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Using the *Theory of Constraints* to design a farm

Bill Greenley, MS

Swine Graphics Enterprises, L.P., Webster City, Iowa 50595

Introduction

At Swine Graphics Enterprises we have been applying the Theory of Constraints (TOC) to pork production since 1996. This includes the design and relative sizing of facilities, swine management protocols, and production/financial measurement systems. At the 1997 Leman Conference, I presented an overview of the Theory of Constraints and briefly introduced its application to pork production. In this document I will discuss in more detail the problems in pork production that can be addressed by a TOC-based solution and some of the details of such a solution.

This document assumes that the reader has a basic understanding of Dr. Eli Goldratt's Theory of Constraints by having read the book *The Goal* at the very least. Further reading of *It's Not Luck* and *Critical Chain* by Dr. Goldratt is encouraged as is *Constraint Management Handbook* by Drs. James Cox and Michael Spencer. The latter is in textbook format and presents more detail than does Dr. Goldratt in his publications. Those of you who are already familiar with the Theory of Constraints should note that the pork production solution described in this paper bears more resemblance to the TOC Distribution Application (inverted) than to the Production Application.

Overview

Once understood, the underlying philosophies in the Theory of Constraints and their applications are common sense. However, the transition from traditional paradigms about system optimization, management, and standard cost accounting to TOC paradigms requires us to question and then dismiss some fundamental assumptions. One such assumption is that local efficiencies are "good"; that is, many of us assume that if we optimize each process in a system and fully utilize its resources, then the system—as a whole—is more profitable. TOC exposes the dangers of this false assumption.

In TOC terminology, we would say that "the global optimum is not the sum of local optima." In other words, the global optimum (greater profitability) will be characterized by locally inefficient processes, with the possible exception of a single process. In fact, if we strive for local optima, we will sub-optimize the overall system.

Another important principle TOC makes that we will discuss below is to "balance flow, not capacity." In pork production, all facility sizing rules of thumb direct us to design balanced capacity systems: gilt sources to gilts pools to gestation to farrowing to nurseries to finishers.

The reason TOC allows us to make these strong—and negative—claims about optimizing local efficiencies lies in the fact that variation, or statistical fluctuation, occurs around process means. In pork production, we all but ignore variation. For example, a NPPC task force recently compiled a list of key production metrics. Not a single metric in that list addressed variation; only means and rates were considered. Whatever the reasons for this oversight, process variation and the impact of variation in sequential, dependent processes have gone unnoticed or have been taken for granted as "facts of life." Whereas biological variation is indeed a "fact of life" and cannot be *abated*, TOC proposes that such variation can and should be *managed*.

For these reasons, I will examine a pork production system where process capacities are intentionally unbalanced resulting in excess capacity much (but not all) of the time at most processes. I will prove that this approach increases the profitability and return on investment of a pork production system. Furthermore, I will examine the production and financial measurements that I have thereby made obsolete and consider new measurements to use in their place.

Balance flow, not capacities

In any manufacturing environment, material flows through a sequence of processes beginning with release of raw material and culminating in the shipment of completed product to customers. Along the route, the rates at which resources are able to process incoming material to create material ready for the next step (along with some nominal scrap) vary over time. One can envision a flow of material—often arbitrarily grouped into batches—from resource to resource. This flow is characterized by surges and ebbs as fluctuation occurs at each process/resource. In typical manufacturing, these phenomena result in work-in-process inventories momentarily increasing in front of a resource that is temporarily unable to keep up with the rate of incoming material. Another undesirable effect is starving out a resource when incoming material is temporarily unavailable due to upstream process slowdowns.

Overall, the result is an uneven and sporadic material flow through the system. However, in pork production we have the ability to "stuff" material (pigs) through some processes (except for gestation) by truncating their time in a process. For example, we could breed gilts on their first heat, wean piglets younger, move feeder pigs to finishers sooner, or sell market pigs earlier at lighter weights. All of these tricks are practiced to accommodate surges in pig flow. When pig flow ebbs due to above-average pregnancy loss or lower-than-average litter size, for example, then some facilities may sit underutilized as pigs advance to the next stage of production.

Previously, the financial consequences of these common practices have not been well understood. However, Dr. John Deen has done extensive work in developing marketing strategies to maximize marginal profit for a group of pigs in a finisher. Two rules emerge for marketing a load of pigs:

1. Sell pigs when the incremental revenue obtained from postponing their sale is no longer greater than the incremental costs of continued maintenance of the pigs.
2. Sell pigs when the space they occupy is needed by incoming pigs.

Special attention should be given to the definition of incremental costs. Fixed costs are never a component of these incremental costs. In owned finishing or even in contract finishing where the payment is not tied to pigs being present, facility costs are not a component of incremental costs either. Only totally variable costs are considered; these are costs that occur if an additional pig is present and that do NOT occur if one less pig is present. This is very nearly exclusively feed expense. Small, but not to be ignored, is "interest" on the slightly deferred revenue. Clearly other issues are involved as well, such as LP costs in sparsely populated barns, the impact on growth rates and feed conversion of the remaining pigs in the group, etc.

Each time rule #2 is invoked, we can calculate the forgone marginal profit for those pigs sold at a weight lighter than if space had allowed rule #1 to have been invoked. When a surge of weaned pigs enters a nursery/finisher sub-system requiring that an additional nursery start to be populated, then rule #2 is typically invoked to make space for two rather than one barn of feeder pigs. For weekly weaning systems, the number of pigs weaned per week often exhibits a coefficient of variation of 20% or greater. Consequently, marketing rule #2 is invoked quite often.

So called "18-week" finisher sub-systems become "17-week" sub-systems from the week a second nursery is required until a week where all weaned pigs fit into the nursery begun the previous week.

When nursery/finisher facility utilization is emphasized due to some cost accounting mind set (what TOC refers to as "cost-world thinking") then nursery/finisher sub-system space is typically tight. The overall result is that much marginal profit is lost. Group-to-group and within-group variation in growth rate accounts for additional forgone marginal profit in space-limited finisher sub-systems, also.

The technique of transferring remaining pigs to the next group may well allow them more time to grow, but probably is neutral relative to marginal profit, given the growth stall from the transport, the growth stall effected in the destination group, and the herd health impact.

Whereas marginal profit is forgone when a pig flow surge occurs, there is a more obvious profit loss from an ebb in pig flow. A "hole" in production clearly reduces revenue and profit during the affected period. Perhaps in the past we have assumed that surges and ebbs balance out and it is therefore satisfactory to concern ourselves with simple means. This is obviously not true; "holes" in production results in profit forever lost and surges pre-empt growth thereby also sacrificing marginal profit.

One solution would be to over-configure the finisher sub-system so that ample space is available. A simple approach would be to consider the spaces required for peak inventories such that marketing rule #2 was never invoked. Since this is obviously extravagant, then retreat from this level until the facility costs saved by a lesser level are equal to the forgone marginal profit. The reader should observe that this increased finishing capacity level would reduce facility utilization despite the fact that it increases profit. This paradox is common in a TOC solution. Though the extra capacity is not always required, it is used often enough that the marginal profit it provides more than offsets its expense.

Furthermore, we could implement this "overflow capacity" in less expensive approaches. For example, a secondary nursery/finisher sub-system that is continuous flow and dedicated to low-end pigs could truncate the excess number of wean pigs when they occur. Then the protective excess capacity in the primary nursery/finisher sub-system could address variation in growth rate, and pig flow surges can be deferred to the secondary sub-system.

Having dealt with the pig flow surges, we must not overlook ebbs in the pig flow. One approach is to over-configure the sow farms to deliver an average greater than the nursery stocking target. This would reduce the periods when fewer than one nursery were produced and the now more prevalent overflow can be shunted into the secondary nursery/finisher sub-system. The performance of growing pigs in this secondary sub-system might not be impressive, but as long as their revenue more than covers their incremental expenses, they will positively contribute to the system's profit.

Dampen variation in weaned pig production

If there was less variation in the number of pigs weaned per period, then many of the issues discussed above would evaporate. However, variation in weaned pig production is the result of variation in the number of replacement gilts available to breed, variation in breeder females returning to heat, variation in conception and pregnancy retention rates, variation in litter size, and variation in pre-weaning mortality. (Piglets are often weaned early or late in a feeble attempt to counteract these effects. In turn, these practice increases wean age/weight variation.)

All sow farm local efficiency metrics aside for a moment, the mission of a sow farm is to produce W weaned pigs per period with minimal period-to-period variation. As mentioned above, we can financially quantify the negative impact of variance above or below this target on the system's profitability.

Over-configure weaned pig production and truncate the resulting distributions at earliest possible process

For ease in calculation, let us consider two new metrics:

- WPM = mean pigs weaned/female mated; and
- StDevWPM = standard deviation in period-to -period values of WPM

If our target number of pigs weaned per period is W, then the traditional suggestion would be to mate W/WPM females per period in order to produce W pigs per period. However, because of the variation in the rate WPM, this approach is flawed. For example, if we want at least W pigs weaned 97.5% of the periods, then we should mate W/(WPM + 2*StDevWPM).

Given the importance of pig flow, both in terms of magnitude and variation, it is ironic that these metrics are not in the current measurement set for pork production. However, given the traditional paradigm of striving for local optima, their absence is not surprising. Now that we recognize their significance, effort should be devoted to construct diagnostic trees for pig flow rather than for resource efficiency measurements such as pigs weaned per mated female per year. Below we will discuss the concept of buffer management that greatly simplifies real-time management protocols.

In a typical manufacturing environment where inventory "shelf life" is not an issue, then we could use the mean process yield in determining how much material to gate into the sequence of processes. Any excess could simply sit until needed to offset a future deficit. In pork production as in manufacturing where "shelf life" is short, we need to gate more material than is typically required in order to minimize starve-out situations caused by below average upstream process yields. The problem arises as to what to do with the excess that will typically result.

We have already addressed one example of an approach to deal with excess incoming material in suggesting that weaned pig production be over-configured with the excess over target shunted into a secondary nursery/finisher sub-system. This approach can be generalized to the entire pork production sub-system.

In general we should over-configure upstream processes to over-produce and then shunt, sell, or sacrifice the resulting (and variable) excess each period. The amount to over-produce can be calculated in a manner similar to the way in which we determined how much nursery/finisher space to configure.

1. Initially determine a level that will prevent all downstream starve-outs.
2. Calculate the marginal profit forgone by a production "hole" of one pig.
3. Retreat from this peak configuration until the forgone marginal profit is equal to the reduction is incremental expenses.

As we consider options for over-configuring the sow farm, we must pay attention to the variation exhibited by each process in the sequence from replacement gilt to weaning. Remember, this entire exercise is required only because variation exists and where there is little variation there is little need for over-configuration. Also remember to consider only the impact on incremental revenue and incremental expense. Expenses that are fixed relative to these fluctuations in production within some overall production window are irrelevant to our decisions. Computing some "standard unit cost" or transfer price serves no useful purpose relative to these decisions and is in fact totally incorrect as an indication of the incremental cost of additional production or cost savings from reduced production.

As we propose over-configuring sow farm production, particularly in the early processes, we may discover the need for additional gestation space beyond standard rules of thumb that were based on balanced capacity models. Rather than price gestation facilities as $X/sow space, consider incremental building costs. Structures can be extended to add square footage at an incremental cost far less than a standard cost per space just as additional wean pigs may be produced for far less than some calculated value of cost per weaned pig.

If we work backward from weaning, we might be tempted to consider each process individually and then aggregate the individual process yields. This approach is naive to the covariance and colinearity of the individual processes. A better approach would be to aggregate the yield across multi-process sequences as a single measurement. For example, we might consider pregnancy retention, litter size, and pre-weaning mortality as one such chain. "Pigs weaned per female pregnant at N days of gestation" would then be the measurement for which to determine a mean and distribution. We would seek to pull sufficient pregnant breeder females into this sequence so that most of the time—even with below average aggregate yield of this process sequence —there would be at least the target number of pigs weaned.

Since the variation exhibited in pregnancy retention is usually the lowest of the processes being considered on the sow farm, it makes sense to establish a "gate" at the beginning of this process stream. If we could establish a target number of breeder females to enter this "gate" and truncate the resulting upstream production to this level, then the variation of the aggregate yield from this point to weaned pigs would be tolerable to our proposed primary and secondary nursery/finisher sub-system. In fact a coefficient of variation of 5% is achievable for total pigs weaned per period using this approach, with greatly reduced wean age and weight spread.

The transition point between conception and pregnancy retention is somewhat arbitrary and should be defined by the opportunity for observation or determination. Day 21+ or day 42+ of gestation are the logical points. Technologies are available that make this determination accurate and feasible.

So, initially we can establish a target number of breeder females desired to pass through this gate each period. Next we must determine the minimal number of matings per period required to achieve this target, even with above average conception failure (and/or early pregnancy loss). Again we are faced with a decision about the typical excess at this gate. Intentionally recycling or increased voluntary culling of the excess breeder females makes sense. Protocols can be developed to target breeder females for this intervention. Recycling some females has an additional advantage in that there is some flexibility in timing their returns to heat to help dampen variation in breeder females available to mate in a period. In fact this approach dampens the variation in replacement gilts needed each period to make up the deficit with the breeding target to the extent that the gilt pool could be managed on a replenishment basis. The gilt pool size should be sufficient and ages distributed such that even with above average demand for replacement gilts and/or above average gilt pool fallout, sufficient gilts are in heat when needed.

Yet, again, we will typically have some excess. In this instance, the excess will be more gilts in heat than are needed to fill the deficit with target matings. Given the protocol at the gestation "gate," these females could be mated anyway. Alternatively, they could be sold as market pigs. A solution discussed above can be generalized and applied here. Rather than sacrifice premium genetics, a secondary (perhaps backcross) line of replacement gilts could act as the fill for the fluctuating deficit in order to achieve the breeding target. When used, these breeder females could later be preferred cull candidates when increased voluntary culling is allowed.

Buffer management

In previous discussions in this document, many targets were calculated based on distributions in aggregate upstream process yields up to the respective "gate." These targets can and should be dynamic. We can consider the resulting excess at each gate to be a buffer that prevents the respective process from partially starving out. These excesses will themselves exhibit a distribution. As the actual distribution differs from the expected distribution, we can adjust the upstream target up or down appropriately. This monitoring for statistically significant variance between expected and actual and the corresponding adjustment when warranted we call "buffer management." It is common in any TOC-based solution.

When the excess is minimal or an actual deficit exists, we can note the upstream process that is to blame. As an upstream process is observed to be a "habitual offender" it can and should be the target of process improvement to make it more reliable and stable. As upstream processes become more stable through focused improvement, the buffer management mechanism will indicate that the targets can safely be lowered without compromising the marginal profit they protect.

We can recognize that sow herd sizes will fluctuate as these buffers are monitored and the indicated action is taken. The implication is that empty gestation crates will appear from time to time. This is a desired effect. Only if the economics of the secondary nursery/finisher sub-system warrant significant and highly variable weaned pig overflow production should sow farms be allowed to drastically overproduce.

Conclusion

I have identified three "gates" in the sequence of processes involved in pork production:

- breeding
- +/- day 42 of gestation
- weaning

I have also described opportunities for using a primary/ secondary sub-system approach for the replacement gilt and nursery/finisher sub-systems. Lastly, I presented the concept of buffer management as a simple and powerful methodology for monitoring production and focusing improvements.

Sow farms exist in a pork production system to produce a steady and specifically sized stream of weaned pigs to the nursery/finisher sub-system. The traditional goals of local process efficiencies and resource utilization are actually in conflict with increasing marginal profit. Cost control efforts are profitable only if they do not compromise the system's ability to realize marginal profit by a greater amount. Special attention must be made in assessing "improvement" decisions as to their impact on the flows of money into and out of the pork production system. The concept of over-production and over-configuration make no sense with a cost-world mentality but make perfect economic sense when viewed as providing additional marginal profit.

This entire approach is in response to the normal variation that is exhibited by pork production's biologic processes. To date, such variation has been winked at or ignored by the swine industry. An undesirable effect of this lack of appreciation for variation combined with a cost-world mentality has been to design pork production systems with balanced capacities based on anticipated mean process yields. Instead, the Theory of Constraints-based solution calls for unbalanced process capacities sized so that the system's marginal profit potential is protected from normal process variation. This approach not only increases profit, but it deploys assets in a manner that increases return on investment.