HARVARD | BUSINESS | SCHOOL

5-606-137

JUNE 15, 2006

TEACHING NOTE

Natural Blends, Inc.

The Natural Blends case is derived from a real orange juice producer located in Florida, but the situation has been greatly simplified with respect to the complexity of the delivery of the oranges, the juice production operations and the contracts with industrial customers. This is an example of a production process where three of the individual process steps are tightly coupled. This is a "continuous process which also involves setups and changeovers. As a consequence there are important management choices for how these changeovers/setups are coordinated given the realities of the production system constraints and the customer requirements.

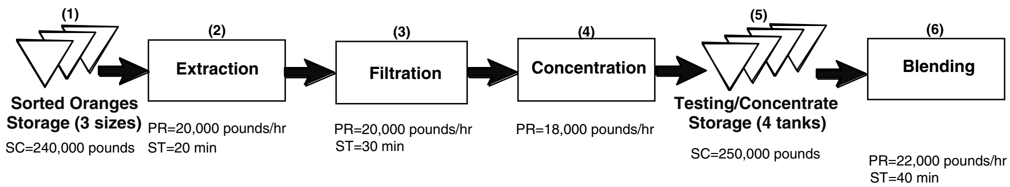
Analysis

Our analysis represents a thorough examination of the facts using the exam questions as the vehicle to understand the process and inform the management decisions presented in the case. As such the case can be used as a diagnostic tool to evaluate students' abilities to understand operations and use the basic tools taught in the first half of the course. The biggest challenge for many students was one of conceptualizing the key attributes of the process so that the problem could be framed. This requires that students step back and think about the problem before applying the TOM tools.

The process flow diagram including information about capacities and setup times is given in the Figure 1.

This note was prepared by Professor H. Kent Bowen for the sole purpose of aiding instructors in the use of the case, Natural Blends (HBS No. 698-012). It has been used to distribute to students after they have prepared and submitted their answers to the case, Natural Blends. HBS cases are developed solely as the basis for class discussion. Cases are not intended to serve as endorsements, sources of primary data, or illustrations of effective or ineffective management.

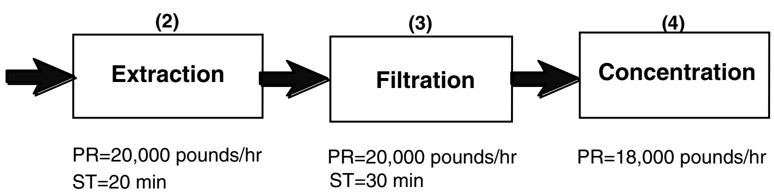
Figure 1. Orange Juice Process Flow Diagram



Part A

Part A of the exam focuses on the 3 tightly linked process steps two through four with the simplifying condition that only one size of orange is being processed. These three processes are buffered from the upstream process by the orange storage bins and from the downstream by the concentrate storage tanks. There is no buffer storage between the individual process steps, therefore they act together as a system. If filtration must shut down for a filter cleanup, then extraction and concentration must shut down at the same time. The rate at which the 3 process steps can produce orange juice is governed by the process with the smallest capacity when the unit is running; in this case the concentrator.

Question 1a- *How much orange juice concentrate can be processed in one 8-hour workday?*



The key here was to recognize that when the process is running that a bottleneck occurs at the concentrator, which has a capacity of 18,000 lbs/hr -- 2,000 lbs/hr less than filtration. In addition, the run-time of the system is limited by filtration, which requires a 30-minute setup for every 90 minutes of run-time. Therefore, the amount of juice product processed in one 8-hour day is:

(amount of time the process is running per day)*(production rate when running) =

(8 hr - (0.5 hr/filter change * 4 filter changes) * 18,000 lbs/hr = 108,000 lbs per day

For this continuous flow process without buffers, each of the steps runs at the *same rate*.
Production Rate $_{\text{EXTRACTOR}}$ = Production Rate $_{\text{FILTRATION}}$ = Production Rate $_{\text{CONCENTRATOR}}$
When the system is running, the **Production Rate** = 18,000 pounds/hour. Similarly, each of the process steps runs for the *same time*.
Production Time $_{\text{EXTRACTOR}}$ = Production Time $_{\text{FILTRATION}}$ = Production Time $_{\text{CONCENTRATOR}}$
which is given by Production Time = 8 hours - Down Time for filter changeovers

The conceptual errors made by students were of two primary types. The first error type looked at each of the 3 processes in isolation, determined the smallest capacity of the three (filtration working for 6 hours at a rate of 20,000 lbs per hour = 120,000 lbs per day), and assigned it as the bottleneck for the system. The second type of conceptual problem was to look at 1 hour units of production as if they were batches. Thus, for the first hour of the two hour cycle, the combined effects of filtration and concentration would produce 18,000 lbs (the concentrator rate) while the second hour would produce only 10,000 lbs (half of the filtration rate where the filtrator operates only half an hour at its maximum capacity of 20,000 lbs per hour).

Question 1b *Assume extraction has previously been set up for the size oranges being processed. How much idle time will there be in the extraction operation during one 8-hour workday?*

Since the time the extraction process is able to run is exactly the same as when filtration is running, the idle time can be calculated from the time required for filter changes over the 8-hour day.

(0.5 hr/filter change * 4 filter changes/day) = <u>2 hours of idle time per day</u>

A few students took an alternative approach based on a different interpretation of idle time. They considered not only the 2 hours when the extractor was not running but also the time while running when there was "unused capacity." This adds extra time,

capacity not utilized when running = (time extraction is running) * (fraction of capacity utilized)

= 6 hours [(maximum extractor capacity - actual production) / (maximum extractor capacity)]

= 6 hours [(6 * 20,000 - 108,000) / (6 * 20,000)] = 0.6 hours

The total idle time using this approach would be 2 + 0.6 = <u>2.6 hours idle time per day</u>

Interestingly, many students recognized that the extractor must be idle when filtration is shut down but failed to recognize that a similar idle time condition occurred with the concentration process.

Question 2a and 2b. *If you could add storage capacity somewhere between steps two and four in this production line in order to increase daily output, where would you place it? How much storage would you add? Why?*

The purpose of inventory storage is to buffer or decouple one process step from another. The decoupling is desired to improve the performance of the system (Alternatively, sometimes buffers are used to make managing the system or a particular process step easier). In the Natural Blends case, we have differences in production capacities of the 3 process steps and changeovers at filtration cause the extractor and concentrator to experience four 30-minute downtimes during the day. The question, then, is how can added storage be used to improve the daily output? Storage won't make concentration fun at a faster rate, but storage may ameliorate the effects of downtime.

Let's see what effect storage after the extractor would have on the performance of filtration. Since in this part of the exam only one size orange is being processed, the extractor causes no changeovers. However the way the extractor runs is determined by what happens downstream--the extractor can only run at the rate of the concentrator and it must shutdown every time that filtration shuts down. Buffer storage after the extractor will not reduce the downtime of filtration changeovers or increase the productive capacity of concentration.

However, there is an advantage to having storage after filtration. This allows us to compensate for the downtime during filter changes and take advantage of the fact that filtration can produce extra juice for storage during the 90-minute runtime. Because filtration has a higher production capacity than concentration (20,000 - 18,000 lbs per hour = 2,000 lbs per hour), it can be run at the higher rate if there is a place to store the extra juice, the excess of 18,000 lbs per hour going through the concentration process during the 90-minute period. Following the accumulation of this extra juice in storage, the concentration process can continue to run during the filtration downtime. The net result is an increase the output of the system.

Thus, storage should be added after filtration (before concentration) to decouple the filtration and concentration processes and increase daily output. The amount of storage needed is determined by the <u>smaller of the two values</u>: (a) the amount which can be processed in the concentrator during filtration's 30 minute down time, and (b) the amount of extra juice that can be processed during the 90 minute run time while maintaining the system production rate of 18,000 lbs per hour

(a) amount processed in concentration in 30 minutes = (0.5 hours) * (18,000 lbs per hour)

= 9,000 lbs

(b) amount stored during 90 minute run = (1.5 hours) * (20,000 - 18,000 lbs per hour)

= 3,000 lbs of storage capacity

<u>The amount of storage capacity needed between filtration and concentration is 3,000 lbs.</u>

During the 8-hour work day, this would improve the output of the system by 12,000 lbs of finished concentrate [(4 cycles of filter changeovers) * (3,000 lbs per 30 minute changeover)] for a total output quantity of 120,000 lbs. (see Figure 2 for the schematic of these cycles)

Question 3b *If the cost of adding storage is $30/pound and the cost of reducing set-up time by 50% using additional fixtures is $20,000 for the filter process and $10,000 for the extraction process, what action would you recommend in order to maximize the output of this production line?*

Reducing the setup time of the extractor has no effect on the current situation because we are processing only one size of orange. Some students anticipating the need to process the three sizes recognized the advantage of doing this improvement in the long term.

Since the time the system runs is determined by the filtration set-ups and the production rate when the system is running is determined by the concentration process, we have three options to increase output: (1) add storage capacity, (2) reduce filter setup time by 50%, and (3) reduce filter setup time and add storage capacity. To determine whether these improvements are worth implementing, an evaluation of the increased output should be conducted for each option.

(1) The calculation of the amount of storage needed and the increased daily output was determined above: add 3,000 pounds of storage after filtration to gain 12,000 pounds of added output per day. The cost would be $90,000 [($30 per pound) * (3,000 pounds)].

(2) Reducing the filter changeover time by 50% allows filtration to have more run time during the day. If we first just look at how the system might run on average, we can calculate the average number of filtration cycles we can run during the by reducing the filtration cycle from 2 hours (90 minute run + 30 minute set-up to 1.75 hours (90 minute run + 15 minute set-up):

480 min/day / (90 min + 15 min) = 4.57 filtration cycles per day (setups per day)

This would give approximately 123, 390 lbs of juice [(4.57) * (18,000 lbs/hr * 1.5 hrs)]. Thus, the benefit would be: 123,390 lbs - 108,000 lbs = <u>15,390 additional product/day</u>. Note that this does not include a fifth setup during the day, the rest of runtime before changing filters is assumed to carry over to the next day.

A more reasonable approach to running the system is a bit more conservative. After 4 (15-min) setups and 4 (90-min) runs, 60 minutes are left over at the end of the day. During this 60 minutes, another setup is conducted and a run of 45 minutes. Thus 45 minutes per day of extra capacity results. This more conservative approach, allowing time to change the filters after every run , would add 13,500 lbs of daily capacity [0.75 hours * 18,000 lbs per hour].

Using either method to calculate the added capacity yields more capacity for less money than does the storage option (13,500 to 15,390 lbs at a cost of $20,000 vs. 12,000 lbs at a cost of $90,000).

(3) Adding both storage and reducing filtration set-ups by 50%, allows us to add the two results. This is shown schematically in Figure 3 for the case where the extra 60 minutes (4 * 15 minutes) do to reduced setups is used for a 45 minute run and 15 minute setup. The added daily capacity is due to

(added run time due to shorter setups) + (added use of the concentrator due to storage)

= 13,500 lbs/day + 12,000 lbs/day = 25,500 lbs/day at a cost of $110,000.

Qestion 3b. *How much will your recommended improvement(s) cost?*

Depending on which of the three options one chooses, the costs range from $20,000 to $110,000. The result of the recommendation is that on a daily basis one gets added output at a particular investment cost:

(a) Storage only: $7.50 per added pound per day [($90,000) / (12,000)]

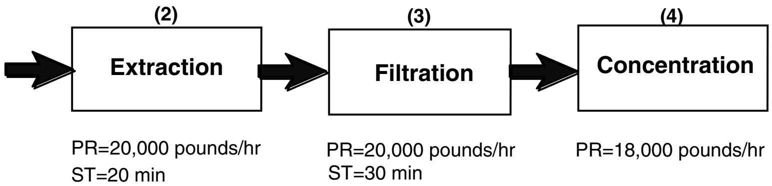
(b) Set-up reduction only: $1.48 per added pound per day [($20,000) / (13,500)]

(c) Both: $4.31 per added pound per day [($110,000) / (25,500)]

Given the kinds of margins described in Part C on the exam, one would likely recommend that both options be implemented.

Part B

In Part B of the exam we have the added complication that three orange sizes are being processed which requires that changeovers are necessary in extraction every time a different size is processed. The case states that over the 6-day week the same amount of oranges of each size must be processed and that each day some amount of each size must be processed. (It is also stated that none of the improvements in set-up times and no storage has been added.)

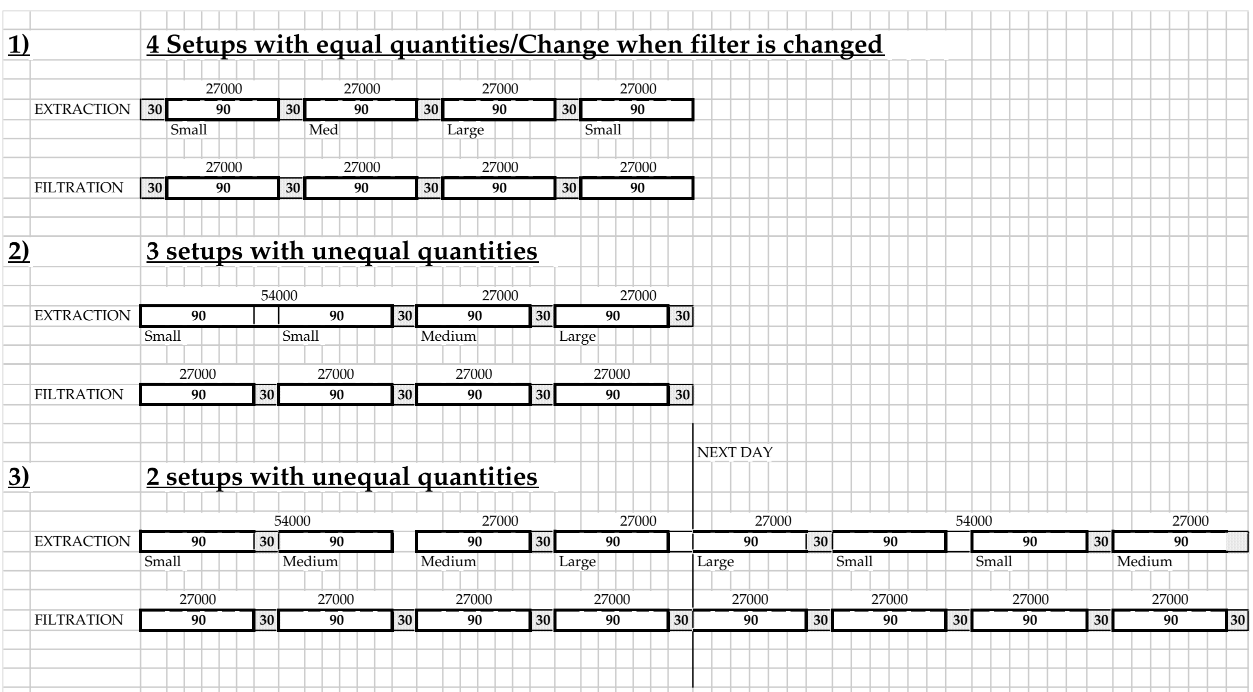


The key to understanding issues posed in Part B is related to understanding the importance of coordination of the setups between extraction and filtration. In order to keep productive capacity for the entire continuous flow system, the number of shutdowns must be minimized which necessitates that the extraction setups be coordinated with those in filtration. This will result in an overall daily production rate just like that in Part A.

Question 4a and 4b *How often during an 8-hour workday would you have a set up change in the extraction process (i.e., how often would you changeover to another size)? Why?*

To answer this question, it is useful to think about the conditions we must satisfy : (a) the set ups for extraction and filtration must be coordinated (i.e., occur during the same time); (b) some amount of all three sizes of oranges must be processed each day; and (c) over the course of a week, equal amounts of the three sizes must be processed. It is also assumed that we do not want to reduce the capacity of the system.

We can see from the charts below where the extraction and filtration runs and set ups have been laid out over the day that there are several choices for extraction changeovers which do not diminish the capacity of the system. Thus, the <u>extractor can be changed 2 times, 3 times or 4 times during a day</u> and meet the constraints listed above.



As production schedules for these cases are planned for each of the six days of the week, they would be of the form:

2 changes per day: (Six days of production would be - 8 batches of each size)
S M M L | L S S M | M L L S | S M M L | L S S M | M L L S |

3 changes per day: (Six days of production would be - 8 batches of each size)
S M M L | L S S M | M L L S | S M M L | L S S M | M L L S|

4 changes per day: (Six days of production would be - 8 batches of each size)

S M L S | M L S M | L S M L | S M L S | M L S M | L S M L

where S, M and L refer to the small, medium and large oranges, respectively.

In each of the schemes for coordinating changeovers and set ups, the amount of downtime remains constant at 2 hours and the production rate while the system is running during 6 or the 8-hours is 18,000 lbs/hr.

Some students tried to consider options with extractor setups at times other than when filtration was down for cleaning. In most cases this was because, they had chosen to do equal amounts of the 3 sizes of oranges each day. This reduces the runtime and therefore the system capacity.

Question 4c *What quantity of oranges of a particular size would you process before switching to another size.?*

Because the maximum output occurs by coordinating the setups necessary in extraction and filtration, the amount to be processed of a particular size is in units of what can be processed during one of the 90-minute runs.

Quantity Processed Per Bin = (1.5 hours run time) * (18,000 lbs/hour) = <u>27,000 lbs/bin</u>

If we chose to changeover the extractor two or three times a day, then we will process 27,000 lbs of 2 sizes and 54,000 lbs of the remaining size. If the changeovers occur four times a day, then 27,000 lbs will be processed during each changeover.

Question 4d- *What is the total amount of juice concentrate you can process through the three process steps (two through four) in one 8-hour workday?*

The system, running at its maximum capacity, is controlled by the interactions described in Part A of the analysis. When the system is running, the rate is determined by the bottleneck at concentration (18,000 lbs/hr), and the available time to run the system (6 hours) is determined by the shutdowns at filtration (if the extractor changeovers are coordinated). Without this coordination, less juice concentrate can be produced.

The total amount processed is: 27,000 lbs/bin * 4 bins or 6 hrs. * 18,000 lbs/hr = <u>108,000 lbs/day.</u>

Part C

Part C of the case allows us to look at the final operations in the plant, the storage/test and the blend operations, and connect the process to customers who with to contract for customized blends.

Blending is buffered from the upstream processes with the four tanks which have a capacity to hold more that twice the daily production capacity of the upstream processes. Natural Blends has received some proposals to contract for weekly deliveries of concentrate. If the company accepts a contract, it must deliver the specified number of orders in the contract on a weekly basis while also meeting the specifications for sugar content, color, etc. If there is still available capacity after filling a set of customized orders, Natural Blends can sell as much of its standard blend as it wants, but the maximum order size is 24,000 pounds.

The case states that the characteristics of the concentrate in the four tanks is adequate to accommodate the blend variations (the mix) required to fill any sequence of the orders proposed by the customers. We don't need to worry about having enough concentrate with the right color and sugar content to meet the specifications for any of the proposed contracts. In addition, the case states that Natural Blends has a policy that the amount of tested concentrate in inventory (in the four tanks) is the same at the end of each week. Thus the total amount processed during a week is constant and must be equal to that determined by the capacity of the upstream system. This amount (6 days * 108,000 lbs/day = 648,000 lbs/week) becomes a constraint on blending. A further constraint on the operation of blending is the total available time during the week (6 days * 8 hrs/day = 48 hours or 2880 minutes).

Question 5 *How much time does it take for the blending operation to process one 8,000-pound order from Company A?*

To process one 8,000 LB order from Contract A, a 40-minute setup time is required. The order then is processed at a rate of 22,000 lbs/hr. Assuming that a setup for this order was not conducted at the end of the previous day and must be conducted before processing the order, the time it would take to process 8,000 lbs would be:

(setup time) + (process time) =

(40 minutes) + [8,000 lbs / (22,000lbsper hr / 60 minutes)] = <u>62 minutes per order</u>

This helps us think about comparisons between orders,--a key parameter is how much time is required to process any of the proposed orders.

Some students used other processing rates, e.g., the concentrator production rate of 18,000 lbs/hr to determine the process time. The concentrator rate will set an overall constraint on how much can be processed on a daily basis, but its rate does not determine the time for processing a particular order <u>because</u> the blending operations are buffered from the concentrator.

Question 6a and 6b *Which of the contracts in Table A would you recommend that Natural Blends accept? Why?*

To recommend which orders Natural Blends should accept, contracts should be evaluated by maximizing the contribution (margin) generated per minute while meeting the constraits that on a weekly basis we have: (a) a total process time in blending of 48 hours (2,880 minutes) and (b) a concentrate output of 648,000 pounds. The ratio of contribution for processing a particular order to its blending time must take into account the total blending time required over the week; i.e., the quantity and number of setups required for each contract. **Table C-1** provides a comparison of quantities, processing time and copntribution on a per order and per contract basis. The constraints of total the blending time and output required for the combination of contracts on a weekly basis must also be analyzed.

Table C-1

Contract Name	No. of Orders Per Wk	Quantity (lbs) Per Order	Margin Per lbs ($)	Process Time/ Order (min)	Setup Time Per Contract (min/wk)	Run Time Per Contract (min/wk)	Ttl Proc. Time Per Contract (min/wk)	Quantity Per Contract (lbs/wk)	Margin Per Contract ($/wk)	Margin Per Min ($/wk)
A	24	8000	0.03	62	960	524	1484	192000	5760	3.88
B	18	16000	0.028	84	720	785	1505	288000	8064	5.36
C	**15**	**24000**	**0.026**	**105**	**600**	**982**	**1582**	**360000**	**9360**	**5.92**
D	10	18000	0.024	89	400	491	891	180000	4320	4.85
S	1	24000	0.02	105	40	65	105	24000	480	4.55

Assumptions:

a- weekly processing time = 480 min/day * 6 =2880 minutes

b- weekly production capacity = 108,000 lbs/day * 6 days = 648,000 pounds

As shown in **Table C-2**, the Contracts C, D and S generate the highest contribution, while meeting system process time and capacity constraints. The amount of S that can be blended in the time remaining after filling the weekly C and D contracts isdetermined by the amount of time left; i. e., the upstream system running at 108,000 pounds per day or 648,000 pounds per week can process more concentrate than can be blended if we choose to maximize the contribution. Thus the blending operations will be the ultimate bottleneck for the plant.

time remaining each week after filling Contracts C and D = (2,880 min) - (1,582 + 891 min)

= 407 minutes

number of orders of S possible = (407 minutes available) / (105 minutes per 24,000 lb order)

= 3.88 orders (this would be 3 24, 000 lb orders and one of 21,000 lbs.)

Table C-2 shows includes the calculations and the contributions for this optimal set of contracts.

Table C-2

Contract Name	No. of Orders	Total Process Time <=2880 min	Total Quantity <=648000 lbs	Total Margin ($)
C	15	1582	360000	9360
D	10	891	180000	4320
S	3.86	407	92640	1853
TOTAL		**2880**	**632640**	**15533**

Assumptions:

a- A x weekly processing time = 480 min/day * 6 =2880 minutes

b- A x weekly production capacity = 108,000 lbs/day * 6 = 648,000

While it might be desirable to accept contracts B and C because they generate the highest contributions, to do so would require more blending time than is available during the 6-day work week. These two contracts do exactly meet the total production volume constraint of 648,000 pounds. Other combinations either violate the constraints or they do not maximize the contribution.

Some students interpreted the exam question to mean that only one on the customized contracts could be accepted. In evaluating students' responses here and throughout the exam, we looked for the logic and consistency of the approach given the starting assumptions.