Improving Decision Making by Consideration of Type I and Type II Error Costs

Michael W. Overton, *DVM, MPVM*
University of Georgia, College of Veterinary Medicine, Department of Population Health, 501 D. W. Brooks Drive, Athens, GA 30602, moverton@uga.edu

Abstract

Dairy producers must make good decisions regarding potential new products or interventions in order to optimize profitability. Choosing to use a product that does not yield a profitable response is an example of a type I error. The concept of minimizing type I error cost by good decision making is usually intuitive. However, the concept of "lost opportunity cost" is a bit more nebulous. The choice of not using a product that in reality would have returned a profit is an example of a lost opportunity or a type II error cost. Calculation of the error costs for a single product with sound research is straightforward. Applying this concept to reproductive interventions is more problematic due to the difficulty in measuring the value of reproductive change. The model presented in this paper attempts to quantify the value of improved reproductive performance by estimating the value of the change in milk production, the value of calves produced, and the effects of culling changes. Application of type I and type II error theory to the question of "should TAI be used" yielded different results in the two examples. In the first scenario, the conclusion reached was that overall, herds with a baseline pregnancy rate (PR) of 16% or less utilizing AI based upon detection of estrus should carefully consider the use of TAI based on the large advantage of type II vs type I error costs. However, in scenario two, herds that have already achieved a PR of 17% have less to gain economically by making the reproductive management change.

Résumé

Les producteurs laitiers doivent prendre les bonnes décisions par rapport aux nouveaux produits et aux novelles interventions pour optimiser la profitabilité. Le choix d'un produit qui n'est pas profitable représente l'équivalent d'une erreur de type 1. Le concept de minimisation des coûts associés aux erreurs de ce type par une prise de décision éclairée est souvent intuitif. Toutefois, le concept des coûts d'opportunités est moins bien connu. Le choix de ne pas utiliser un produit qui aurait été bénéfique est un exemple de coût d'opportunité ou d'erreur de type 2. Le calcul du coût associé à ces erreurs, basé sur une solide recherche, n'est pas compliqué pour un simple produit. L'application de ce concept aux interventions en reproduction n'est pas aussi simple en raison de la difficulté à évaluer la valeur d'un changement au niveau de la reproduction. Le modèle détaillé dans cet article tente de quantifier la valeur d'une amélioration de la performance de reproduction en estimant la valeur d'un changement dans la production du lait, la valeur des veaux produits et l'effet des changements au niveau de la réforme. L'application de la théorie des erreurs de type 1 et de type 2 au problème de l'insémination artificielle (IA) sur rendez-vous a donné des résultats différents dans deux cas. La conclusion dans le premier cas est qu'en général les troupeaux qui ont un taux de gestation de base de 16% ou moins et qui utilisent l'IA à la détection de l'œstrus devraient considérer avec soin l'utilisation des IA sur rendez-vous compte tenu du grand avantage des coûts d'erreur de type 2'par rapport à ceux de type 1. Dans le second cas, toutefois, un changement dans la régie de la reproduction est moins avantageux économiquement pour les troupeaux qui ont déjà atteint un taux de gestation de 17%.

Introduction

Dairymen routinely make decisions in a risky and often, uncertain environment. They are presented with opportunities purported to help grow their business or improve the economic status of their dairy. Some choices involve a large amount of uncertainty, a situation where all possible outcomes are unknown or the probability of potential outcomes is unknown. Other decisions involve risk, the situation where possible outcomes are known, along with the probability for each, but the outcome is uncertain. In other words, risk is mathematically measurable and uncertainty is not.

For each of these types of decisions, there are tools or management approaches available to help decrease the probability of incurring an economic loss. In the case of uncertainty, for example, a dairy manager may be faced with the prospect of hiring a new breeder. He may not have any information about this individual other than a letter of recommendation, but as a form of risk management, he will probably want to put this individual through an employee training program, followed by working with the current breeder or herdsman, and then limited breeding responsibilities for a period of time. Mistakes by an inseminator can be very costly if his responsibilities include a large proportion of the milking herd, and these mistakes may be compounded by the time delay necessary to determine the outcome. In the case of a large dairy herd, a couple of months of breeding may pass before a decision is made that conception risk has dropped below acceptable levels. In a small herd, the total dollar value of this decline in reproductive efficiency is smaller, but on a *relative* scale, may be more costly to the dairy. Small herds often cannot generate numbers quickly enough to make confident decisions due to normal variation and a much smaller sample size, resulting in a delay in making management interventions.

In the case of other decisions, there may be much more information available. For example, if a salesman approaches the dairyman about feeding product "XYZ", he will probably look at the available scientific literature to help objectively critique this product. He may also rely on expert opinion from his veterinarian or nutritionist for their subjective assessment and own experiences in other dairies. The goal is to gather information regarding the likelihood that the product will deliver as promised. Lower levels of variation around the predicted results, and multiple studies documenting the results across a variety of dairy conditions, improves his potential decision making accuracy. Ultimately, the manager must decide if the economic investment will deliver a profit to his business or not. This decision has one of four potential outcomes as shown in Figure 1.[2]

In this figure, there are correct and incorrect decisions possible, depending on the actual performance of product "XYZ". Correct and profitable decisions have been made when the dairyman chooses to use product "XYZ" and it delivers a profitable response (quadrant 1) or when he decides not to use this product because in actuality, it fails to deliver a profitable response (quadrant 4). Conversely, incorrect economic decisions are

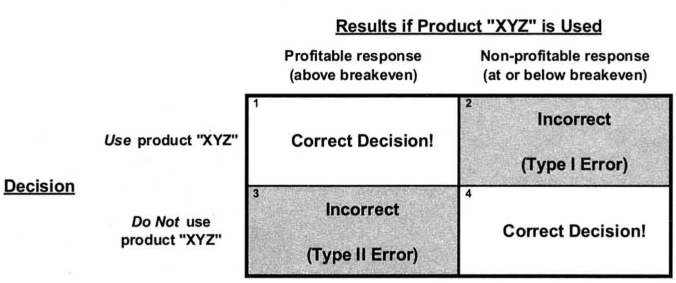

Figure 1. Potential decisions and corresponding outcomes that illustrate the concept of type I and type II error.

also possible. If the producer chooses to use a product that does not deliver the expected profitable response (quadrant 2), a type I error has occurred. If he chooses not to use product "XYZ", when in reality it would have made him money (quadrant 3), he has incurred lost opportunity cost by failing to use it and thus, made a type II error.

Obviously, other variables besides long-term profitability impact daily decision making on dairies. Tangibility of results may significantly impact how decisions are made. For example, if a product has an immediate, explicit result (such as five additional pounds of milk per cow that appear very soon after product adoption), it is much more likely that adoption of that product will occur. However, if the product or technology delivers similar, but delayed results, many producers may not adopt its use, often due to a failure to recognize a direct cause and effect relationship.

The concept of magnitude of risk vs. reward also comes into play on dairy decisions with producers being more hesitant to adopt high cost products, even if research indicates profitable responses. Many producers are risk averse to these large capital investments, or due to cash flow issues, fail to invest in opportunities that would appear to be profitable over the intermediate-to- long term.

Reproductive management programs are an example of an investment opportunity with an intermediate time horizon that often requires a significant level of initial capital and time investment. Many producers are reluctant to invest significant capital in the form of hiring additional labor or the use of reproductive hormones and timed artificial insemination (AI) programs due to the delay in payback and due to the risk involved. The objective of this paper is to demonstrate the application of type I and type II error theory for economic decision making by utilizing the example of adoption of a total timed AI breeding program.

Materials and Methods

A stochastic simulation model was built using Excel® spreadsheets and @RISK® simulation software to mimic the potential economic returns associated with improving reproductive performance, as previously described.[1,3-6] Briefly, distributions describing conception risk (**CR**) and breeding submission risk (**BSR**), fit from California dairy data, are used to mimic the normal variation seen between and within dairies across different 21-day breeding cycles. Daily milk and 305-day mature equivalent milk production estimates were also obtained from a variety of dairies and used to fit lactation persistency curves based on day in milk and level of herd milk production. Milk price estimates, market cow values, wet calf values, stillbirth risk, labor wage estimates, pharmaceutical costs, feed costs and other key inputs, derived either from published work or adapted from actual herd data, were set up as model inputs. Herd removal risks were obtained from herd records and mathematically adjusted from 30-day to 21-day intervals to fit with the breeding cycles. Simulated pregnancy rates (**PR**) were obtained by multiplying randomly generated samples from the CR distribution and BSR distribution for each 21-day period.

Changes in PR and culling risk impact the herd's predicted average day-in-milk and the number of pregnancies generated. Economic impact of changes in reproductive performance is estimated by comparing simulated herd data for the reproductive program in question with a baseline program. The baseline breeding program is a simple estrus detection-based reproductive program with CR and BSR distributions at each 21-day interval following a predetermined voluntary waiting period. The CR, BSR and resulting whole-herd PR for the baseline program in this paper was set at approximately 31, 51 and 16%, respectively, and remained as a deterministic output for comparison purposes. The potential breeding period was twelve 21-day cycles for a total of 252 days of breeding, with a 50-day voluntary waiting period.

The baseline program is then compared to a total timed AI program (**TAI**) based upon a Presync-Cosynch 72, with a day 32 resynchronization.[7] This program includes an injection of prostaglandin F2α at approximately 36+/- 3 days-in-milk, followed in 14 days with a second injection. After an additional 14 days, cows receive an injection of GnRH, followed in seven days with another prostaglandin. At 72 hours, the final GnRH injection is given along with a timed insemination, resulting in an expected first insemination at 74+/3 days in milk for the herd. No estrus detection is used. In the model, no ultrasound is used and instead, all cows are given an injection of GnRH 32 days post-breeding. In seven days, cows are examined via palpation per rectum; non-pregnant animals are given a prostaglandin injection and then proceed to complete the Cosynch portion of the TAI. Following this schedule, all non-pregnant cows are re-inseminated every 42 days until the breeding period is concluded.

Compliance to the TAI protocol will dramatically affect both the cost incurred and the benefit derived for the program. Compliance was defined as the proportion of cows starting a program that received each of the injections and the insemination. The compliance distribution was best described by a beta general distribution with a mode of 92%, a mean of 88%, a median of 89%, a maximum of 99% and theoretical minimum of 60%. Cows that received an insemination incurred the entire cost of the injections, as per the schedule, and non-compliant or culled cows incurred half of the cost of the protocol.

The economic value of the change in reproductive efficiency due to the TAI is estimated by use of partial budgeting approaches and comparison of the marginal return predicted from the new program compared to the baseline.[8] Sources of revenue include milk per cow per day over the year and annualized value of calves and market cows. Expenses include cost of breeding management, replacement costs, marginal feed consumed, feed for any additional dry cows, and any housing, labor or medical expenses for the additional dry cows (if reproductive efficiency improves). Finally, the difference is adjusted for the time value of money, since returns occur in the future. All net returns are reported as dollars gained (or lost) per lactating cow slot on the dairy per year, which represents the average herd size. The simulation software utilizes Monte Carlo sampling and runs 1000 iterations, displaying the results as probability distributions, with an expected mean and 90% confidence interval.

In my previous paper that was presented at the 39th Annual Conference of the American Association of Bovine Practitioners, the distribution of expected economic returns from the use of TAI had a mean of $19, with a 90% confidence interval of ($25) to $42, as shown in Figure 2.[5] However, this set of returns was based upon deterministic inputs of milk price of $13.00/ cwt, herd production of 24,000 lb (10,909 kg) 305ME, and a cash cost for replacements (purchase price minus market cow value, minus cost of dead and condemned cows) of ~ $1400.

In order to more accurately evaluate the wide range in expected returns across the US set of dairy herds, input variables were reset to sample out of distributions for milk price, herd milk production and replacement

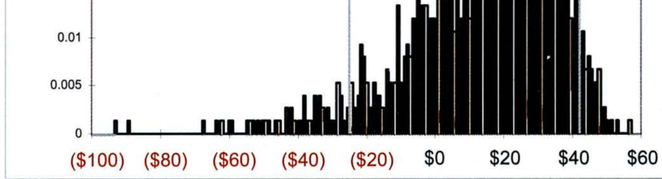

Figure 2. Distribution of modeled economic returns for Presynch-Cosynch 72 with Resynch with stochastic compliance estimates as compared to a deterministic baseline of 16% PR (as previously reported[4]).

costs instead of utilizing only the mean expected values. Milk price and herd 305ME production were input as normal distributions, based on data collected from multiple California dairies, CDFA published estimates and from personal communication with various industry sources. The mean and standard deviations for milk price and herd 305ME milk were $12.97/ cwt ($3.06) and 25,419 lbs ± 2550 (11,554 kg ± 1159), respectively. Replacement costs were input as a gamma distribution with a mean of $1918 and a mode of $1880. The other inputs, including the compliance distribution estimates, were the same as previously described.

The results shown in Figure 2 are best described as a beta general distribution. This set of returns should come as no surprise since its primary source of variation, based on sensitivity analysis, was the compliance distribution which was also beta general in form. The current set of results that is shown in Figure 3 is more normal in shape. In addition to the beta general compliance distribution, there are also several normal distributions that contribute significantly to the range of potential economic returns including milk price, herd production level and replacement costs. The addition of these other stochastic variables creates a wider range of possible economic outcomes from the use of TAI as compared to a baseline of 16% PR, and it is this data set that we will now use to demonstrate the concept of type I and type II error in the first example.

Calculation of Expected Error Costs – Example 1

For the first example, the comparison is between TAI and the baseline PR of 16%, as previously described. As a reminder, the type II error is the potential profit that is NOT realized due to the failure to use an intervention or product that would have been profitable. The type I error is the potential loss that would be realized for choosing to adopt an intervention that fails to yield a profitable result. Figure 4 shows a smoothed fitted area curve for the predicted returns over the various scenarios for the use of TAI vs. the 16% PR of the baseline program and the associated type I and II error areas. At the break-even point, the predicted profit is $0 after considering the cost and returns. This figure shows that 8.6% of the modeled iterations resulted in a break-even or loss. Subtraction of 8.6% from 100% yields 91.4%, or the expected proportion of the time that a profit would be realized, under the assumptions of the model.

There are several necessary steps to calculate the type I and type II error costs of a particular intervention or product. The first part involves calculation of the frequency distribution of all potential net returns to the intervention or product, including the break-even point. Whenever a new intervention is implemented, there is rarely a single possible cost and return, but rather, a range of potential costs and returns associated with the intervention. Each iteration of the stochastic model results in an individual output of the predicted return, and each of these variable returns can then be transported back into a new spreadsheet using the @Risk add-in.

Next, the error costs are calculated by taking the product of each response by its associated frequency, and then summing the total for each region. For the type II cost estimate, each predicted response that is above break-even is multiplied by the frequency of that response, and all of the resulting products are then summed. For example, [($0.01∗0.0001) + ($0.04∗0.0002) ... + ($75.04∗0.0002) + ($81.52∗0.0001) = $19.54. The type I error cost is done in the same manner for each

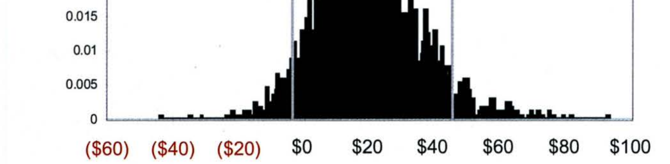

Figure 3. Distribution of modeled economic returns for Presynch-Cosynch 72 with Resynch as compared to a baseline of 16% PR, using stochastic inputs for compliance, milk price, herd production, and replacement costs.

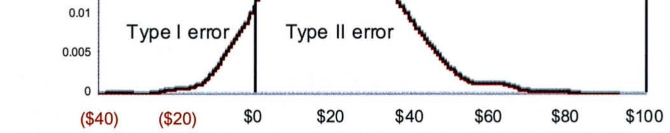

Figure 4. Fitted area curve of modeled economic returns and the breakeven point for TAI as compared to an estrus detection-based program with a 16% baseline PR.

response that is below the break-even level, and the net result is a cost of ($0.54).

Alternatively, the value can be estimated by multiplying the average value of all of the profitable responses by the proportion of iterations that are above the breakeven point. In the example above, the average of the profitable responses was $21.37 and the predicted proportion of profitable outcomes was 91.4%, yielding a type II error cost of $19.53. The type I error cost is calculated similarly. The average value of less-than-break-even response is ($6.34) and an unprofitable response occurred 8.6% of the time, yielding a type I error cost of ($0.55).

Over the range of milk prices, herd production levels, replacement prices, compliance estimates and other distributions used within this model, the type II error cost exceeded the type I error cost by a difference of $19. The comparison of the type II vs. the type I error costs would strongly suggest that in order to avoid potentially committing a very costly type II error, the herd should elect to move from the baseline breeding program to the TAI, although there is a small chance of having an unprofitable response.

Calculation of Expected Error Costs – Example 2

The previous example's conclusion was based on the idea that the baseline PR would not change over time. For the second example, let us consider the scenario where the starting baseline is not 16%, but is instead 17%. This program is still an estrus-detection based AI program, but is slightly more efficient at delivering pregnancies than the baseline program used in example 1. In example 1, TAI produced 18 more pregnancies, on average, over the breeding period as compared to the baseline. In the current example, the pregnancy gap is down to nine, after adjusting for the effects of culling throughout the lactation. All other deterministic and stochastic inputs for the model are exactly the same; however, the mean expected return is only $2.18, as shown in Figure 5.

Figure 5 clearly shows that the difference between the type I and II errors is much smaller than in the first example. By using the same calculation methods as before, the exact error costs are estimated. The average of the profitable responses was $9.90 and the predicted proportion of profitable outcomes was 60%, yielding a type II error cost of $5.94. The average value of the non-profitable responses is ($9.44) and an unprofitable response occurred 40% of the time, yielding a type I error cost of ($3.78). The net difference between these two is $2.16.

In this current example, just as in example 1, type II error cost exceeded the type I error cost, but now by only $2.16. The comparison of the type II vs. type I

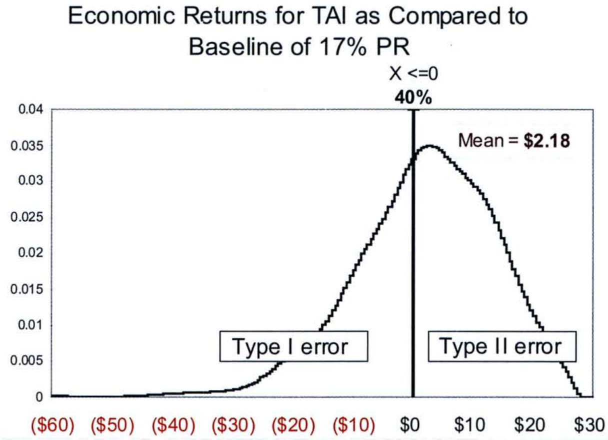

Figure 5. Fitted area curve of modeled economic returns and the breakeven point for TAI as compared to an estrus detection-based program with a 17% baseline PR.

error costs would suggest that there is still a potential to gain economically over the long term by using TAI, but there is much greater risk of loss if the baseline is already at 17%. Most producers would likely opt to try and maintain status quo instead of investing in TAI unless there was some other reason to make the switch, despite the small mathematical advantage to TAI under the assumptions of the model.

Conclusion

Dairy producers and their advisors must make good decisions regarding potential new products or interventions in order to optimize the profitability of the business. A variety of tools exist that can aid in this decision-making process, including the consideration of type I and II error costs. The concept of working to minimize type I error cost by good decision making and improved management is intuitive, but to many people, the concept of "lost opportunity cost" or a type II error is a bit more difficult to grasp.

Calculation of the error costs for a single product with sound research is fairly straightforward. However, applying this concept to reproductive interventions is much more problematic due to the difficulty in assessing the value of reproductive change, and due to the potentially large variation amongst the many factors that directly or indirectly affect profitability of reproductive change. The model presented in this paper attempts to quantify the value of improving reproductive performance by estimating the value of the new level of milk production, value of additional calves produced, and effects of culling changes. Care has been taken to try and mimic real dairies in all areas possible, but no model can accurately describe all potential scenarios, and caution should be exercised when interpreting their exact results. The assumptions used in the model may or may not accurately reflect an individual dairy. Another important point to remember is that this set of scenarios was merely a comparison of a consistent, steady 16 or 17% baseline PR vs. variations in total TAI. No attempt was made in this paper to compare the predicted economic benefit of increasing the baseline PR by means of a combination of TAI and estrus detection.

Application of type I and type II error theory to the question of "should TAI be used" yielded different results in the two examples. In the first scenario, the conclusion reached was that overall, herds with a baseline PR of 16% should strongly consider the use of TAI based on the large advantage of type II vs type I error costs. However, in example two, herds that are already at a PR of 17% have less to gain economically by making the switch.

References

1. Fricke PM, Stewart S, Rapnicki P, Eicker S, Overton MW: Pregnant vs. open: getting cows pregnant and the money it makes. Western Dairy Management Conference. Reno, NV, 2005.
2. Galligan DT, Chalupa W, Ramberg CF, Jr: Application of type I and II errors in dairy farm management decision making. *J Dairy Sci* 74:902-910, 1991.
3. Overton M: Economic returns of improved reproductive performance in dairy cattle. *XXXIV Jornadas Uruguayas de Buiatría*. Paysandu, Uruguay, 2006.
4. Overton MW: Stochastic modeling of different approaches to dairy cattle reproductive management. *J Dairy Sci* 84, Suppl. 1:268, 2001.
5. Overton MW: Cash flows of instituting reproductive programs: cost vs reward. *Proc Am Assoc Bov Pract* (in press) 2006.
6. Overton MW, Galvao KN: Dairy cattle reproduction: measuring efficiency and economics. DIGAL Conference. Delicias, Mexico, 2004.
7. Sterry RA, Welle ML, Fricke PM: Effect of interval from timed artificial insemination to initiation of resynchronization of ovulation on fertility of lactating dairy cows. *J Dairy Sci* 89:2099-109, 2006.
8. Wolf CA: Analyzing reproductive management strategies on dairy farms. Staff Paper 99-23, Department of Ag Econ, Michigan State University, 1999.