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Monitoring Growth and Statistical Variation of Grow-Finish Swine

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ABSTRACT

Growth of hogs at the Osborne Demonstration Farm was measured using data from Feed Intake Recording Equipment (FIRE®) performance testing stations with automatic weighing. The effects of starting weights and growth rates on variation in swine market weights was evaluated using best, average, and worst case stochastic analyses. Variation was shown to be caused by differences in growth rate (ρ = 0.698) more than by differences in initial animal weight (ρ = 0.092.) The economic value of proper weighing and selection of market animals and reducing the variation was also calculated. Analysis of marketing returns for a group of hogs showed quadratic reductions in return when animals are not marketed at the optimal weight. Missing the optimal marketing for an example group by 4.5 kg per pig reduced profits by $0.29 to $0.76/head based on market prices between $0.495/kg to $1.10/kg ($22.50/cwt to $50.00/cwt). Better management of animal weights can also add profits by increasing average market weights and decreasing weight variation. A Taguchi quadratic loss function predicted additional profits of $0.77/head by reducing group weight variation from 7.5 kg to 2.5 kg. Predicted profit increases for reduced sort loss were in addition to predicted profit increases for improving average market weight.

KEYWORDS. Weight, variance, optimize, marketing, statistical quality control

INTRODUCTION

Different animals have different weights and different growth rates. Although producers and scientists are interested in the growth differences among animals, reports of experimental results seldom include how treatments affected variation. Even fewer reports quantify the value of reducing variation in groups of animals. The objectives of this report were to:

1. Describe variation in growth and weights of groups of animals under production conditions.
2. Describe differences in market weight of among individual animals in a group and how that variation may arise.
3. Show the economic value of knowing individual animal weights and growth rates and of measuring and controlling variation within a herd.

An Osborne Demonstration Farm experiment (E1) to compare group sizes evaluated the coefficient of variation (CV) as animals left the nursery and when the first animals reached market weight. Six groups ranging in size from 73 to 105 pigs were individual weighed at mean weights of 23.5 kg (51.6 lbs) and again at 96.8 kg (213 lbs.) Feed disappearance, feed to gain, and weight gain were also measured. One treatment grouped animals into four pens on one side of a finishing room. The other treatment maintained all 90 head on the other side of a room with the same pen layout, but with pen dividers removed.

The CV was used to determine if different group sizes increased variation among animal weights. The CV is calculated as the standard deviation divided by the mean weight. Using CV

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to normalize data simplifies analysis when averages are similar by avoiding additional covariant analysis. Use of the CV is not valid if changes in the deviation are correlated to changes in the mean. CV is often used to normalize for variation among groups of similar size, but should not be used to compare small animals at the start of a test to large animals at the end of a test where differences in average weight are large.

A second experiment (E2) collected production measurements to establish baseline measures of swine on the Osborne Demonstration Farm. Osborne FIRE® performance testing stations collected daily measures of individual animal weights and feed intakes. Data was collected on 54 animals with four FIRE feeding stations during one turn of a finishing barn. Average daily gain (ADG) for individual animals was determined by fitting a straight-line to daily weight measures.

WEIGHT VARIATION CHANGES OVER TIME

No significant differences between treatments were measured for E1. The CV at the start of the experiment was 18.2% for the 23.5 kg (51.6 lbs) animals, for a standard deviation of 4.32 kg (9.38 lb.) The standard deviation nearly doubled to 9.63 kg (21.2 lb) (CV = 9.95%) by the time the animals reached 96.8 kg (213 lbs.) There are four hypotheses as to the cause of the final weight variation:

H1. The variation is there at the beginning. The final weight variation would be the same as the starting weight variation if this is the only cause of variation.

H2. Each animal has a different genetic growth rate. Differences in potential growth allow some animals to gain more weight than other animals over a fixed time interval.

H3. Some animals are more susceptible to the stresses present in their environment. Some responses to a stress are positive. Compensatory growth helps animals recover from previous stresses, and cold conditions can cause animals to eat more and grow faster than they would in a more thermal-neutral environment. More often stress is recognized by reductions in intake and growth. The presence of stress is a given, but identifying particular causes is a continuing challenge.

H4. Non-linear growth differences act to increase or decrease weight variation among animals at market weight. For a typical logistic (s-shaped) growth curve, small differences in initial weight will increase as animals reach peak growth, but large differences in weight for animals near their peak growth rate may decrease as animals approach a similar ultimate weight.

A simple linear growth model is used to evaluate the cause of final weight variation. The model uses the starting weights, ending weights, and ADG's measured in E2. Three questions related to H1–H4 are evaluated with the model:

1) What would final weight variation be if all animals grew at the same rate?
2) What would final weight variation be if the animals had started at the same weight, but had different growth rates?
3) What variation would be observed if the lightest animals had the highest growth rate and how would this compare to the variation observed if the heaviest animals had the highest growth rate?

If all animals grew at the same rate, the final weight variation would be the same as the starting weight variation. The starting weight variation for the 54 animals on FIRE performance testing stations was 7.75 kg (17 lb), with an average weight of 23.5 kg (51.7 lb, Table 1.) Over the next 88 days, that variation increased to 11.0 kg (24.2 lb) while the animals grew to an average weight of 103.3 kg (227.3 lb.) This is similar to the group housing experiment (E1) where the standard deviation was 4.29 kg (9.43 lbs) for pigs weighing 23.3 kg (51.2 lbs) and increased to 9.63 kg (21.2 lbs) when the pigs weighed 96.8 kg (213 lbs). Therefore, H1 does not account for most of the variation that was measured. Differences in growth rate (H2, H4) and response to environmental stresses (H3) probably are acting on the animals to increase final weight variation.

Table 1. Actual and model comparisons of animal growth with the same starting weights, or sorted starting weights with inverse rank (best case) or corresponding rank (worst case) ADG.

	Average	Standard Deviation
Actual Start Weight	23.45	7.775
Actual ADG	0.952	0.159
Actual End Weight	103.3	11.04
Same Start Weight	107.3	13.95
Best Case	107.2	6.732
Worst Case	107.2	21.47

A simulation was performed that assumed the animals on the FIRE stations had started at the same weight, but grew at the linear rate measured for each animal. After 88 days, the average animal weight was slightly higher, 107.3 kg, and the standard deviation had increased to 14.0 kg (30.8 lb, Table 1.) Stopping the simulation at 84 days gives similar ending weights (103.5 model vs. 103.3 actual), but the standard deviation is still 13.3 kg (29.6 lb.) The difference in average daily gain among animals (H2, H4) could account for more variation than was actually observed.

The simulation was repeated using actual starting weights but assigning the smallest animals the lowest ADG (worst case) or assigning the largest animals the lowest ADG (best case.) The best and worst case simulations both ended at the same average weight, 107.2 kg (235.8 lb, Table 1.) In the best case, the standard deviation is 6.7 kg (14.7 lb), while the worst case model ends with a standard deviation of 21.5 kg (47.3 lb.)

Actual variation in final weight was similar to the variation calculated in the simulation where the animals start with the same weight. Actual variation was also similar to the mean of the best and worst case examples (14.1 kg, 31.0 lb), suggesting that differences in growth rate (H2) account for most of the final weight variation. There also is a low correlation coefficient (ρ) between ending weight and start weight (0.092), especially compared to ρ of 0.698 between ending weight and ADG. Based on these results, reducing differences in rates of gain among animals will be more beneficial than reducing the variation among starting weights to produce a uniform group of finishing hogs.

A negative ρ is found between starting weight and ADG of –0.451. If the market-weight animals were approaching their ultimate potential weight, a non-linear, exponential-growth rate (Brody, 1945; Parks, 1982) could account for the smaller-starting pigs growing faster than the larger-starting pigs. For this non-linear situation (H4), the smaller-starting pigs would spend more of the experiment near their peak growth rate, giving them a higher ADG.

HOW DOES VARIATION AFFECT PROFITS

Knowing Weights Can Improve Profits by Improving Marketing

Computer software and automated tools to measure weights can greatly enhance a producer's ability to achieve better returns by measuring growth and weight distributions to plan marketing. Selecting the best date to market a group of animals requires knowing what the animals will be worth based on buyer premiums, growth rates, and feed and facility costs. A computer program was developed to predict future animal weights and market value of hogs. The software uses a single estimate of average daily gain, feed conversion, and feed costs to predict animal weight and the production costs (Figure 1.) Starting weights are entered into the program and it then uses average daily gain to predict animal weights on subsequent days. The amount of feed consumed and the feed costs are calculated for the expected weight gain.

This program also computes a market value for each animal, given the animal's predicted weight and a packer's buying program (Figure 2.) A computer can quickly iterate over multiple days and animals to compute expected weights, prices, and feed costs. Future marketing values are calculated as the sum of market price minus incremental costs to feed the animal until the future date. This provides accurate market predictions that are extremely difficult to make manually. The software quickly finds the best return for a group of animals by comparing market values for today and for several days into the future. Following basic economics of sunk costs, no adjustment is made for past production costs.

A realistic example shows the extra income generated when a group of hogs are sold at the right weight. Starting weights were measured by FIRE® performance testing feeders used at the Osborne Demonstration Farm. The 41 starting weights were: 65.5, 85.5, 86.4, 92.3, 93.2, 93.2, 94.1, 95.5, 95.5, 96.4, 96.4, 96.4, 96.4, 96.4, 96.8, 98.2, 98.6, 98.6, 98.6, 99.1, 99.1, 99.1, 99.1, 100, 100.5, 100.5, 101.4, 101.4, 101.8, 101.8, 103.6, 103.6, 103.6, 104.1, 105.0, 105.5, 106.4, 106.4, 106.8, 107.3, and 111.4 kg. This group obviously contained several heavier animals, two smaller animals, and one "tail-ender."

Figure 1. Screen shot of Market Values form used to enter production information.

Production numbers for the example animals were:

- Average Daily Gain: 0.91 kg/d (2.0 lbs/day),
- Feed Conversion: 3.45 feed/gain,
- Feed Cost: $0.1375 /kg ($6.25 /cwt.)

An example buyer had 5 premium levels for under-weight pigs and 5 for over-weight pigs. The base price was $0.495/kg ($22.50/cwt) when these animals were sold. A second set of calculations were made for a base price of $1.10/kg ($50/cwt)

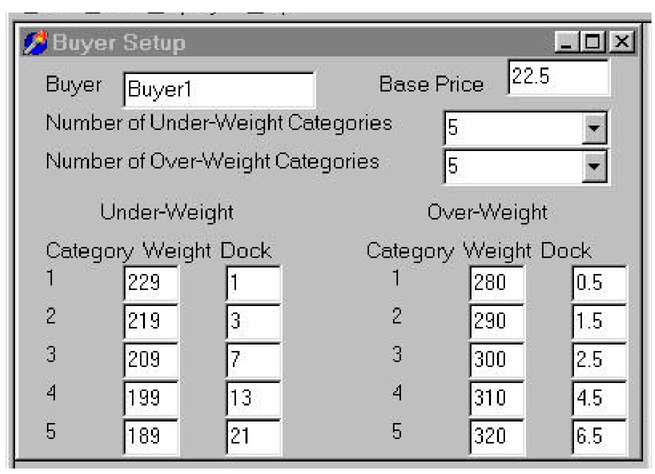

Figure 2. Screen shot of Buyer Setup form used to enter packer premium schedules.

On the day these animals were removed from the FIRE stations, one animal was in the <86 kg (<190 lb) weight class, two were in the 100–105 kg (210–220 lb) weight class, and one was in the 100–105 kg (220–230 lb) weight class. Using that date as a basis, the market price was $2,483.42 for these 41 hogs. Feeding these pigs for those 25 days would have cost $452.81, reducing their market value to $2,030.61.

A comparison was made of the market returns for incorrect estimates of group weights for these animals (Figure 3.) The average pig weight at the optimal market date was calculated as 119.5 kg (263 lbs.) Selling hogs below or above the optimal weight reduces returns in proportion to the difference from optimal weight squared.

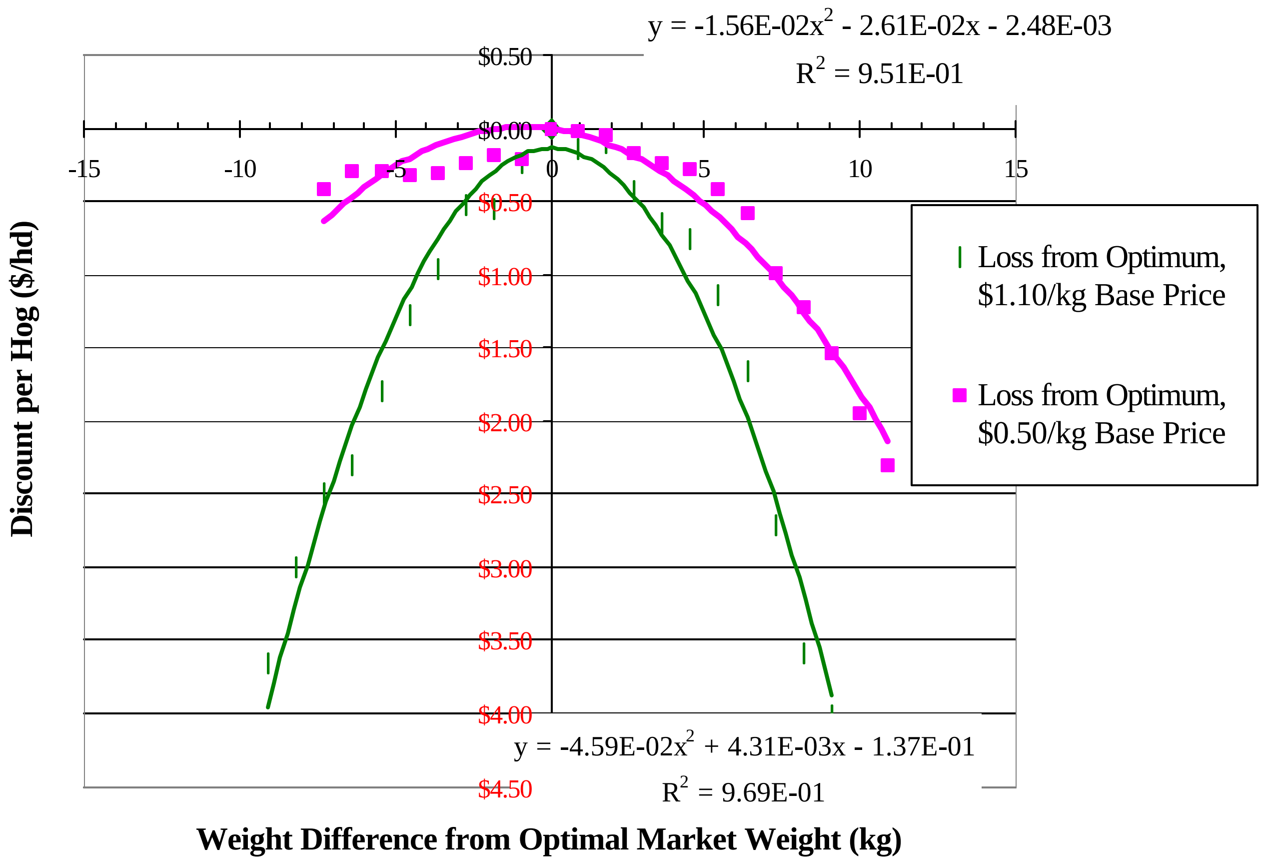

Figure 3. Comparison of discounts per hog for missing optimal marketing weight with different base market prices.

The center of the buyer's preferred weight range was 115.9 kg (255 lb), 3.6 kg (8 lb) below optimal market weight for this group. If the animals were marketed when the group average weight was 115.9 kg, the returns would have been reduced $0.31/head ($0.459 /kg base price) to $0.96/head ($1.10 /kg.)

The return for the 4.5 kg (10 lb) heavier animals was predicted to be $10.78 lower, a loss of nearly $0.29/head under low-market prices. Holding those same pigs another day would decrease total returns $0.42/head. Again, missing the optimal market weight by more than 3 kg (6 lbs) causes greater losses under higher market prices. The equivalent losses of $0.29 for being 4.5 kg (10 lbs) overweight increases to $0.76 as base prices increase from $0.495/kg to $1.10/kg.

Under-weight hogs also reduce profits quickly. Selling 4.5 kg (10 lbs) prior to optimum reduces returns by $0.32/head with base prices of $0.495/kg and $1.29/head under a base price of $1.10/kg. This implies that the average producer estimating animal weights only to within 4.5 kg (Ahlschwede and Jones, 1992) will typically miss the opportunity to make an additional $0.76-$1.30 per hog.

The simple act of weighing animals when selecting animals to sell can improve profitability. For example, the Osborne Demonstration Farm farrows 12 sows per week and thus markets approximately 120 finishing hogs per week. A local buyer pays a premium for animals between 100 and 118 kg (220–260 lbs.) Taking the heaviest animals and a predicted maximum gain of 0.91 kg/day (2 lb/day) for a weekly slaughter group of 120 animals, weights can be within a range of 6.5 kg (14 lbs). To keep all animals under the 118 kg (260 lb) upper weight limit, all animals above 112 kg (246 lbs) should be sold each week, resulting in an average market weight of 115 kg (253 lbs.) The previous marketing strategy sold visually-selected animals above 105 kg (230 lbs.) Over the last two years, this produced an average market weight of 108 kg (238 lbs), 6 kg (13 lbs) below "optimal." Average cost of gain was \$0.46/kg (\$0.21/lb) and average market value was \$0.70/kg (\$0.32/lb) during these two years. A potential existed to make an additional

6 kg/hog * (\$0.70/kg – \$0.46/kg) = \$1.43/head   Eq. 1.

Carcass weights of animals selected based on visual weight estimates had an estimated actual live weight spread of 22.5 kg (50 lbs) instead of 6.5 kg (14 lbs). The lower marketing weight minimized discounts for animals outside of the buyer's desired weight range, but significant discounts still occurred. Realizing the extra \$1.43 per animal requires precise weight selection to keep animals within the buyer's weight specifications. Manually weighing each animal once a week when they exceed 95 kg (210 lbs) for a total of five weights at an estimated cost of \$0.10 per weighing can still return an additional \$0.93/head while keeping animals within the desired weight range. Over 6,240 animals (52 weeks * 120 hd/week), a \$0.93/head return pays for a \$1,300 scale in two years and provide a 50% annual return on investment after that. If this same scale is used on a 1200 sow farm selling four times as many animals, the payback time is ½a year yielding a 200% annual return on investment after that!

Predicting the Value of Reduced Weight Variation

The previous subsection discussed losses caused by missing the optimal marketing date, but there are additional costs for missing the buyers target weight range. Dr. Taguchi (Taguchi, 1981; Quesenberry, 1997) developed a quadratic loss function (L(x)) that can be used to quantify the cost of group variation. The loss function has four properties:

$L(x) \geq 0$ for all x, and is expressed in dollars,   Eq. 2.

$L(\tau) = 0$, because there should be no loss at $x = \tau$ Eq. 3.

$L'(\tau) = 0$, so the loss function has a minimum at $x = \tau$ Eq. 4.

L(x) is expandable in a Taylor series about τ Eq. 5.

Writing out the Taylor series expansion gives:

$$L(x) = L(t) + \frac{L'(t)}{1!}(X - t) + \frac{L''(t)}{2!}(X - t)^2 + \ldots \qquad \text{Eq. 6.}$$

Because $L(\tau) = L'(\tau) = 0$, the Taylor series expansion can be reduced to the dominant term:

$L(X) \cong k(x - \tau)^2$ Eq. 7.

The loss function can be calculated by fitting a quadratic function to the buyer's discounts. For the buyer discount table given in Figure 2, the discount function would be:

$L(x - \tau) = 0.01749\ (\$/kg^2)\ (x - \tau)^2$ Eq. 8.

Different average loss values (ALV) can then be calculated using:

$ALV = E[0.01749\ (\$/kg^2)\ (x - \tau)^2]$ Eq. 9,

or substituting for the estimated mean square values:

$ALV = 0.01749\ (\$/kg^2)\ (\sigma^2 + (\mu - \tau)^2)$ Eq. 10.

This equation can quickly be used to replicate the results shown in the previous subsection for different means (μ) and deviations (σ) to quantify the cost of poor quality control in reduced profits (Table 2.) Following the example of the previous subsection, improved selection of market animals can reduce total variation from 22.5 to 6.5 kg (49.5 to 14.3 lb), similar to a reduction in sigma from 7.5 kg to 2.5 kg (16.5 lb to 5.5lb.) The reduced variation and difference from the new target weight can be substituted into equation 9, to show a reduction in the average deduction per pig from

Table 2. Average loss values (\$/pig) for differences in average weights from target weight ($\mu - \tau$, kg) and for different variations (σ, kg) in group weights. Underlined values used in examples given in text.

	σ, kg		
$\mu - \tau$, kg	2.5	5.0	7.5
0.0	\$0.11	\$0.44	\$0.98
2.5	\$0.22	\$0.55	\$1.09
5.0	\$0.55	\$0.87	\$1.42
7.0	\$0.29	\$0.61	\$1.16
7.5	\$1.09	\$1.42	\$1.97
10.0	\$1.86	\$2.19	\$2.73

$0.98 to $0.11, an increase in profits of $0.87/pig just in reduced discounts. This does not include the previously calculated profits of $0.93/pig by increasing average weight.

Increasing the average weight shifts the target weight further from the center of the optimal weight range, which is expected to increase the number of overweight animals. A tradeoff can then be made for the quadratic decrease in returns from more animals being overweight against the linear increase in return for higher weights. The optimum return occurs at the point of maximum difference between the linear increase in return for higher weight minus the quadratic loss calculated for having more over-weight animals (Figure 4). The target weights are essentially the same in this case, but the calculated return is greater because it includes the expected returns for fewer discounted animals. At the 7 kg (15 lb) heavier target weight, the net additional return (Table 2 and Equation 1) is:

(+0.98-0.29)($/head) + 7 kg * (2.2 lb/kg)($0.32/lb – $0.21/lb) = +$2.38/hog Eq 11.

The $2.38/head improvement for reduced variance and increased weight is $1.05/head more than the $1.43 calculated for just the heavier weight. Applying the $0.50/head investment for weighing each animal several times and recalculating the payback on 6240 head/year yields $1,173/year. This pays for a $1,300 scale in 13.3 months and provides a 90% annual return on investment.

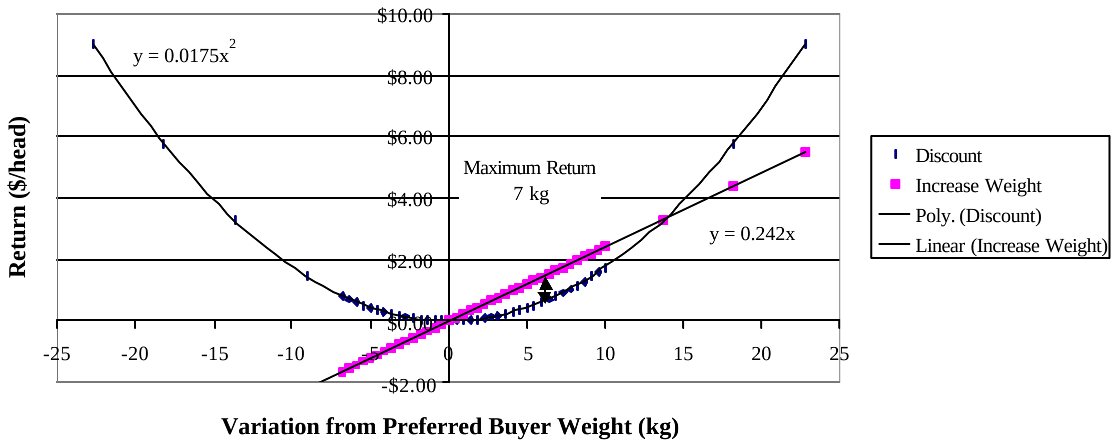

Figure 4. Taguchi quadratic loss function for animal weight variability and linear increase in return for heavier animals.

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