Integrated Resource Management Through Mathematical Optimization Techniques

D. A. Dargatz
W. C. Miller
USDA:APHIS:VS
555 S. Howes, Suite 200
Fort Collins, CO 80525 USA

Introduction

Recent years have been good to cattlemen with most segments of the beef industry showing profits. For a variety of reasons, including an expanding National beef herd, reduced grain stocks and thus increased feed costs, and a lack of growth in beef demand, profit margins are projected to shrink in the coming years. A significant proportion of cow/calf producers may show negative profits in the future, this could be especially true for those with smaller herds. Because of this, there will be increased interest in production efficiency and cost containment. Since producers are mostly price takers, most will rely on reducing production costs to increase profits. Relatively little has been done to evaluate the effect of animal health on production costs and profits. In most cases these investigations have taken a partial budgeting approach focusing on the parameter of interest and neglecting the remainder of the operation. A more holistic approach to the evaluation process is desireable as it is more realistic. The beef operation is complex, making use of a wide variety of resources and having seemingly unlimited options for combining them. This complexity makes the manual consideration of animal health impacts on profitability in a holistic manner impossible and necessitates an approach more encompassing than partial budgeting. Mathematical modeling and specifically linear programming is ideally suited to consideration of such complex issues. A series of mathematical formulas are derived that describe the operation. There is a single objective function which is an equation to be evaluated and maximized or minimized. Frequently this objective function is an equation describing net returns for the operation. The remaining equations are constraints for the model that describe the amount of resources available such as the amount of labor available, and the amounts of resources required for activities such as the amount of protein required for cows in a specific stage of gestation. The model then evaluates the objective function (net return) and the constraints to describe the optimum (maximum net return) use of the resources available and the best mix of activities (how should the resources be used) given the many constraints on resources described. Rather than focus on a single issue such as lowering feed costs which can result in other changes not considered, such as reduced reproductive performance, the model allows for the investigation of changes to a specific program in light of the operation as a whole. The purpose of this investigation is to assess the relative economic impact of various health and reproductive performance parameters on the operation's profitability using a mathematical model that will allow the simultaneous consideration of impacts throughout the ranch enterprise.

Materials and Methods

A linear programming model was constructed to simulate the operation of a typical cow-calf operation in the Rock Mountain West for a one-year planning horizon. The objective function of the model is a net revenue or profit function. The constraints of the model limit the herd to 100 cows. Herd activities are propagated through six periods that compose the entire year (Table 1). Resources such as land and labor are also limited. In the current model, all calves are sold at weaning. Replacement heifers are selected from a pool of heifer calves from the previous calving season. The calving season is subdivided into 21 day intervals and replacements may only be selected from heifers born in the first two 21 day periods of the calving season. This maximizes the probability that they are of sufficient size to cycle and become pregnant during the breeding season. If a sufficient number of heifers are not available heifers may be purchased. The ability to alter health and reproductive efficiency were programmed into the model. The impact of disease is mediated through

Table 1. Model periods for Rocky Mountain region.

Seasons	Dates	Major Activities
1	11/1-12/31	Weaning and sale of calves
2	1/1-3/31	Last 3 months gestation
3	4/1-5/14	Calving
4	5/15-6/30	Calving continues Breeding begins
5	7/1-8/31	Hay harvest Breeding continues
6	9/1-10/31	Grazing meadow aftermath

decreased performance (e.g., lower weaning weights) or death loss. In addition, the opportunity exists to incorporate costs of treatment and extra labor requirements. The price for inputs and outputs was standardized for all runs of the model (Table 2).

Table 2. Prices for inputs and outputs.

Cull cows	$45/cwt
Bulls	$1600/hd
Cull Bulls	$850/hd
Replacement heifer purchase	$750/hd
Sales-Steers	
> =534	$85/cwt
500-533	$87/cwt
467-499	$89/cwt
434-466	$91/cwt
402-433	$93/cwt
370-401	$95/cwt
< =369	$97/cwt
Sales-Heifers	
> =497	$80/cwt
447-496	$82/cwt
406-446	$84/cwt
363-405	$80/cwt
321-362	$88/cwt
298-320	$90/cwt
< =287	$92/cwt
Hay-sale	$78/ton
Hay-purchase	$80/ton
Corn-purchase	$.06/#
Protein supplement-purchase	$.07-.17/#
Labor	$5/hr.

A baseline model was selected and the outcome of all other models were compared against the baseline model (Table 3). For all runs of the model, resource availability for land, labor and capital were held constant. A series of health and reproductive parameters were targeted for investigation and these include; 1) death loss of calves in the first three months, 2) death loss among cows, 3) bull to cow ratios, 4) calf morbidity in the first three months, and 5) calving profile (i.e., percentage of cows and heifers calving by 21 day period). For each of these, a reference value was identified to be used in the baseline model and thus to which other models would be compared (Table 4). A range was identified over which the parameters would be perturbed to assess the impact on profitability (Table 4). In the case of the calving profile a series of profiles indicative of various disease or management problems was used (Table 5). Changes in parameters were investigated one at a time to avoid confusion associated with compound effects.

Table 3. Baseline model activities.

Cow herd size	100 Head
Public grazing	600 AUM
Irrigated pasture	120 acres
Deeded pasture	1600 acres
Labor	1 person

Table 4. Reference values and ranges for health and reproductive parameters.

Activity	Reference	Range	Increment
Calf death loss < 3 months	4%	0%-25%	1%
Cow death loss	2%	0%-5%	1%
Bull to Cow ratio	1:25	1:15-1:60	1:5
Calf morbidity (decreased weaning weight)	0%	0%-15%	1%

To allow the widest possible application of the model results, the impact of calf morbidity was manifested by reductions in productivity (i.e., total and average weaning weights). A specific disease or effect need not be assumed allowing exploration of the impact of a diagnosed or undiagnosed disease syndrome. Instead some overall effect is observed on weaning weight of calves. In fact, this fits best with actual practice at the ranch where a disease outbreak is translated to a decrease in the total pounds of calf weaned and this is compared to the total pounds of calf expected to be weaned in the absence of the disease. A large effect, for example 15% decline in overall weaning weight, maybe seen with severe disease with moderate incidence or a moderate disease with high incidence.

As each parameter was altered incrementally over the allowable range, the model was exercised and the projected profit recorded. The ratio of these values to the value for the model at the reference value were then plotted to show the relative impact of the parameter over the range. In addition, since the model is free to alter the mix of other activities (eg. the purchase v raising replacements, the type of feeding program, or whether the cattle operation would exist all all) any changes in the mix were noted.

Table 5. Calving profiles; Percentage Calving by 21 day period, length of calving season, and median calving day.

Profile	21 Day Period 1	2	3	4	5	6	7	Overall percentage calving (%)	Calving season (days)	Median calving day
1	62	27	11	0	0	0	0	95	63	20.8
2	51	26	11	6	6	0	0	95	105	29.4
3	42	22	11	7	6	6	6	95	147	43.1
4	31	17	6	6	11	17	12	95	147	62.6
5	22	13	8	12	19	13	13	95	147	70.1
6	16	11	15	10	11	16	21	95	147	77.9
7	16	26	41	17	0	0	0	95	84	43.9
8	16	26	36	16	6	0	0	95	105	46.2
9	10	20	31	16	11	6	6	95	147	60.9

Results

The base model with all parameters set to their reference value would predict a profit for the operation of $36,476. All of the projected profit values will be reported as a ratio to that value.

Bull to Cow Ratio

As expected, a reduction in required bull power while maintaining similar fertility levels resulted in decreased costs and consequently increased profits (Figure 1). The decreased costs were largely due to feed savings. The mix of activities remained largely the same over the range of values for bull to cow ratios. The increase in profit is non-linear over the range of values investigated. Changing the bull to cow ratio from 1:15 to 1:20 results in a 4% increase in profit or a change from profit ratio of .94 to a profit ratio of .98. At the other end of the range of interest, a change in the ratio from 1:55 to 1:60 results in a .2% increase in profit or a change from a profit ratio of 1.0415 to 1.0444.

Calving Profiles

As the calving season becomes more prolonged, profitability of the operation decreases (Figure 2). This is in spite of the same percentage of exposed cows calving and increased prices for lighter weight calves born later in the season. Moving from a 63 day calving season (profile 1) to a 105 day calving season (profile 2), still with good concentration of calving early in the season, results in a nearly 2 percentage point decrease in the profitability. This is the result of shifting the median calving day by 8.6 days. Maintaining the same level of overall fertility (95% of exposed females calve), but simply delaying conception into the fourth, 21 day period, results in a profit nearly 8% below the reference value (comparison of profile 1 and profile 7). In this profile the median calving day is 43.9 days com-

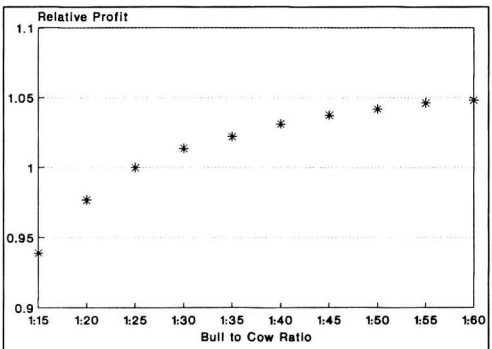

Figure 1. Relative profit achieved by varying bull to cow ratios.

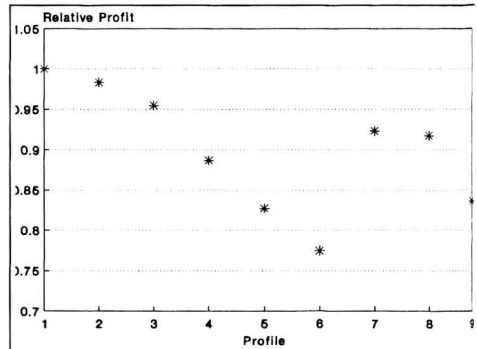

Figure 2. Relative profit achieved by varying calving profile.

pared to 20.8 days for profile 1. As the calving season is extended to 105 days with a relatively normal distribution (profile 8), the profit declines further all be it a small decrease (relative profit 0.923 v 0.918 respectively). The median calving day is 46.2 days. Increasing the calving season to the full 147 days (profile 9) results in another severe decrease in profit to a value 16% below the reference value. The median calving day in profile 9 is 60.9 days. When the calvings are distributed rather evenly across all of the 21 day periods in a 147 day calving season (profile 6) and the median calving day is 77.9 days, the most severe effect on profit is seen, approximately 22% below the reference value.

For profile 1, 2, and 3, the mix of activities remain essentially the same. For profile 4 fewer replacement heifers are sold in order to support a steady replacement rate. For profile 5 no replacements are sold and in fact 2 heifers are purchased. Profile 6 requires the purchase of 6 replacement heifers. Profiles 7 and 8 are essentially similar to profile 4 with 2 replacements being sold and none purchased. Profile 9 results in the purchase of 4 replacements to maintain the 20% culling rate.

Calf Mortality

Relative profit is a linear function of the calf mortality percentage (Figure 3). A 4% death loss is the reference value. Saving 2% more calves results in a 1.7% increase in profitability. Increasing the death loss to 10% results in an operation that is only .93 times as profitable as the operation with a 4% calf death loss. A 20% mortality among calves results in an operation .82 times as profitable as the base operation.

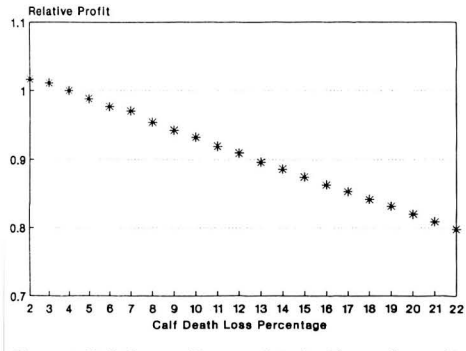

Figure 1. Relative profit associated with varying calf death loss percentage.

Discussion

The model appeared relatively stable over all of the ranges of parameters tested. From the author's past experience the model would seem to accurately portray ranching operations in the Rocky Mountain region. These analyses show that gains may be made by altering management practices and also demonstrate the relative impact of health problems on the profitability of the enterprise. The modeling approach of this investigation is unique in that unlike a partial budgeting approach, the mix of activities is free to change as the parameter of interest is altered. This represents a more holistic approach to investigating economic impacts.

Bull to Cow Ratio

The model would indicate that profit could be increased nearly 3% by altering the bull to cow ratio from 1:25 to 1:40 if the same reproductive efficiency could be maintained. Some would say that at a ratio of 1:40 we have not yet begun to tax the bull's reproductive capacity. In this instance, a difference in profit of $1026 would go a long way toward paying for breeding soundness evaluations as an insurance policy. The response in profitability is non-linear due to the fact the smaller and smaller portions of a bull (and therefore feed costs) are saved with each incremental change in the bull to cow ratio. For example, for a ratio 1:15, 6.67 bulls are required while for a ratio of 1:20, 5 bulls are required, a difference of 1.67 bulls. At the opposite end of the range, a ratio of 1:55, 1.81 bulls are required while at 1:60, 1.67 bulls are required, a difference of .15 bulls. Since virtually all of the increase in profit is accounted for by decreased costs of feeding bulls, the profit function is closely related to the number of bulls required by the model.

Calving Profiles

The negative impact of prolonged calving seasons is to be expected. In spite of increased prices for lighter weight calves born later in the season the pricing structure pressures cattlemen to raise calves with heavier weaning weights. The model demonstrates well the impact that prolonged calving seasons can have on profitability. Relatively small changes in the median calving day can have large impacts on the relative profit of the enterprise. For example, the 8.6 day shift between profile 1 and profile 2 resulted in a nearly 2% decline in profits. Some of the impact of the prolonged calving season could be recouped if accurate predicted calving dates could be obtained and groups of cows managed differently (fed differently) based on gestational age of the calf. In the current model it is assumed that the herd is managed as a single unit and that the nutritional program is based on the calendar rather than the stage of gestation of the majority of animals. Some of

the impact of the prolonged calving season is due to the need to purchase replacements to enter the breeding herd since heifer calves born late in the season likely will not achieve sufficient weight to cycle and conceive in a reasonable time frame in the subsequent year.

Calf Mortality

Calf mortality can have a large impact on profitability. Saving a few more calves can have an impact on the profitability however, the cost of saving the additional calves must always be weighed against the gain. In spite of rather severe death losses among calves the model did not suggest that the operation was not viable. This is in contrast to what is often seen in real life. Frequently we associate things like high death losses with insolvency. It is likely that the insolvency is multifactorial and that the operation has other problems as well as the calf mortality. In addition, the model considers only the current planning year and does not easily allow for investigation of effects across multiple years. Under the current formulation of the model, the profitability is a linear function of the death loss among calves because the model is accounting for decreased sales of calves almost exclusively. The model is not currently accounting for the treatment costs for sick calves so the impact is likely to be a conservative estimate. It is assumed that cows losing calves (except for those losing calves in the perinatal period) will be retained in the herd and will not be managed separately from the remainder of the herd. A future modification of the model is anticipated to allow cows losing their calves to be fed differently until they enter the breeding pasture and to allow a variable number of these cows to be retained in the herd.

This model represents a first attempt by the National Animal Health Monitoring System (NAHMS) to evaluate the economic impacts of animal health and health management in beef herds in a more holistic manner. The model will continue to be developed to account more accurately for differences in ranching enterprises and to facilitate the investigation of economic impacts of health and management. It is evident that management strategies can be changed to overcome some of the costs associated with animal health problems. As we continue to develop more sophisticated models that parallel the opportunities and experiences of managers in the real world, we can gain many insights into appropriate responses to events and do a better job of planning for the future. These results should help focus future research that is aimed at helping the cow-calf industry become more efficient and boost net returns.

Summary

Linear programming can be used to assess the economic impact of health issues and management for beef cattle operations. The current model shows that substantial increases in relative profit may be achieved by increasing the ratio of cows per bull for breeding. A 3% increase in profit is projected by moving from a bull to cow ratio of 1:25 to 1:40. In addition, the distribution of calvings over the calving season can have dramatic effects on the profitability of the operation. A prolonged calving season (147 days) can result in an operation only 77% as profitable as an operation with a 63-day calving season. A calf death loss of 15% is projected to result in an operation only 87% as profitable as an operation with a 4% death loss.