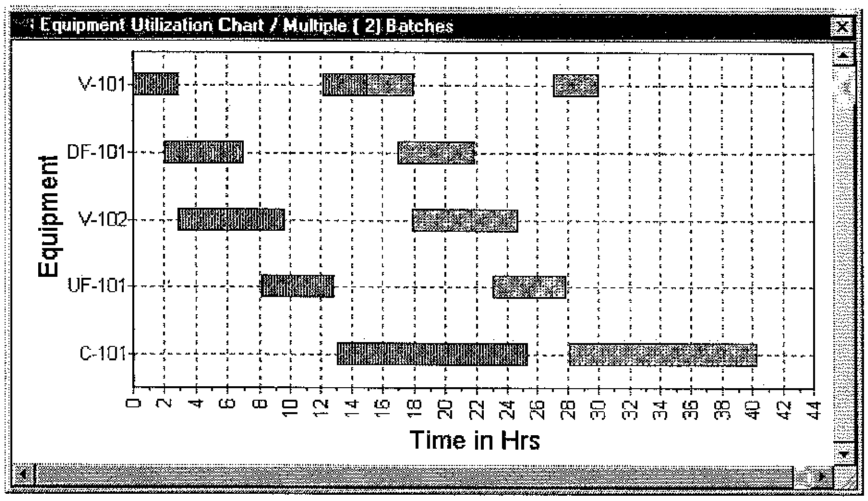
The bottlenecks that limit the number of batches per year are known as "time or scheduling" bottlenecks. Those that limit the batch throughput are know as size bottlenecks. Finally, those that limit the overall plant throughput are know as throughput bottlenecks. Typically, the time or size bottleneck is also the plant throughput bottleneck. Efforts aiming at reducing the cycle time of a process and consequently increasing the number of batches and the plant throughput are know as **Cycle Time Reduction** studies.



Time or Scheduling Bottlenecks

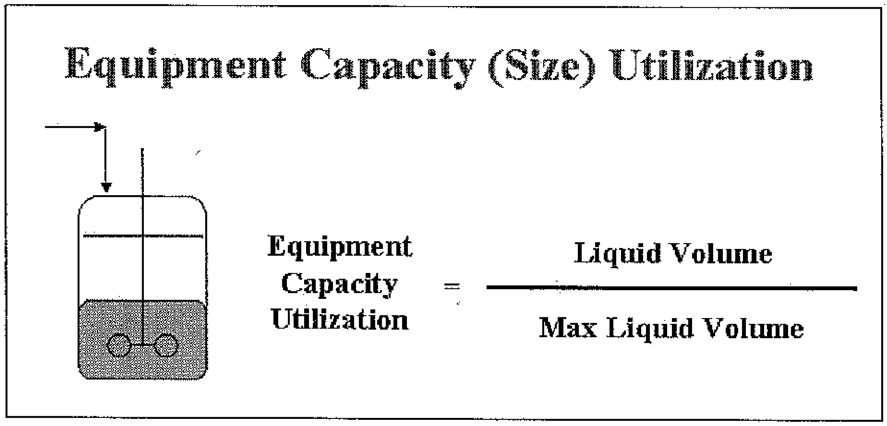
Let's focus first on Equipment time (scheduling) bottlenecks. The equipment utilization chart (see figure below) that is generated by SuperPro enables the user to visualize equipment utilization in time and identify the time (or scheduling) bottleneck, which is the equipment with the longest cycle time. That equipment determines the min Recipe (Plant) Cycle Time and consequently the Max Number of Batches per year (or per campaign). As can be clearly seen, V-101 is the scheduling bottleneck in this case. The two bluish rectangles for V-101 represent sharing of V-101 by two different processing steps (unit procedures) within a batch. It is obvious that elimination of sharing (by installation of extra equipment) can eliminate the current bottleneck. In that case, C-101 will become the next equipment time bottleneck. To eliminate the bottleneck caused by C-101, we can install extra equipment and operate it in staggered mode. For an example of this type, go to the Literature page and download the BioPharm paper (Throughput Analysis and Debottlenecking of Biomanufacturing Facilities).

Please note that auxiliary equipment, such as CIP (clean in place) skids, and resources (e.g., utilities, labor, raw material supply) also can become time bottlenecks. Information on how resources can become time bottlenecks is provided further down.



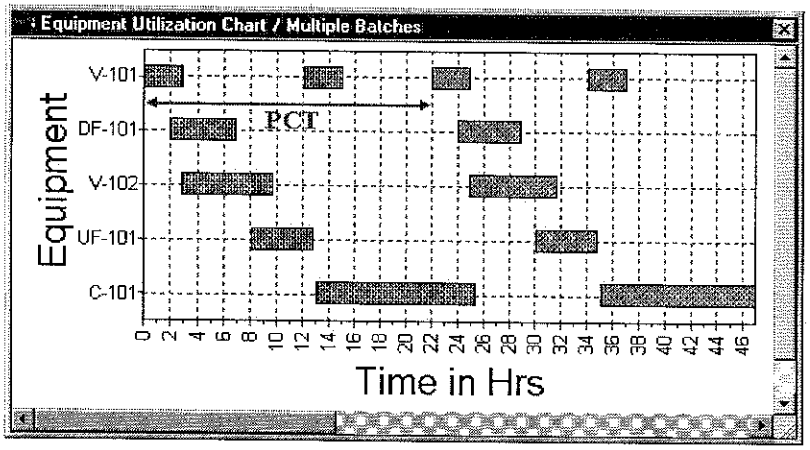
Size Bottlenecks

The equipment item that limits the batch size is known as "size bottleneck". To identify this bottleneck, for each piece of equipment of a process we calculate the "Equipment Capacity (Size) Utilization" that represents the fraction of an equipment's capacity utilized during an operation. This can be easily illustrated with a vessel operation (see figure below). If the red line represents the max allowable liquid level in the vessel during the operation and the blue area represents the actual level, obviously only a fraction of the vessel's capacity is utilized during that operation, which is equal to the ratio of "Liquid Volume" over "Max Liquid Volume". The vessel with the highest size utilization is the "Size Bottleneck" and it determines the max batch size. However, if that equipment has a short cycle time and can operate for multiple cycles within a batch, then, that must be taken into account in the estimation of the max batch size.



Time Utilization of Equipment

To identify throughput bottlenecks, in addition to size utilization we must also consider the time utilization of each piece of equipment. This is done by calculating the "Equipment Uptime", which is defined as the total time a piece of equipment is utilized per batch divided by the Plant Cycle Time (PCT). PCT, also known as recipe cycle time, represents the time between consecutive batches (see figure below).

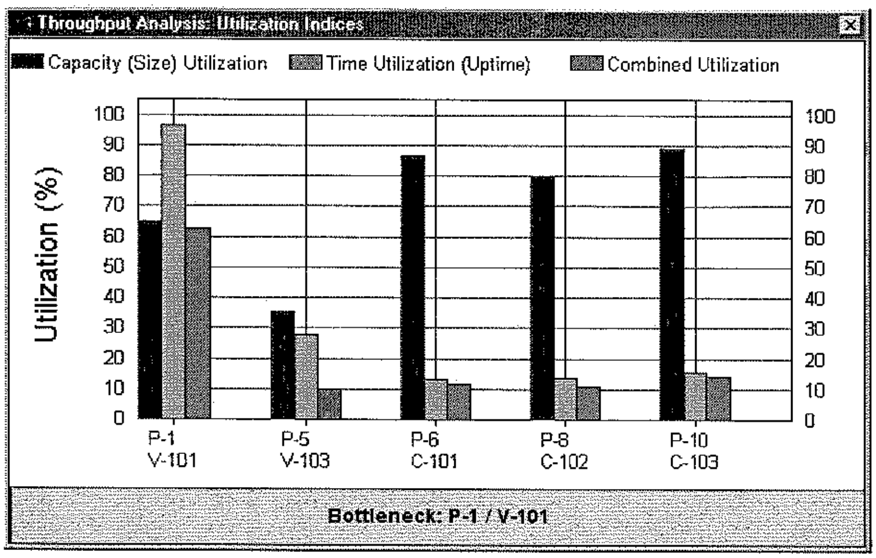


$$\textbf{Equipment Uptime} = \frac{\textbf{Total Time Equipment is Utilized per Batch}}{\textbf{Plant Cycle Time (PCT)}}$$

Throughput Bottlenecks - Approach (A)

To identify throughput equipment bottlenecks in the entire recipe (flowsheet), we simply calculate and plot the Combined Utilization for each equipment item. For a piece of equipment, its Combined Utilization is defined as the product of its Capacity (Size) Utilization times its Equipment Uptime. In the chart below, the blue bars represent capacity utilization, the orange represent time utilization, and the green represent combined utilization.

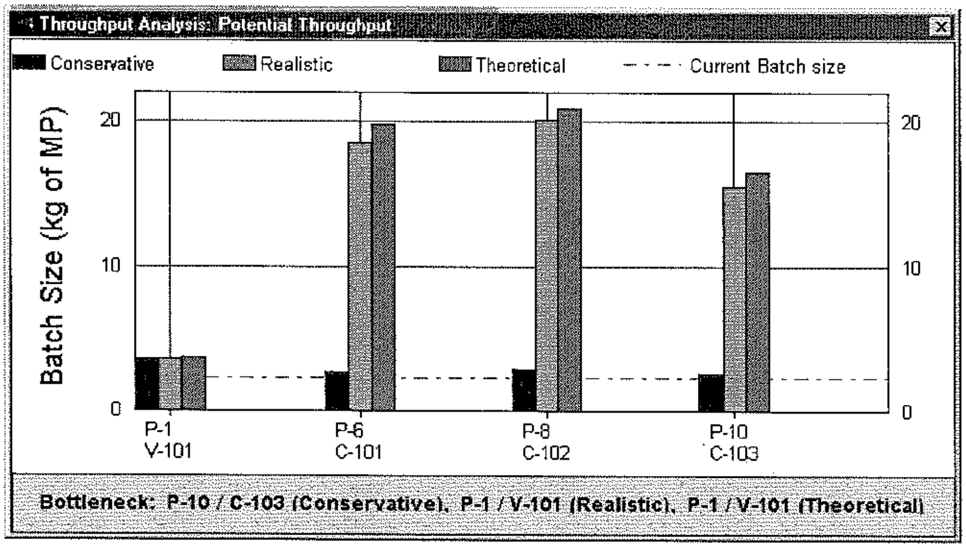
The equipment with the highest combined utilization will become the first throughput bottleneck as we try to increase plant throughput. How do we eliminate throughput bottlenecks? Elimination of equipment sharing and installation of extra capacity are the common ways. Changes in operating conditions (e.g., level of dilution for protein refolding that affects size utilization and batch size) may also eliminate certain throughput bottlenecks. Does this methodology work 100%? The answer is no. Real world limitations in time utilization may lead to situations where a procedure that does not have the max Combined Utilization is the true bottleneck under practical conditions. For instance, if you have a plant with a PCT of 24 hr and a certain vessel procedure has a cycle time of 16 h, it is very difficult under practical conditions to utilize the remaining 8 h. If this vessel operates at full capacity (size), then, it is the current true bottleneck even if some other procedure has a higher combined utilization.



Combined Utilization = **Equipment Capacity Utilization** x **Equipment Uptime**

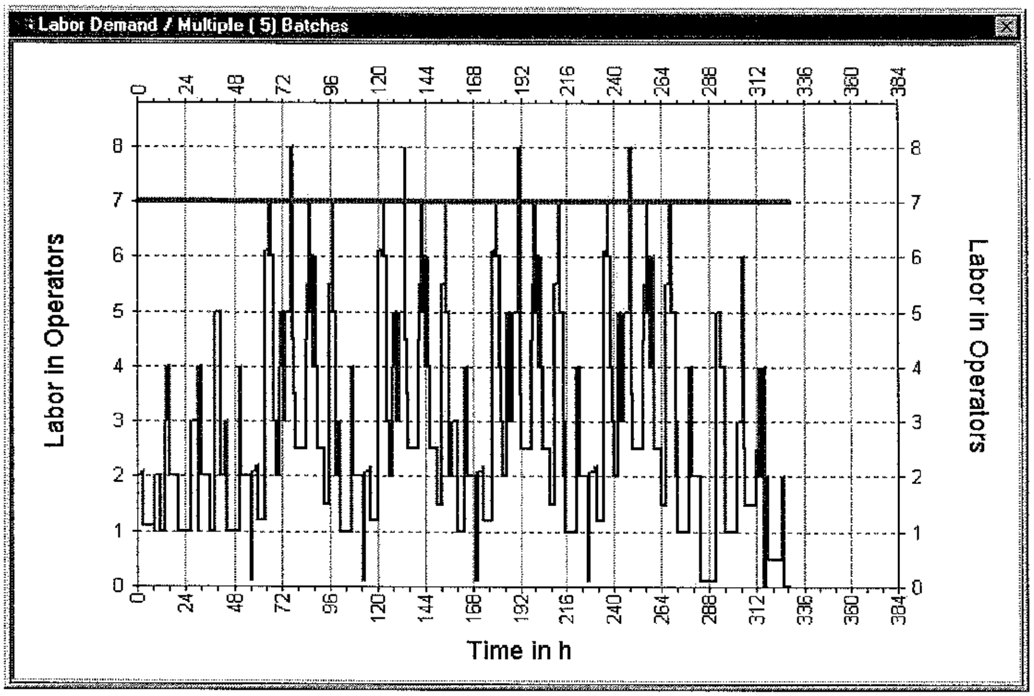
Throughput Bottlenecks - Approach (B)

To address the shortcomings of the "Combined Utilization" methodology for identifying throughput bottlenecks, we have developed an alternative methodology that is based on the max batch throughput potential of each procedure. To have a common basis of comparison, the batch throughput potential of each procedure is expressed in equivalent final product. SuperPro calculates three different batch throughput potentials (the Conservative, Realistic, and Theoretical) and generates a chart that displays those values for each procedure (see figure below). The procedure with the lowest conservative batch throughput potential is identified as the Conservative throughput bottleneck (P-10/C-103 in the case). Similarly, the procedures with the lowest realistic and theoretical batch throughput potentials are identified as the Realistic and Theoretical throughput bottlenecks, respectively. Our objective with this methodology is to identify the TRUE bottleneck based on the value of the realistic bottleneck. For more info on how the throughput potentials are calculated, please check our literature on the subject.

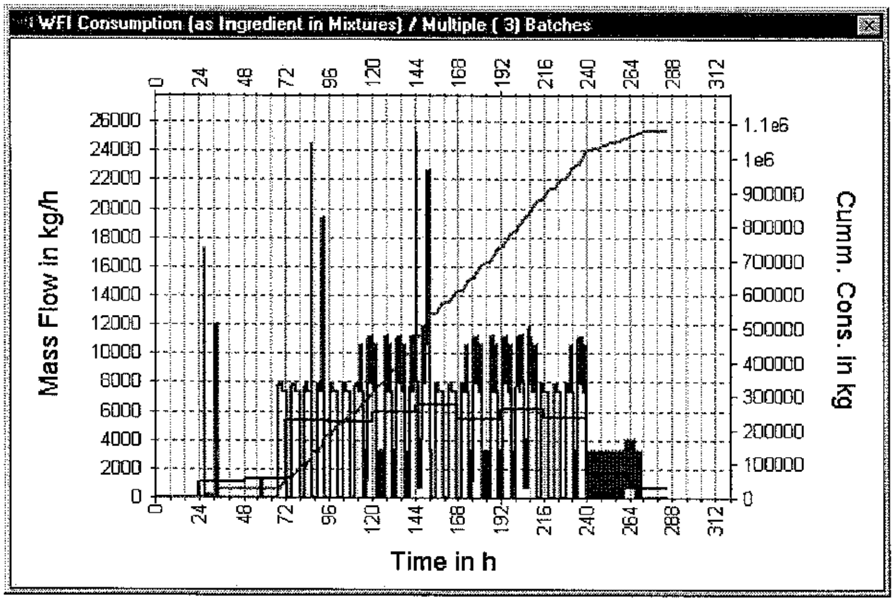


Resource Bottlenecks

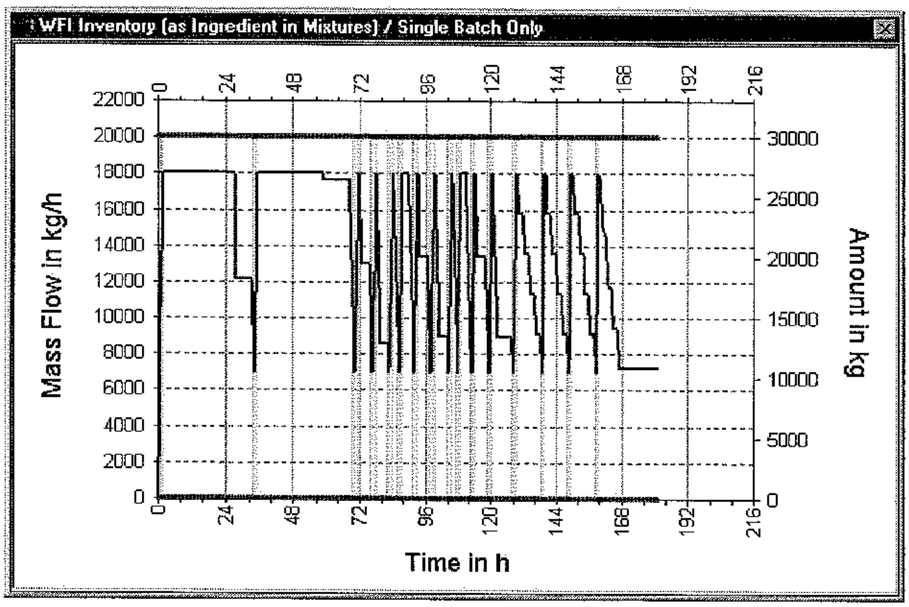
Resources that cannot be stored (e.g., labor, steam, power) can become bottlenecks if the available capacity cannot meet the instantaneous demand at some point in time. For instance, the figure below displays the labor requirement (blue lines) for four consecutive batches. The red line represents the limit (7 operators available). Notice that for short periods of time there is a need for eight operators. If that need cannot be met, then certain operations will need to be delayed to accommodate that constraint. Oftentimes, such resource constraints become time bottlenecks that determine the maximum number of batches that can be processed over a period of time.



A storable resource (e.g., demand for a material) can become a bottleneck if the cumulative demand (shown with the green line on the figure below) over a period of time exceeds the cumulative capacity during the same period.



A storable resource may also become a bottleneck if there limited storage capacity and a high demand for a short period of time. For instance, the figure below shows the level of WFI (water for injection) in the storage tank. The blue line (the values correspond to the y-axis on the right-hand-side) represents the level of WFI in its storage tank. The red lines represents the limits of the tank (full and empty). If for a short period of time the blue line hits the bottom (the tank runs dry), the operation that requires WFI at that moment must be delayed and that delay may create a new time bottleneck.

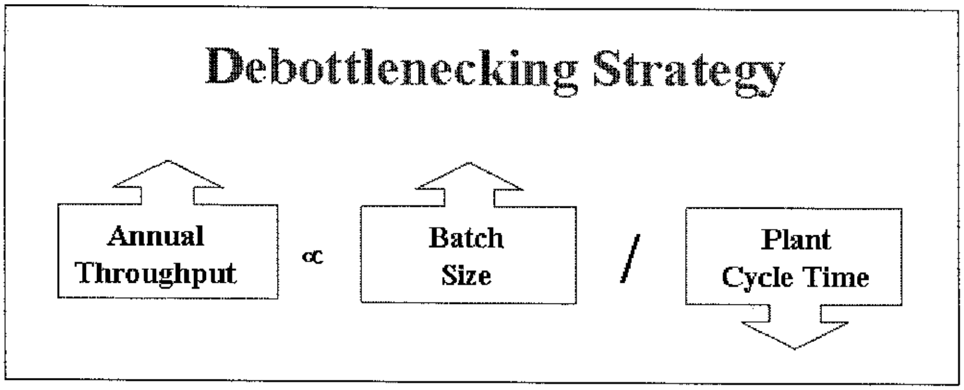


Debottlenecking Strategy

It is clear from the previous analysis that, if our goal is to increase plant throughput, we should make changes that increase the batch size and/or reduce the plant cycle time. In general, we recommend the following strategy:

1) Increase batch size until at least one cyclical step operates at 100% capacity utilization. If its uptime is low, try increasing its number of cycles per batch. This may create opportunities for additional increases in batch size. A side benefit of increased batch size is the reduced cost for quality control (QC) and quality assurance (QA), which depends on the number and not the size of batches.

2) If a process operates at its maximum batch size, focus on plant cycle time reduction through elimination of time bottlenecks. Long process steps and equipment sharing are the causes of time bottlenecks. Bottlenecks created by equipment sharing are eliminated by installing extra equipment that reduces sharing. The size of the new equipment should be chosen in a way that creates opportunities for batch size increase (sizing based on the most demanding step). Rearrangement in the order of equipment use (for shared equipment) may also create opportunities for cycle time reduction and sometimes for batch size increase. If the time bottleneck is caused by a step that has a very long cycle time, the new equipment should be operated in a staggered mode based on the cycle time of the next time bottleneck. Sometimes a time bottleneck can be eliminated by moving secondary operations from bottleneck to non-bottleneck equipment. For instance, instead of heating material in a vessel, the heating can be done using an external heat exchanger during the charge/transfer of the material into the vessel. Please note that whenever a recommendation is made to buy new equipment, the final decision should be based on overall project economic evaluation criteria, not simply on throughput considerations.



Additional Information on Debottlenecking

Go to the Literature page and download the following documents:

[3] Throughput Analysis and Debottlenecking of Biomanufacturing Facilities.
This article appeared in the August issue of BioPharm. It includes theory on throughput analysis and a thorough example on debottlenecking of a monoclonal antibody (MAb) production facility. It illustrates how to reduce cycle times and increase plant throughput by operating equipment with long cycle times in staggered mode (out of phase).
[4] Cycle Time Reduction and Economic Evaluation.
This is the Powerpoint document of a presentation on "Throughput Analysis, Debottlenecking, and Economic Evaluation of

Integrated Biochemical Processes" that was given at the annual AIChE meeting in Reno (November, 2001). The complete text of the presentation can be found in the "Notes" page of the slides.

[5] Process Fitting and Technology Transfer.

This is the Powerpoint document of a presentation on "Technology Transfer, Process Fitting, and Debottlenecking". The complete text of the presentation can be found in the "Notes" page of the slides. This document deals with the transfer of a synthetic pharmaceutical process from R&D to manufacturing. It explains how to use process simulators to facilitate fitting of a new process into an existing facility and then how to increase plant throughput by installing extra equipment and operating it in an intelligent way.

[8] Product Formulation and Packaging.

This Powerpoint file explains how SuperPro Designer can be used to model, visualize, and optimize product formulation and packaging lines. The major emphasis is on cycle time reduction. It is applicable to professionals in the food, consumer product, pharmaceutical, beverage, and related industries. Essentially, whenever there is a combination of batch and semi-continuous lines that share some equipment, SuperPro can be used to reduce cycle times and increase plant throughput. A description of this is also provided on the Consumer Goods page.