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Optimization across requirements: Making a buck out of production data in real time

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Essential Knowledge

Introduction

Owners, managers, veterinarians and consultants have long dreamed of being able to evaluate and optimize the economic implications of changes to pig production systems. This is not possible to achieve fully using conventional tools such as spreadsheets for even a simple, small enterprise. In contrast, the list of variables and requirements that may be supported by optimization models is potentially endless.

Exploring the dynamics of a production system using optimization requires the following (Mayer et al 2005):

- A model of the system
- An objective function to be optimized, e.g. profit
- Input parameters which drive the model and are progressively improved during optimization
- An algorithm for the process of optimization

Optimization lends itself to several important functions. The first is tuning of the model where variables are optimized to give the 'best fit'; an example of this is aligning the model's predictions with real-world production and financial data. In reality, the process of seeking a 'best fit' often involves meeting competing requirements; examples include limited capital or finishing capacity, cost of inputs, variable supply of pigs, and variable specification and price for the product (Deen, 1999). The second key purpose of optimization is to use the objective function, e.g. profit or ROE, to optimize the model. In fact, any variable of the model may be optimized in this way, e.g. total kg sold, weaning age, sow inventory, etc.

Historically, model development has been focused on concise tasks, or a discrete production phase to manage the complexity of optimization. Such models gain precision within their selective domain, but require careful interpretation before applying recommendations to production systems. These sophisticated models may also require special expertise to operate. Alternatively, an all encompassing enterprise model has relatively broader focus, less depth, perhaps less demanding operating skills, and potentially affords more accessibility to a wider audience. Both modeling approaches may co-exist to jointly generate the complementary insight required when optimizing business performance.

- The practical requirements of a broad spectrum optimization model include the following:
- Encompasses the whole production system, while judiciously incorporating the key drivers to limit complexity
- Can be intuitively used by moderately skilled "information providers" or "decision makers"
- Affords flexibility for customization to suit varying production situations and user needs
- Can access existing and emerging electronic data capture sources for calibration and validation
- Integrates with other "deep" models to gain their precision without the burdening overhead of their inherent complexity
- Ability to be focused at both long and short term optimization tasks
- Deliver results within a useful time frame to retain practical value in short term optimization scenarios (Frey 2007).

This paper describes an example of optimization across competing requirements for a multi-site production system using a whole-farm model in commercial use in Australia (ePiggery®, www.primepulse.com.au).

Model structure

The ePiggery® model (see **Figure 1**) is designed to accomplish the following:

- Quantify the change in a production variable (e.g. lean meat yield) in terms of any other production or finance variable (e.g. EBIT - earnings before interest & tax)
- Optimize financial performance through automated variable assignment incorporating the Dupont Model (DiPietre, 1997) using evolutionary algorithms

The model is comprised of a deterministic breeder model linked at weaning to a stochastic progeny population model. This is coupled to a monitoring tool utilizing statistical process control techniques. The optimization model is partitioned into five components that can be mixed and matched to service specific optimization requirements. Each model services a discrete population within the production chain, where upstream dynamics and decisions affect all downstream populations. This modular structure enables any model to be omitted from the analysis process. For example, the Reproductive Model could be used separately to gauge EBIT responses to any reproductive variable (Frey, 2007). Similarly, the Post-weaning and Marketing Models may be linked in tandem to optimize a contract finisher production system.

The model was set up to represent a 5,000 sow farrow-to-finish multi-site enterprise using current Australian benchmark performance data and production operation costs, including current housing asset replacement costs. Reproductive relationships and post-weaning responses to changes in lactation length used in the model have been described previously (Frey 2006, 2007). A lean meat price grid was employed that penalizes moderately outside the prime live weight range of 230-290lbs. Pigs were sold in a single draft at a target live weight of 250 lbs. Baseline settings of the model are shown in **Table 1**.

Sample optimization project objectives

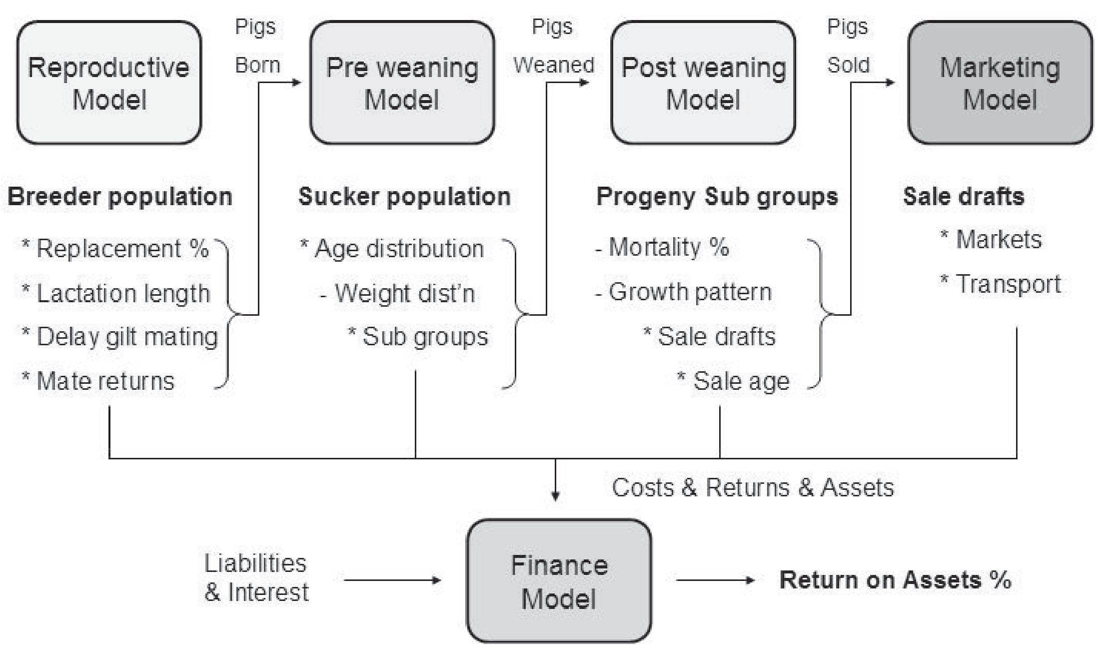
An optimization project incorporating extremes (rather than reality) was contrived to illustrate the process. The project was designed to optimize a complementary breeder and grower strategy, including sale strategy. The following model parameters were fixed:

- Sow numbers set at 5,000 and number of farrowing crates fixed at 1,280
- Initial housing for the entire farrow-to-finish population was established
- A single weaner population was specified which links pre-weaning growth performance to a post-weaning growth curve so that changes in either or both domains can be modeled and optimized, e.g. changes in weaning age and cascading effects (multiple populations could be modeled, e.g. different gender, genotype, weight and variance, etc)
- Time in the nursery was fixed at 56 days
- Sow replacement rate was fixed (but could be varied to reflect changes in reproductive efficiency with changes in lactation length)
- A single price grid system was used (but could be set to explore multiple markets)
- The number of finisher locations was fixed, as was stocking rate
- For simplicity, tax was excluded from calculations (0%)

The following parameters were set to vary for optimization:

- 'Additional' housing could be added as required by the model at current asset value at 5% interest
- Lactation length (weaning age) was set to vary from 14 to 28 days. For simplicity, variance of weight at weaning was set as constant (but could be varied with change in weaning age)

Figure 1: ePiggery® Model Structure



* asterisks denote strategic decisions, and - hyphens denote downstream consequences

Table 1: Baseline settings of the model.

Parameter	Setting
Weaned / female / year	21.23 pigs
Litters / female / year	2.25 litters
Weaned / Litter	9.44 pigs
Average age at weaning	21 days
Sale Age	162 days
Sale Live Weight	248 lbs (112 kg)
Progeny ADG over life	1.51 lb/day (686 g/day)
Progeny FCR over life	2.63

- Finisher days to market was set to vary to allow the model to optimize sale weight (age) and value
- Number of sale drafts was fixed at 4, with the age offset (days between pulls) set to vary

The project was optimized using three different response variables as follows:

- EBIT: to illustrate the effect of optimization on profit independent of capital structure
- ROA: to simulate the effect of optimization where management is financially conservative, the business employs primarily its own capital and seeks to maximize return on assets
- ROE: to simulate the effect of optimization where management has access to capital and can finance against its existing asset base, carry interest costs, etc.

Optimization results

It is not surprising that optimization of multiple input parameters can produce such a substantial increase in profitability (see **Table 2**). It is also not surprising that optimization via EBIT, ROA and ROE resulted in similar sale weight and age, draft offsets and financial outcome, since every subsystem (breeder, nursery and finisher) is fully represented in their calculation. Subsystem differences between the three response variables are summarized in **Table 2** below.

As shown in **Table 3**, sow herd output varies only slightly in response to changes in lactation length. The main drivers of financial outcome in this comparison are differences in farrowing crate utilization and associated asset value relative to lactation length, mortality, throughput, sale weight and value. It is interesting to note that while the model was set to allow addition of extra space if required, the artificially generous farrowing crate capacity set in the base model resulted in changes in facility use without added housing in this instance. Differences in facility utilization are reflected in the housing asset valuation in each optimization.

Discussion

Results depicted in **Table 2 and 3** open an interesting can of worms which illustrate the challenges of being able to explain, interpret and apply the output of optimization modeling across requirements. These can be summarized as follows:

- The process tests the physical constraints you think you started with.
- When a driver variable is changed, you need to understand what effect this has in the model (see **Figure 1**). Said in another way, interpreting the results tests your understanding of the relationships between production and financial variables
- The process tests your understanding of the interplay of financial variables with choice preference and risk aversion
- If the numbers generated by the optimization model don't seem right or you don't believe the outcome, this does not necessarily imply that the model is 'wrong'. Either:
    - You need to drill down to each level of the model contributing to the output to understand how the model arrived at the values of interest, not so much to verify the result as to confirm the process, or

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Table 2: Comparison of optimization results

Response Variable	EBIT ($)	ROA (%)	ROE (%)	Lactation Length	Finisher Days to Closeout	1st Draft Offset (days)	2nd Draft Offset (days)	3rd Draft Offset (days)	Average Sale Age	Average Sale Live Weight
BASE	1,669,160	5.39	5.36	21	85	0	0	0	162	248
EBIT	2,978,010	8.68	9.19	27	107	-18	-15	-9	179.5	290
ROA	2,958,473	8.75	9.21	23	108	-15	-12	-6	178.8	288
ROE	2,971,069	8.74	9.24	23	110	-17	-14	-8	179.3	289

Essential Knowledge

Table 3: Comparison of differences in input variables following optimization

Variable	Units	BASE	EBIT	ROA	ROE
Number of Females	females	5,000	5,000	5,000	5,000
Avg Lactation Length	days	21	27	23	23
Total Born per Litter	pigs / litter	11.66	11.98	11.77	11.77
Pigs Weaned per Litter	pigs / litter	9.44	9.7	9.53	9.53
Litters per Female per year	litters / year	2.25	2.18	2.23	2.23
Pigs Weaned per Female per Year	pigs/yr	21.23	21.18	21.22	21.22
Pigs Weaned per Annum	pigs/yr	106,172	105,922	106,087	106,087
Effective Post Weaning Mortality	%	6.05	4.85	5.65	5.65
Progeny FCR Over Life (LW basis)	ratio	2.64	2.74	2.75	2.75
Progeny Cost of Production	$ / pig sold	147.40	170.73	169.74	170.38
Progeny Sold per Annum	pigs / year	99,749	100,781	100,094	100,094
Days to Market	days	141	163	164	166
Sale Age	days	162	190	187	189
Average Sale Live Weight	lbs	248	290	288	289
Average Sale Value	$ / pig sold	216.92	253.17	252.07	252.81
Total Assets	$	31,542,640	35,273,268	34,749,109	34,999,483
Housing Assets	$	19,644,371	22,406,436	21,909,463	22,080,772
Breeder Housing Assets	$	9,290,600	10,129,492	9,574,563	9,574,563
Progeny Housing Assets	$	10,353,771	12,276,945	12,334,900	12,506,209
Total Breeder Area	m^2	8,498	9,361	8,790	8,790
Farrowing Crates Utilized		1,263	1,197	1,239	1,239
Gestation Stalls Utilized		3,580	3,413	3,524	3,524
Group Breeder Spaces Utilized		631	598	619	619
Total Actual Progeny Area	m^2	24,439	24,439	24,439	24,439
Turns per Year (Finisher Location)		3.99	3.19	3.16	3.11
Breeder Revenue	$ / year	429,159	429,159	429,159	429,159
Progeny Revenue	$ / year	21,637,636	25,514,461	25,230,962	25,304,644
Total Revenue	$ / year	22,066,795	25,943,620	25,660,121	25,733,803
Breeder Costs	$ / year	5,499,026	5,571,619	5,523,711	5,523,711
Progeny Costs	$ / year	14,868,609	17,393,991	17,177,936	17,239,023
Total Costs	$ / year	20,367,636	22,965,610	22,701,648	22,762,734
EBIT	$ / year	1,699,160	2,978,010	2,958,473	2,971,069
Return On Assets	%	5.39	8.68	8.75	8.74
Return On Equity	%	5.36	9.19	9.21	9.24

- You don't understand the cascading effects of the changes you made. This sometimes requires a paradigm shift in common assumptions made about the nature of the production system and the relationships that it is comprised of. This is one of the most stimulating and valuable aspects of optimization modeling.

- Once you have performed an optimization run on a given scenario, the result naturally points to a chain of questions that beg further 'what if…?' inquiry into the model. This is a valuable aspect of fine tuning to enhance the model's precision and predictive value for a given set of circumstances
- Across multiple variables, you are not likely to be able to derive a reliable 'rule of thumb' since it is so subject to the prevailing circumstances that you specify in the model. Results are generally specific to the scenario and system being optimized
- How do you know if the output of the model is telling you the right story? Once you have reviewed and tested your inputs and assumptions, the bottom line is: does the result make biological and financial sense?

Application

Optimization models can be used to investigate, quantify and optimize any aspect of whole farm performance. Examples include optimization of:

- Design and evaluation of price grids including optimization of sale to multiple markets, and interpreting price system payment changes
- Changes in facility utilization, inventory and throughput
- Changes in reproductive strategy, e.g. lactation length, and the cascading effects on reproduction, throughput and subsequent progeny growth (Frey, 2006)
- Any aspect of financial performance including changes in livestock valuation and debt structure
- Auto-sort and marketing strategies (Frey, 2006)
- Planning optimal use of existing facilities or planning and design of new facilities
- Evaluating the cost:benefit of new products or services
- Evaluating performance under variable conditions, e.g. seasonal factors (Beukes et al, 2005)
- Comparative analysis

Conclusion

Pork producers want to reduce costs, increase production and stay profitable in the face of changing economic conditions. Consultants and veterinarians want to understand the complex biological and economic interactions and be able to give sound management advice (Beukes et al, 2005). You can't do this with a spreadsheet; the answer is to use a mathematical process like this. Optimization modeling meets these demands, particularly when performing complex analyses across requirements of the production system.

The ePiggery® model has struck an acceptable, practical balance between the depth and breadth of mainstream optimization modeling requirements. The limitations associated with depth capacity are diminished by integration with other models and real time data capture. Accessing real time data through the use of RFIDs, auto-sort gear and electronic slaughter data provides the critical facility required to compare prediction against reality. The program can thus be used to flip between modeling (optimization) and monitoring (SPC) modes to immediately detect changes in physical and financial circumstance and optimize in either environment. This flexibility provides the capacity to first plan, and then review and refine business strategy as required to preserve or protect predicted profit. As such it provides a much needed generic entry level package suitable for a wide range of industry applications.

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