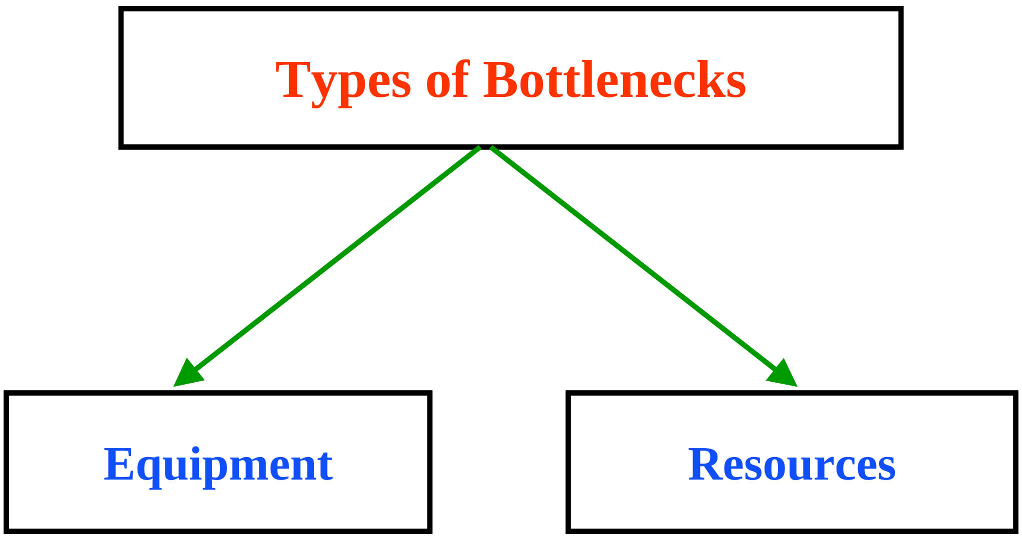
9.0 Throughput Analysis and Debottlenecking

The annual (or campaign) throughput of a batch manufacturing facility is equal to batch throughput times the number of batches that can be processed per year. Therefore, we can increase annual throughput by increasing the batch throughput or the number of batches per year or both at the same time.

Annual Throughput = **Batch Throughput** x **Number of Batches per Year**

In our effort to increase annual throughput we run into bottlenecks that are either equipment or resource (e.g., utilities, labor, demand for raw materials) related.



The equipment or resource that limits the number of batches per year is the **Scheduling or Time Bottleneck**. The equipment or resource that limits the batch throughput (amount of material processed per batch) is the **Size or Throughput bottleneck**. In continuous plants, we only have throughput bottlenecks.

Please note that for a batch plant the “Batch Throughput” and the “Number of Batches per Year” are interdependent. More specifically, as the batch throughput is increased (operating closer to the maximum), the cycle time of most procedures will increase resulting in longer plant cycle times and fewer batches per year. Consequently, the maximum annual plant throughput cannot be simply set equal to the maximum batch throughput times the maximum number of batches per year. Instead, it should be calculated in an iterative way by gradually increasing the batch throughput and letting SuperPro calculate the corresponding maximum number of batches.

➔ Identifying Equipment Time (Scheduling) Bottlenecks

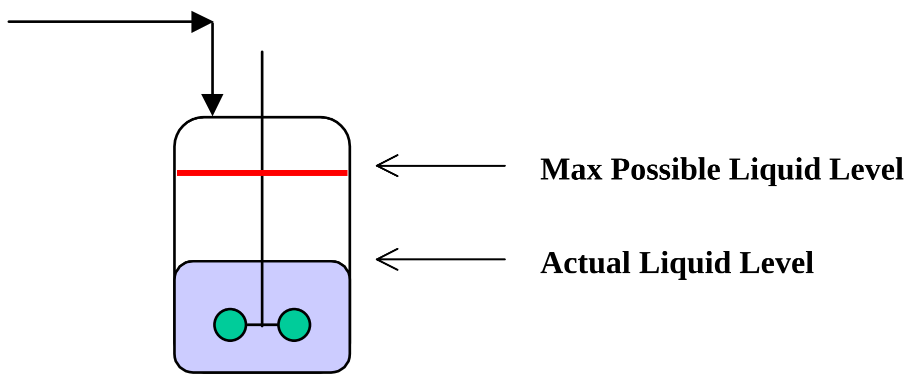
Information on the equipment scheduling bottleneck is provided on the Recipe Scheduling Information dialog (see Chapters 2 and 6). The same information can be visualized graphically on the Equipment Utilization chart. The scheduling (or time) equipment bottleneck is the piece of equipment that has the longest cycle (occupancy) time. This piece of equipment determines the minimum time between consecutive batches and consequently the maximum number of batches per year. For equipment items that are shared by multiple procedures, their occupation time is set equal to the time interval between the start of the first procedure that is hosted by the equipment to the end of the last procedure that is hosted by the same equipment. Please note that resources also can become time bottlenecks (see section on resource bottlenecks below).

➔ Identifying Equipment Size (Throughput) Bottlenecks

The Equipment Size (Throughput) bottleneck can be identified by considering the Capacity and Time utilization of each equipment item.

Equipment Capacity Utilization

This variable represents the equipment capacity utilized during a certain procedure. For instance, if a piece of equipment that can process up to 100 kg/h of a certain material it is operated at a rate of 80 kg/h, its equipment capacity utilization will be 80%. If a piece of equipment is of vessel type, its capacity utilization can be defined based on the ratio of actual and maximum liquid levels for a certain operation. The figure below illustrates this in detail. The Capacity Utilization for a unit procedure is calculated by selecting the maximum capacity utilization among all operations of that procedure.



$$\text{Equipment Capacity Utilization} = \frac{\text{(Actual Liquid Level)}}{\text{(Max Liquid Level)}} \times 100$$

Equipment Uptime

This variable represents the percent of plant operating time that a certain piece of equipment is occupied. For plants operating in batch mode, equipment uptime can be defined as follows:

$$\textbf{Equipment Uptime} = \frac{\textbf{(Total Time Equipment is Utilized per Batch)}}{\textbf{(Plant Cycle Time)}} \times 100$$

Plant Cycle Time is the time interval between consecutive batches. If a piece of equipment is used by multiple procedures (in a batch plant), the equipment uptime accounts for the overall (of all procedures) utilization in time.

Many procedures have uptimes (as well as cycle times) that are proportional to the amount of material processed per cycle. For example, if you have a filtration procedure in which the volume of material that needs to be filtered is doubled, the filter uptime will double (assuming that the filtrate flux remains the same). Equipment items of this type usually operate at 100% capacity utilization and changes in their throughput amount only affect their uptime. This is an important point to understand – just because a piece of equipment is listed at 100% Capacity Utilization does not necessarily make it a throughput bottleneck. In the filtration example, the equipment can simply be run for twice the amount of time, as long as the total filtration time does not exceed the cycle time.

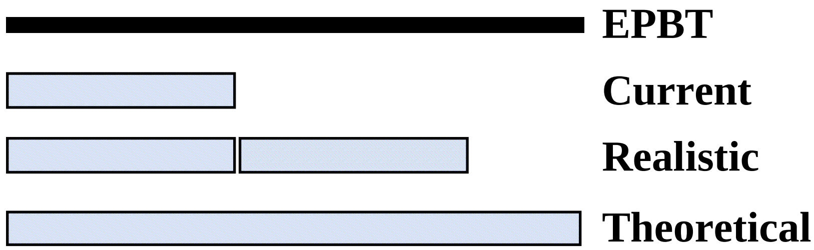
Combined Utilization

Combined Utilization of a procedure is simply its Equipment Capacity Utilization times its Equipment Uptime. To have a Combined Utilization of 100%, the procedure's equipment would have to be run at maximum capacity and its cycle time would have to be the same as the plant cycle time.

The procedure with the highest Combined Utilization % will generally be the throughput (size) bottleneck for the process. This will always be the case for unit procedures which have cycle times proportional to their throughput (whether or not a unit procedure's cycle time is proportional to its throughput is noted in the Throughput Analysis Report tables). However, in some cases where the cycle time is not proportional to throughput, the unit procedure with the highest Combined Utilization will not necessary be the throughput (size) bottleneck. This can occur when particular unit procedures cannot run 100% of the time. For instance, if the plant's cycle time is 100 hours, and a series of reactions in a particular vessel takes 60 hours, you will only be able to use that vessel 60% of the time. In some cases, you may be able to run multiple cycles (and even partial cycles) to increase your equipment uptime, but in many processes (such as pharmaceuticals) this may not be an option.

Potential Maximum Throughput

A better way of identifying throughput (size) bottlenecks is by calculating the Potential Maximum Throughput (PMT) of each procedure. For procedures with cycle times proportional to their throughputs (e.g., filtration, centrifugation, etc.), the PMT is calculated by assuming 100% equipment capacity utilization and 100% uptime. For procedures whose cycle times are not proportional to their throughputs (e.g., vessel procedures, chromatography, etc.), their PMT is calculated under Conservative, Realistic, and Theoretical assumptions for their uptime (see figure below). The Equipment Capacity utilization is assumed 100% in all the cases.

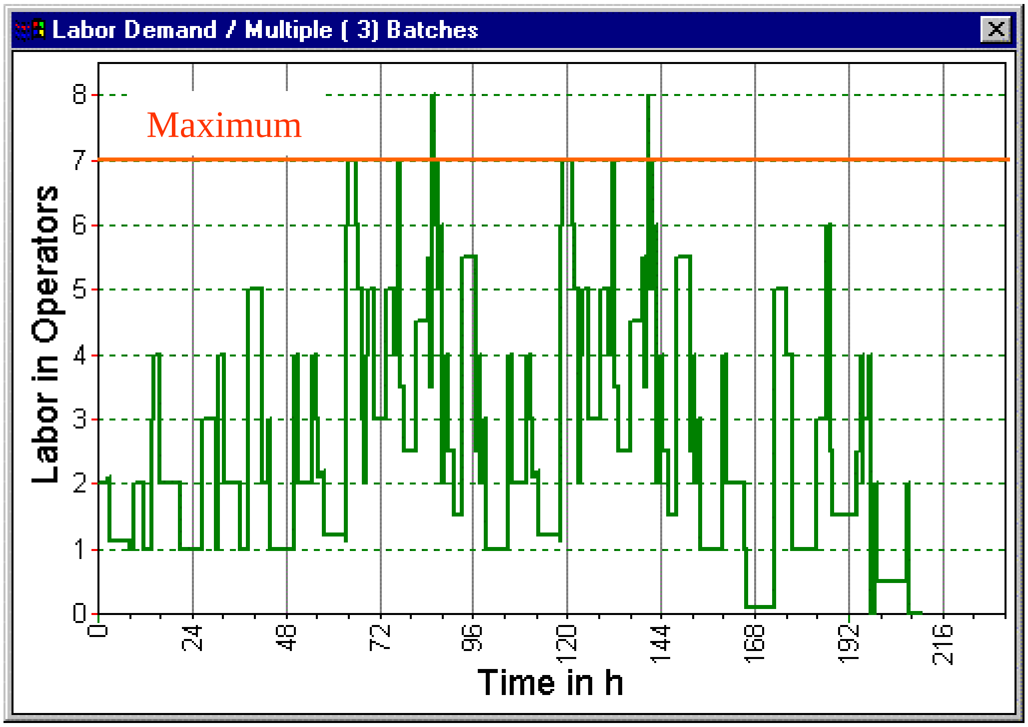


1) In the **Conservative** case, the Equipment Uptime is kept the same as its current uptime.
2) In the **Realistic** case, the Equipment Uptime is set to correspond to the highest number of complete cycles that can be performed in that piece of equipment within the time window of the plant cycle time.
3) In the **Theoretical** case, the Equipment Uptime is assumed to be at 100%. This would require mixing of partial lots of product, which may not be an option in many processes.

The objective is to identify the TRUE size (throughput) bottleneck based on the realistic scenario. The conservative scenario corresponds to the case where we operate all the equipment items at 100% capacity utilization but without making any changes in the number of cycles per batch. Batch plants that are dedicated to manufacturing of a single product should be designed with equipment capacity utilization and uptime of close to 100% for all equipment items. For multi-product batch plants this is not feasible. In such cases, the above methodology can be applied to maximize the plant throughput for each separate product by identifying the appropriate capacity utilization and uptime for each procedure/equipment.

➔ Resource Bottlenecks

Resources can become size (throughput) and time (scheduling) bottlenecks when their average or instantaneous demand exceeds their average or instantaneous capacity, respectively. For instance, the figure below shows the demand for labor as a function of time for three consecutive batches of a process. For short periods of time, there is a need for up to eight operators. If seven (red line) is the maximum number of operators that can be available at any time, then, certain operations will have to be delayed to accommodate that constraint. That delay of operations may increase the plant cycle time and reduce the maximum number of batches per year and therefore become the new time bottleneck. The current version of Pro-Designer does not identify resource time bottlenecks. However, it calculates and displays the demand for any resource (e.g., raw materials, heating/cooling utilities, power, and labor) and enables the user to visualize and interactively eliminate potential resource bottlenecks. Future versions of the software will enable the user to specify maximum capacity values and the program will automatically delay certain operations in order to meet those constraints.



9.1 Throughput Analysis Report Structure

The first table (see below) displays information on the current annual and batch throughput, the plant batch time, the number of batches per year, and the time bottleneck equipment (NFD-101 in this case).

1. OVERALL PROCESS DATA

Annual Operating Time	7,883.65	h
Annual Throughput	28,463.53	kg MP
Batch Throughput	171.47	kg MP
Plant Batch Time	81.60	h
Number of Batches per Year	166.00	
Time Bottleneck Equipment	NFD-101	

MP = Main Product = Total Flow in Final Product

The second table (see below) displays information on Equipment Capacity Utilization, Equipment Uptime, and Combined Utilization for all the procedures of a flowsheet. The procedure with the highest Combined Utilization (P-9 in this case) is considered the Throughput (Size) Bottleneck based on this approach. Please note that this may not be the true bottleneck under real world conditions. Equipment items that are in Design Mode do not appear on these tables because their size is calculated by the program to meet the current processing demand.

2. EQUIPMENT CAPACITY UTILIZATION AND UPTIME (ENTIRE PROCESS)

Equipment	Procedure	% Capacity Utilization	% Equipment Uptime	% Combined Utilization
R-101	P-1	53.18	43.77	23.28
	P-7	62.49	43.77	27.35
R-102	P-3	68.22	60.24	41.09
	P-9	69.69	60.24	41.98
NFD-101	P-4	61.87	37.46	23.18
	P-6	0.91	37.46	0.34
	P-8	46.24	37.46	17.32
	P-10	4.77	37.46	1.79
	P-12	51.92	37.46	19.45
R-103	P-5	57.79	46.94	27.13
	P-11	72.22	46.94	33.90
TDR-101	P-13	100.00	26.26	26.26
Limiting Equipment	**Procedure**			
R-102	P-9			

The third table is a summary of potential maximum throughput (PMT) under conservative, realistic and theoretical assumptions for equipment uptime. It also identifies the bottlenecks (limiting procedure and equipment item) under each assumption. For each category, the bottleneck is the procedure with the lowest value of PMT. In this case, the same procedure (P-11 in R-103) is the conservative and realistic bottleneck whereas (P-9, R-102) is the theoretical size bottleneck. The bottleneck identified based on the theoretical PMT approach is always the same as the one identified by the Combined Utilization approach (previous table).

The rest of the report displays the individual potential throughput figures for each unit procedure, based on the Conservative, Realistic, and Theoretical assumptions. In Table 4 this is shown for Procedure1. Furthermore, the limiting procedure and equipment bottlenecks are identified for each section of the flowsheet in their respective Section Summaries.

SUMMARY OF THROUGHPUT INCREASE OPTIONS (Throughput kg MP/batch)

Equipment	Procedure	POTENTIAL Conservative	MAXIMUM Realistic	THROUGHPUT Theoretical
R-101	P-1	322.42	322.42	736.66
	P-7	274.39	274.39	626.91
R-102	P-3	251.36	251.36	417.26
	P-9	246.03	246.03	408.41
NFD-101	P-4	457.69	457.69	457.69
	P-6	50,052.36	50,052.36	50,052.36
	P-8	457.69	457.69	457.69
	P-10	9,600.54	9,600.54	9,600.54
	P-12	457.69	457.69	457.69
R-103	P-5	296.71	296.71	632.11
	P-11	237.43	237.43	505.83
TDR-101	P-13	653.05	653.05	653.05
Limiting Equipment		R-103	R-103	R-102
Limiting Procedure		P-11	P-11	P-9

4. DETAILED THROUGHPUT INCREASE OPTIONS PER SECTION AND

PROCEDURE

SECTION NAME = Product Synthesis			
Procedure Name: P-1 (Chlorination, Salt Formation)			
Equipment Name: R-101 (shared with other procedures)			
Limiting Operation: Salt Formation			
Throughput Increase Options	**% Equipment Capacity Utilization**	**% Equipment Uptime**	**Plant Throughput kg MP/batch**
Conservative	100.00	43.77	322.42
Realistic	100.00	43.77	322.42
Theoretical	100.00	100.00	736.66
Current	53.18	43.77	171.47
Cycle Time is Not Proportional to Throughput			

9.2 Throughput Analysis Example

The first table (see below) displays information on the current annual and batch This example is based on the Synthetic Pharmaceutical design case (**SynPharm** directory). The goal is to produce at least 33,000 kg/year of our pharmaceutical intermediate compound in the most economical way possible by utilizing existing equipment. Here is a brief description of the design cases:

File SPhr5_5L: This process is based on lab-scale data, which has been scaled up to pilot plant production volumes. At this point all equipment is in Design Mode. In other words, the equipment capacities have not yet been defined.

File SPhr5_5a: This process was designed based on pilot plant volumes of reagents in manufacturing scale equipment. It is the same as SPhr4_0L except that the calculation mode for all equipment items has been switched to Rating. In addition, the reactors and filter are used for multiple unit procedures. Two 1000 gal reactors, one 4 m^2 filter and one 10 m^2 tray dryer are utilized.

File SPhr5_5b: This process is the same as SPhr5_5a, but the throughput has been scaled to 100% capacity utilization of the limiting-size reactor (R-102).

File SPhr5_5c: This process is the same as SPhr5_5b, except that THREE reactors are used in order to decrease the plant's cycle time (so that more cycles can be run per year).

File SPhr5_5d: This process is the same as SPhr5_5c except that a second filter (NFD-102) has been added.

File SPhr5_5e: This is the same as SPhr5_5d except that procedure P-11 in R-103 (and subsequent procedures) have been split into two cycles, and the batch throughput has been increased to 100% in the new capacity-limiting piece of equipment (R-102).

File SPhr5_5f: This is the same as SPhr5_5e except that the utilization of several reactors has been rearranged. Specifically, the reactors for procedures P-5 and P-7 have been switched. This allows more cycles to be run per year because the batch cycle time of reactor R-103 is decreased.

These design cases will be analyzed in greater detail later in this section. In order to save space, only certain parts of the Throughput Analysis Reports are reproduced below. To see all Throughput Analysis tables in their entirety, please open the SPhr4_0 (L, a, b, c, d, e or f) example files and create the reports as follows: click on **Reports/Throughput Analysis (THR)** main menu item. For more information on the report format see Chapter 11.

➔ Interpreting the Throughput Analysis Report

The throughput analysis results for file SPhr5_5a show that Procedure P-11 in reactor R-102 is the limiting step (see table below). In other words, if we try to increase batch throughput (material processed per batch) without installing extra equipment, R-102 will become the first throughput bottleneck. The current batch size is 55.72 kg of pharmaceutical intermediate. This corresponds to 32.5% capacity utilization of R-102 in Procedure P-11. If the process were scaled up to full Capacity Utilization of R-102, the throughput could be increased to 171.48 kg/batch. This is exactly what we do in file SPhr4_0b. Note - to adjust the throughput of the entire flowsheet automatically, you can go to **Tasks: Adjust Plant Throughput**, and then enter a scaling factor to adjust the throughput to the desired level. This adjustment can be done universally (all input streams are multiplied by the same factor) or stream-by-stream. Please remember to redo the simulation calculations after the throughput adjustment (by clicking the Solve icon, or selecting: **Tasks/Solve M&E Balances**).

EQUIPMENT CAPACITY UTILIZATION AND UPTIME (Entire Flowsheet)

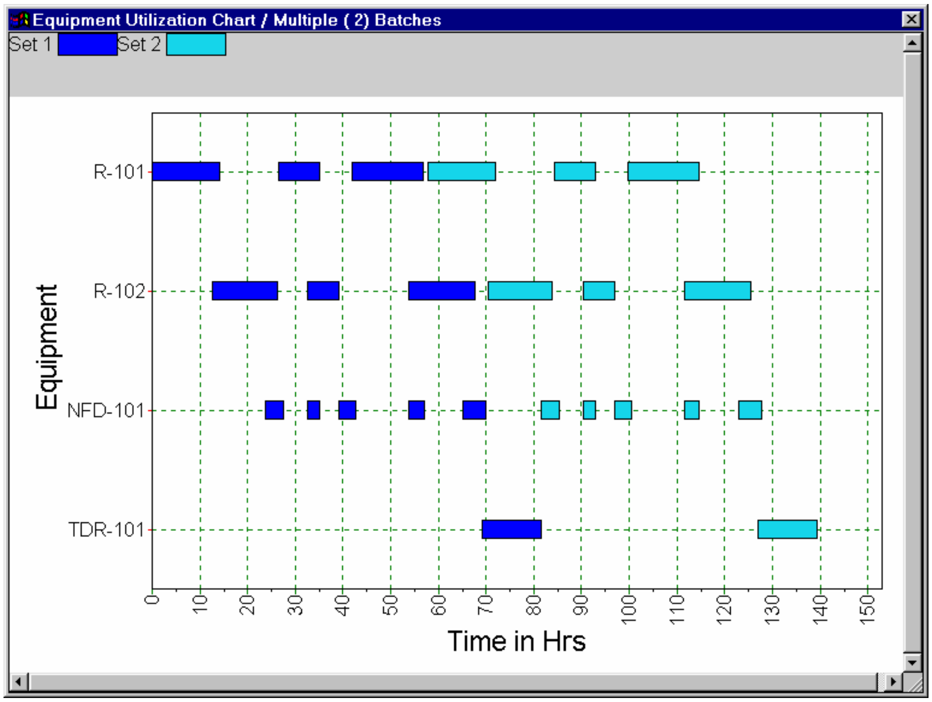
Equipment Tag	Procedure Name	Capacity Utilization (%)	Equipment Uptime (%)	Combined Utilization (%)
R-101	P-1	17.28	65.42	11.31
	P-5	18.60	65.42	12.17
	P-9	22.65	65.42	14.82
R-102	P-3	22.17	58.01	12.86
	P-7	20.02	58.01	11.62
	P-11	32.50	58.01	18.85
NFD-101	P-4	100.00	15.82	15.82
	P-6	100.00	15.82	15.82
	P-8	100.00	15.82	15.82
	P-10	100.00	15.82	15.82
	P-12	100.00	15.82	15.82
TDR-101	P-13	100.00	11.02	11.02

Limiting Equipment / Procedure R-102 / P-11

The Equipment Capacity Utilization and Uptime table for file SPhr4_0a.

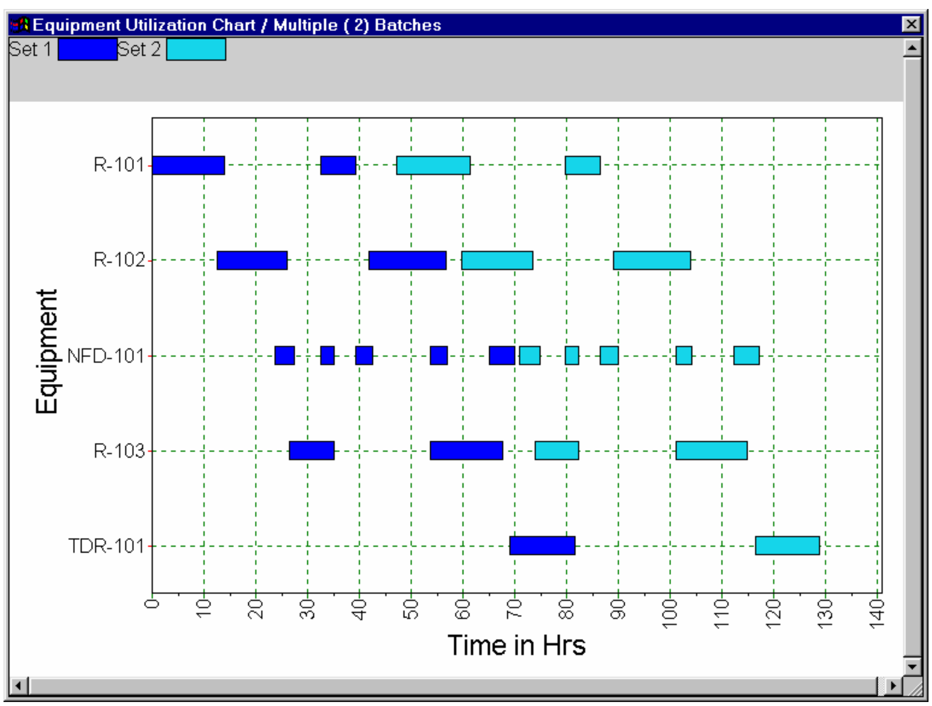
The throughput analysis results for SPhr4_0b (please open the report and view the results) show that the plant's cycle time increases to 57.79 hours (it was 40.69 hours in SPhr4_0a). The increased batch cycle time is due to the fact that some operations in this example (such as filtration) have their cycle times specified to be proportional to flowrates. Since the total batch size was increased, the total volume of liquid that flows through the filters was increased. Thus the time required for these operations increased proportionally. The larger batch time causes the number of batches per year to decline from 194 (in SPhr4_0a) to 136. This is based on a 7920 hour maximum for the annual plant operating time. The annual operating time can be changed through the Recipe Scheduling Information dialog (select **Tasks: Recipe Scheduling Information**). Despite the lower number of batches per year, the increase in capacity utilization of R-102 increases the overall annual throughput of this process (recall that the annual throughput is equal to the number of batches per year times the batch throughput.) The original annual throughput was 10,810 kg, but by increasing the capacity utilization of R-102 we reach an estimated annual throughput of 23,320 kg.

After scaling file SPhr4_0a up by roughly 3-fold, the Capacity Utilization % of the other pieces of equipment is higher as well (the lowest Capacity Utilization becomes 53.18% during P-1). At this point, other options can be considered to lower the cycle time or increase the batch size. One option is to buy more equipment so that each piece of equipment is used for fewer unit procedures. This is what is done in file SPhr4_0c. This file is identical to SPhr4_0b, except that an extra 1,000 gal reactor (for a total of three reactors) has been added. The decision to add this unit was based on a review of the multiple batch Equipment Utilization Chart for SPhr4_0b (see below.) A quick look at this chart reveals that R-101 is the current scheduling bottleneck. If a third reactor is added, the batch cycle times for R-101 and R-102 can be reduced because fewer unit procedures will take place in each reactor. After adding the third reactor (in SPhr4_0c), the cycle time decreases to 47.3 hours, and the number of cycles per year is increased to 166. This allows the annual throughput to increase to 28,464 kg/yr. It should be noted that the purchase of an additional reactor significantly increases the overall cost of the project. In fact, despite the increased throughput possible under this setup, the Internal Rate of Return (IRR) for this process actually decreases from 56.0% to 50.1% (The IRR is listed in the Economic Evaluation Report and the Executive Summary). In some situations, a decrease in IRR caused by buying more equipment could be much greater than the decrease calculated for this particular example. Thus, although adding extra equipment units or buying larger pieces of equipment are obvious methods to increase throughput, they sometimes have a negative effect on the overall economics of the process (other times the increase in throughput more than compensates for the increased capital expenditure). This is why *the economic reports should be used in conjunction with the Throughput Analysis Report when determining the best setup for your process.*



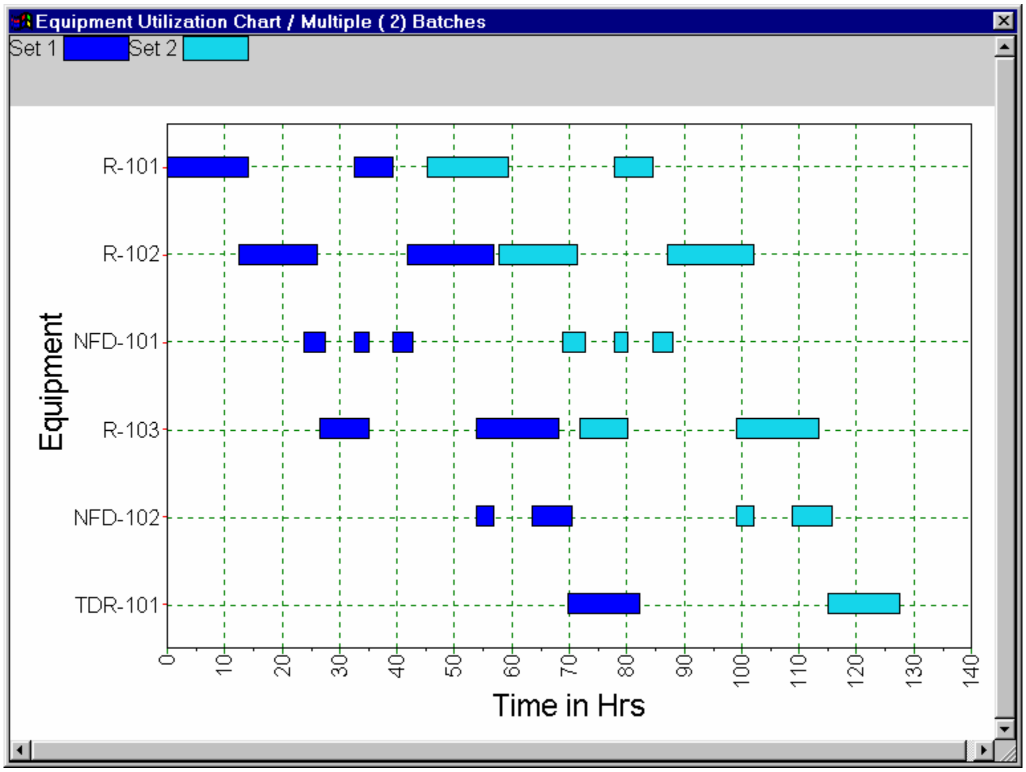
The multiple-batch Equipment Utilization Chart for SPhr4_0b

After the third reactor is added (file SPhr4_0c) another Equipment Utilization Chart is produced (see below). This chart shows that the new equipment bottleneck is the filter NFD-101.



The multiple-batch Equipment Utilization Chart for SPhr4_0c

Since we have not yet reached our target of 33,000 kg/year, we must increase throughput again. One way to do this is to purchase a second filter. This will further decrease the plant cycle time and therefore increase the number of batches produced per year. The use of a second filter is incorporated in file SPhr4_0d, and the new multi-batch equipment utilization chart is displayed below. With this change, the number of batches per year increases from 166 to174, and the new annual throughput goes from 28,464 kg/yr to 29,836 kg/yr. Although the addition of the second filter does not increase the annual throughput greatly, it is relatively inexpensive and it will allow us to make several additional changes that will increase both the annual throughput and the IRR.



The multiple-batch Equipment Utilization Chart for SPhr4_0d

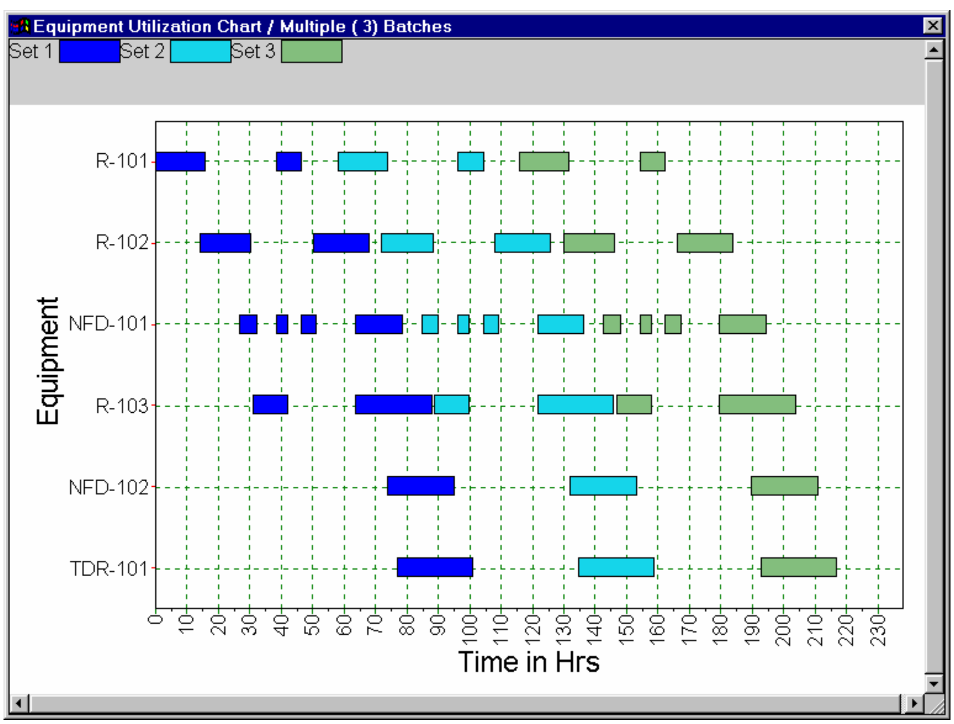
After adding another filter, our options for increasing throughput become more limited. Addition of more equipment will not decrease the cycle time very much (unless 3 more reactors are added so that each unit procedure has its own dedicated piece of equipment.) However, if we look at the Throughput Analysis Report for SPhr4_0d (see below), it becomes apparent that only one unit procedure (P-11 in R-103) uses its full equipment capacity. Note – recall that the filters and dryer listed below are not really at full capacity because an increase in throughput would simply increase their cycle times and uptime, as opposed to overfilling them. If we split the batch in half for procedure P-11, we will no longer be constrained by the capacity of R-103. As a result, we will be able to increase the batch throughput in all other pieces of equipment. This is what is done in file SPhr4_0e; procedure P-11 (and subsequent procedures) are split into 2 cycles, and the batch throughput is increased to the point where the new capacity bottleneck (P-9 in R-102) is at maximum utilization. Procedure P-10 is also switched from NFD-102 to NFD-101. When this is done, the total number of batches per year is decreased from 174 to 135 because the equipment uptime for R-103 is increased. However, the batch throughput is increased from 171.47 kg/batch to 246.05 k/batch. As a result, the annual throughput increases from 29,836 kg/yr to 33,217 kg/yr. This meets our goal of producing 33,000 kg/year of our product. However, one other simple change can be made which will further increase throughput, as well as increase the project's return on investment. Please refer to the multi-batch Equipment Utilization Chart for file SPhr4_0e on the next page.

EQUIPMENT CAPACITY UTILIZATION AND UPTIME (Entire Flowsheet)

Equipment Tag	Procedure Name	Capacity Utilization (%)	Equipment Uptime (%)	Combined Utilization (%)
R-101	P-1	53.18	45.75	24.33
	P-7	61.62	45.75	28.19
R-102	P-3	68.22	62.97	42.95
	P-9	69.69	62.97	43.88
NFD-101	P-4	100.00	21.55	21.55
	P-6	100.00	21.55	21.55
	P-8	100.00	21.55	21.55
R-103	P-5	57.25	47.51	27.20
	P-11	99.99	47.51	47.51
NFD-102	P-10	100.00	17.65	17.65
	P-12	100.00	17.65	17.65
TDR-101	P-13	100.00	27.45	27.45

Limiting Equipment / Procedure R-103 / P-11

The Equipment Capacity Utilization and Uptime table for SPhr4_0d



The multiple-batch Equipment Utilization Chart for SPhr4_0e

The SPhr4_0e Equipment Utilization Chart above reveals that there is one other easy way to increase throughput for this process: rearrange the reactor utilization sequence. If the second procedure in R-101 (P-7) is switched to R-103, and the first procedure in R-103 (P-5) is switched to R-101, the batch cycle time of each is shortened. This allows the cycle time to be cut to 54.86 hours, which increases the number of batches per year to 143 and increases the annual throughput to 35,185 kg. Of course, the calculated values for annual throughput, IRR, etc., are only as good as the data that was used to produce them. *However, the trends in IRR, annual throughput, etc., are likely to be correct if you have modeled your process correctly*. For instance, it is easy to understand that by going from example SPhr4_0e to SPhr4_0f you will have a better IRR since you are increasing your annual throughput simply by changing your procedure scheduling (and without buying additional equipment, etc.)

Even after the scheduling of unit procedures in these three reactors has been optimized, there will be gaps between their uptime periods (none of the equipment is running 100% of the time). This will be typical of most batch processes. As the unit procedures in this example (SPhr4_0f) are currently configured, the only way to have constant utilization of any given piece of equipment would be to have fractional batches during a given cycle. For example, reactor R-101 has an Uptime of 61.74% (see table below).

EQUIPMENT CAPACITY UTILIZATION AND UPTIME (Entire Flowsheet)

Equipment Tag	Procedure Name	Capacity Utilization (%)	Equipment Uptime (%)	Combined Utilization (%)
R-101	P-1	76.29	48.75	37.19
	P-5	82.15	48.75	40.05
R-102	P-3	97.89	61.74	60.44
	P-9	100.00	61.74	61.74
NFD-101	P-4	100.00	51.92	51.92
	P-6	100.00	51.92	51.92
	P-8	100.00	51.92	51.92
	P-10	100.00	51.92	51.92
R-103	P-7	88.42	58.94	52.12
	P-11	71.74	58.94	42.28
NFD-102	P-12	100.00	38.72	38.72
TDR-101	P-13	100.00	43.63	43.63
Limiting Equipment / Procedure			R-102 / P-9	

The Equipment Capacity Utilization and Uptime table for SPhr4_0f

Thus in order to have constant utilization of this reactor, roughly 1.62 batches would have to be produced in R-102 during each plant batch cycle. This would require mixing several “lots” of material during other steps of the process. This mixing of different “lots” during various steps of a process can be highly undesirable (or even strictly prohibited) in many processes, especially production of pharmaceuticals. If mixing of different material “lots” was allowed, the maximum possible throughput during the current cycle time (without installing additional equipment) would be 398.52 kg of our synthetic pharmaceutical intermediate, which corresponds to 100% Combined Utilization of the throughput-limiting piece of equipment. In this example, the limiting equipment unit is reactor R-102, procedure P-9. However, as stated previously, 100% Combined Utilization may not always be possible to achieve.

Following the Equipment Capacity Utilization and Uptime table in the Throughput Analysis Report is the Summary of Throughput Increase Options table. This table lists the Potential Maximum Throughput (PMT) for each unit procedure. The PMT is calculated in three ways, with different assumptions associated with each. In all three cases, the PMT is based on 100% Capacity Utilization. However, the Equipment Uptimes for the three cases differ:

1) In the **Conservative** case: For a procedure which has a cycle time that is not proportional to throughput, the Equipment Uptime is kept the same as its current uptime. In cases where the procedure cycle time is proportional to throughput (such as filtration), the Equipment Uptime is set at 100%.
2) In the **Realistic** case: For a procedure which has a cycle time that is not proportional to throughput, the Equipment Uptime is set to correspond to the highest number of complete cycles that can be performed in that piece of equipment within the time window of the plant cycle time time.
3) In the **Theoretical** case: All equipment is assumed to be at 100% Capacity Utilization all the time (100% Equipment Uptime). This would require mixing of partial lots of product, which may not be an option in many processes.

SUMMARY OF THROUGHPUT INCREASE OPTIONS (Throughput in kg MP/batch)

Equipment Tag	Procedure Name	POTENTIAL Conservative	MAXIMUM Realistic	THROUGHPUT Theoretical
R-101	P-1	322.53	322.53	661.53
	P-5	299.51	299.51	614.33
R-102	P-3	251.36	251.36	407.12
	P-9	246.05	246.05	398.52
NFD-101	P-4	473.89	473.89	473.89
	P-6	473.89	473.89	473.89
	P-8	473.89	473.89	473.89
	P-10	473.89	473.89	473.89
R-103	P-7	278.28	278.28	472.12
	P-11	342.99	342.99	581.91
NFD-102	P-12	635.46	635.46	635.46
TDR-101	P-13	563.92	563.92	563.92
Limiting Equipment		R-102	R-102	R-102
Limiting Procedure		P-9	P-9	P-9

The Summary of Throughput Increase Options table for SPhr4_0f.spf.

The table above displays the potential maximum throughput for each procedure under the "Conservative", "Realistic", and "Theoretical" assumptions defined previously. It also identifies the bottlenecks (limiting procedure and equipment item) under each assumption. The highest potential throughput (using the current equipment configuration) is represented by the lowest value in one of the above columns (which column depends on which assumption you use). For instance, if you are interested in the maximum possible throughput given the “Conservative” assumption, you should look for the lowest value under the “Conservative” column. This value is 246.05 kg, which is listed next to procedure P-9 in R-102. (A batch throughput of 246.05 kg is also the current throughput, as we can see from the very first table in the Throughput Analysis Report – see below). Similarly, the maximum possible throughputs under the “Realistic” and “Conservative” assumptions are 246.05 kg and 398.53 kg, respectively.

```
OVERALL PROCESS DATA
=======================================================
 Annual Operating Time      =       7890.60 h
 Annual Throughput          =      35185.07 kg MP
 Batch Throughput           =        246.05 kg MP
 Plant Batch Time           =        100.79 h
 Number of Batches Per Year =        143
 Time Bottleneck Equipment  =      R-102
=======================================================
 MP = Main Product = Total Flow in Final Product
```

Additional tables in the Throughput Analysis Report display the individual potential throughput figures for each unit procedure, based on the Conservative, Realistic, and Theoretical assumptions. Furthermore, the limiting procedure and equipment bottlenecks are identified for each section of the flowsheet in their respective Section Summaries.

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