TACTICAL IMPLEMENTATION OF BEEF CATTLE BREEDING PROGRAMS

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INTRODUCTION

The animal breeder must juggle many issues when s/he makes decisions resulting in implementation of a breeding program, including concerns about breeding objectives, genetic gains, crossbreeding, inbreeding, logistical constraints, and various types of operational cost.

One approach to solving these problems is to follow sets of rules recommended by geneticists and other practitioners. However, such rules are derived from generalised theories and concepts - and these are usually not well integrated with each other. For example, theories and rules about selection, crossbreeding and inbreeding have been developed largely in isolation from each other, such that it is difficult to mix them in real applications, and we are likely to miss the best overall strategy.

Mate selection incorporates decisions on animal selection and mate allocation in a simultaneous manner. This is an approach that can be used both to integrate all the key issues facing animal breeders, and to implement the program *tactically*. In any breeding operation, there is an almost infinite range of mate selection combinations that can be made, each involving decisions on issues such as animal selection, semen collection and purchase, and mate allocations. Each *mate selection set* is predicted to have a given utility to the breeder - based on factors such as genetic gains, risk, costs and constraints satisfied. The tactical mate selection approach described in this paper works by searching across all these possible routes ahead, and finding one that is predicted to suit the breeder’s needs. This has only recently become possible because of development of efficient computing algorithms that mimic evolutionary processes to find a solution that is best, or at least nearly best.

There are additional advantages in making decisions tactically, rather than following a pre-set strategy. A tactical approach will make use of knowledge of the full range of actual animals available for breeding at the time of decision making, as well as other factors such as availability of mating paddocks, current costs of specified semen, current quarantine restrictions on animal migration, current or projected market prices, finances available to the breeder, etc. Thus tactical implementation of breeding programs gives the power to capitalise on prevailing opportunities - opportunities that would often be missed when adhering to a set of rules.

THE MATE SELECTION INDEX (MSI)

The MSI quantifies the value to the breeder of matings made. It is in fact equivalent to the objective function of Kinghorn and Shepherd (1994). In some cases, the consequences of a particular mating might be simple and quantifiable. For example, if the predicted merit of progeny from a mating is, say, 310Kg yearling weight, or +$12 in breeding objective units, then either of these figures constitutes an MSI *for that mating*. This can be done because the value of a mating in such a scheme is independent from what other matings might be made. However, in most progressive programs this is not the case - the value of a mating depends on what other matings are actually going to be made. For example, the value of a mating using a 'new blood' imported sire to help reduce inbreeding depends on how many other matings will be made using sires from the same outside source.

This means that for most applications the MSI cannot be specified at the level of individual matings - we can only calculate an overall MSI that characterises the combined value of all matings in the mating set. Examples of such an MSI are given by Kinghorn (1998), Shepherd and Kinghorn (1998) and Kinghorn et al. (1999), and a further example will be given later in this paper.

A SIMPLE EXAMPLE: INTEGRATION OF SELECTION, CROSSBREEDING AND SOME COSTS

This is an example in which the value of each mating is independent from what other matings are to be made. When setting up a multi-breed improvement program, the breeder must consider not only crossing parameters (breed means, heterosis, etc.), but also within-breed genetic merit (i.e. selection opportunities) and cost factors, such as the cost of buying in breeding animals. This can be done by simply finding the mate selection set (or mating list) that is predicted to give the maximum genetic merit in progeny, taking account of costs. Figure 1 shows the simple example.

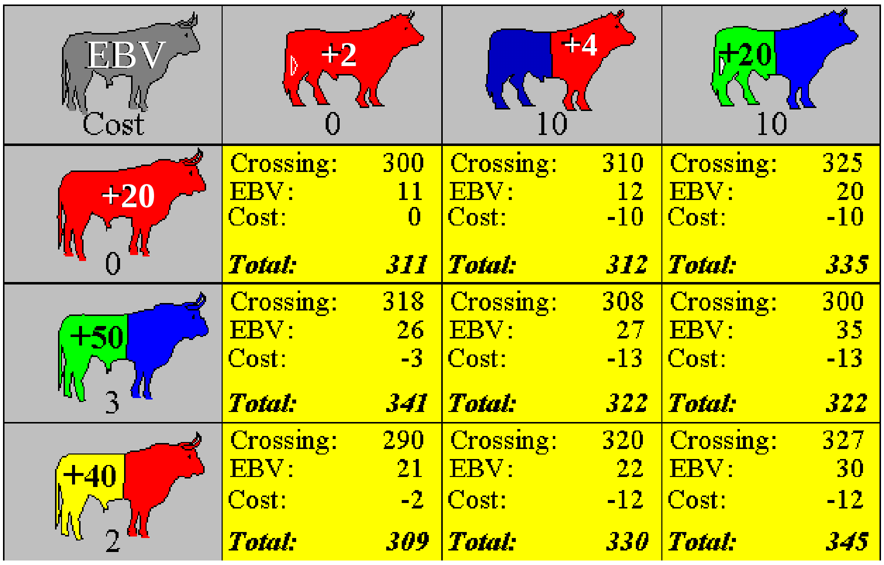

Figure 1. 'Crossing' in this figure is the predicted merit of the offspring from the matings indicated, given information on breed of parents alone. This takes account of direct and maternal additive and heterotic effects. EBV is the estimate of breeding value having fitted all between-breed effects. 'Costs' is the cost of purchasing or otherwise using each candidate as a parent. The single-colour purebreed is taken as the homebred breed, and costs are deviated from this. Costs must be in index units in order to be able to combine all the components in the total score. Notice that cost values are generally higher for females. This is because each female leaves a smaller number of progeny, and so each of these progeny must be better by a larger amount in order to cover the actual cost of buying or rearing this female.

Having calculated the predicted value of progeny from each possible mating, the task is now to make selections and mate allocations. The best three single-pair matings to make have values 341+335+330. Note that, as (341+335+330) > (345+341+312), the very best mating (value 345) is not included, illustrating that making the best mating list is not totally trivial, even in this trivial example. Typical outcomes from applying such a mate selection strategy are shown in Table 1.

Table 1. Typical outcomes from a simple mate selection program involving selection, crossing and some costs.

Conditions	Typical outcome
Direct and maternal heterosis high	3- and 4-breed crosses
Female import costs high	Rotation crossing
Male import costs also high	Import sires for some generations then closed composite
Within breed genetic variance high	Opportunistic crossing to give an open composite

IMPLEMENTATION OF MATE SELECTION

This section describes a general approach that works for cases in which the value of each mating can be dependent on what other matings are to be made. An outline of the approach is shown in figure 2. For each mating set tested, the component outcomes evaluated constitute the overall Mate Selection Index (MSI). Each component must be evaluated on the same scale, typically the scale of the breeding objective in units of, for example, dollars profit per breeding cow per year. The MSI can be set to an arbitrarily low and uncompetitive value for mating sets that break a constraint - for example mating sets that imply migration against a hard quarantine barrier, or greater use of liquid funds than a limit specified by the breeder or group.

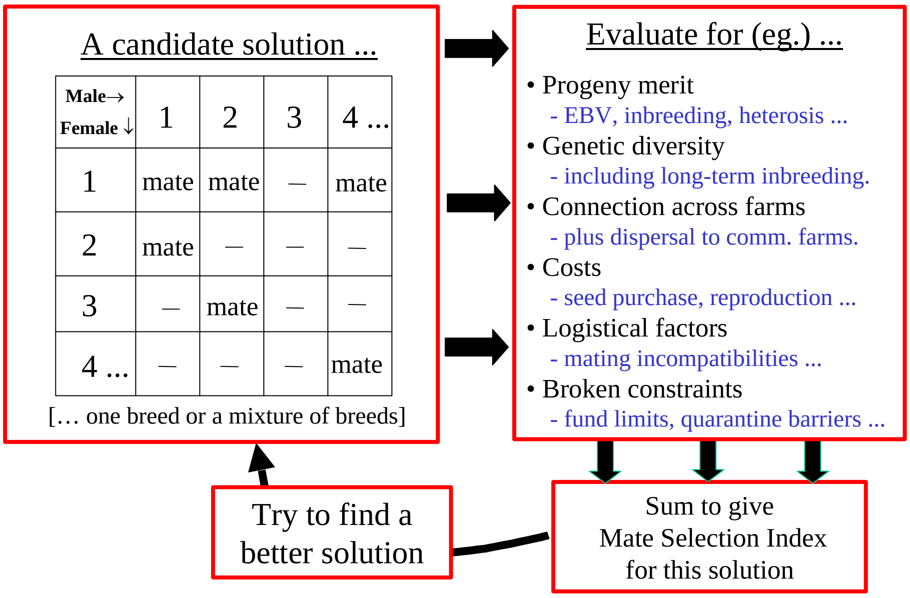

Figure 2. An outline for implementation of a mate selection index. The set of matings shown is an hypothetical test mating set. The matings specified imply the need for collection of semen, IVF etc. The mating set is evaluated for all components in the MSI. An efficient algorithm for finding the best mating set is required.

The computing challenge is to find the mating set that gives the best MSI. For this purpose, an evolutionary algorithm was developed (Kinghorn 1998), based on Differential Evolution

(Price and Storn 1997). The mate selection driver described by Kinghorn (2000) has been developed to conduct the search across all legal mating sets.

A MORE COMPLETE EXAMPLE (OPTIONAL READING)

The following example MSI pays attention to genetic gain, long-term inbreeding, short-term inbreeding, crossbreeding effects, running costs and logistical constraints. This section is included for completeness. It adds little in concept to what is shown in figure 2, and so this section can be skipped by those not wanting to know more about the nuts and bolts of an MSI.

For any given mate selection set (list of matings to be made):

$$\text{MSI} = \frac{x'G}{2M} + \lambda \frac{x'Ax}{4M^2} + \phi F + \chi C - \cos t$$

when no logistical constraint is broken, or

MSI = a very low value when a logistical constrain is broken. This low value is sufficienly low to ensure that the mating set is not the solution of the mate selection algorithm.

- ✓ *M* is the total number of matings to be made. This is typically the number of breeding females, unless MOET or some other form of reproductive boosting is to be an option, whence some breeding females will effectively be mated more than once.

- ✓ *x* is a vector of number of matings to be made for each candidate, over both sexes. For each sex of candidate, the elements of *x* are restricted to sum to the total number of matings to be made, giving a total sum of 2*M* for the elements of *x*. Meuwissen (1997) treats elements of *x* as proportional contributions, with *x* restricted to sum to ½ for each sex of candidates. However, using number of matings as elements of *x* is useful for practical application of selection and mate allocation. The difference is handled by dividing by 2M for each instance of *x* in the MSI. Restrictions on the maximum value of each element of *x* are made as described later. Vector *x* could also be extended to accommodate predicted future contributions from existing juveniles and adults, following Meuwissen and Sonesson (1998).

G is a vector of selection index values for candidates based on multi-trait EBV's, typically in dollar units.

- ✓ $\frac{x'G}{2M}$ is the weighted mean EBV of selected parents - it is in fact an estimate of the mean genetic value of progeny arising from the mating set.

- ✓ λ is a weighting factor on mean coancestory for selected parents (see next item). λ is typically negative, to discourage low effective population sizes. Meuwissen (1997) calculates λ to give a constrained value of *x'Ax*. However, different values of λ can be chosen, effectively giving different index weights on genetic gain (1) and long-term inbreeding (λ), to give a range of results for these two factors, as shown in figure 4.
- ✓ *A* is the numerator relationship matrix for candidates.

- ✓ $\frac{x'Ax}{4M^2}$ is the weighted mean coancestry of selected parents. This reflects long-term inbreeding and reliability of predicted selection response. Just as the numerator relationship between two animals is twice the inbreeding predicted in their progeny, this value is equivalent to twice the rate of inbreeding, $2\Delta F$.

- ✓ ϕ is a weighting factor on predicted progeny mean inbreeding coefficient. A small value for ϕ is often sufficient to have a notable effect to reduce progeny inbreeding. This can also be true even when there are competing mate allocation issues in the MSI. Higher values of ϕ will affect which animals are selected, as well as mate allocation (Kinghorn et al., 1999).

- ✓ F is predicted progeny mean inbreeding coefficient for the mating set under consideration.

- ✓ χ is a weighting factor on predicted progeny mean crossbreeding value C. A sensible value for χ is 1 - this is the implied weight on the genetic gain component $\frac{x'G}{2M}$, and both these components have direct effects on progeny merit, making them of equal importance if merit of later descendants does not feature in the objective.

- ✓ C is predicted progeny crossbreeding value - the value predicted using information on breed genotype alone. This is typically predicted using a dominance model of heterosis, incorporating direct and maternal components of both additive and dominance effects. Use of χC aims just one generation ahead. A more involved approach is required in order to aim further ahead (Shepherd and Kinghorn, 1998), making investment matings (eg. to generate first cross females) as well as realisation matings (eg. terminal sire by first cross female). If χC is included in the MSI then EBVs in G should be net of breed genotype effects, to avoid double counting of these effects.

- ✓ *cost* is the cost of the mating policy implied by x. This can include costs of AI and MOET. It can be calculated to discourage solutions that, for example, nominate allocation of just a few females to a natural mating male, as well as giving both genetic and economic consideration to use of reproductive manipulation. Figure 3 gives a simple example for females. In one mode of operation, the price of reproductive techniques used to drive figure 3 can be decreased until reproductive technology starts to feature in the best mating set, and this illustrates a break-even price for use of that technology. *cost* can include other components such as seedstock purchase prices and transport costs, expressed in the same units as the dollar EBV's in G.

Other MSI components not in this example include penalties on variation in progeny trait expression, attention to connection between herds and optimising QTL expression in progeny.

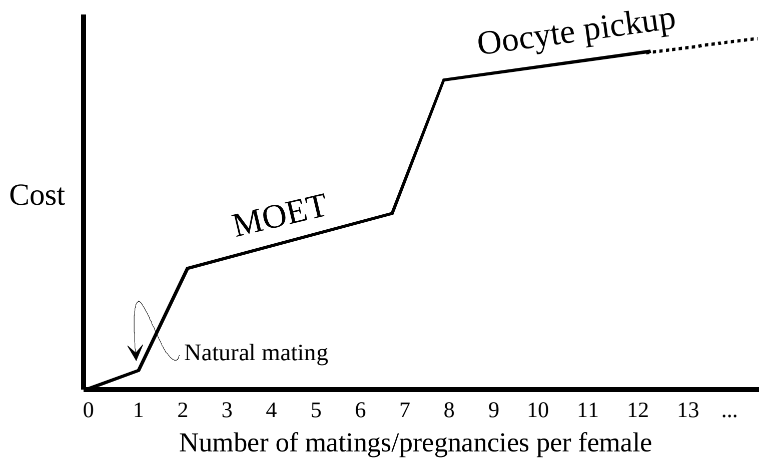

Figure 3. An illustration of one way to formulate costs for female matings. Calculated costs are summed over all candidates, of both sexes, to contribute to the component *cost* in the MSI.

Logistical constraints are simply applied by examining each contending mating set and applying an MSI value of low value, or an overriding penalty, if any constraint is broken. Here are some example constraints:

- ✓ Nominated maximum number of matings for each candidate. This might be, for example, 40 matings for males that cannot have semen taken from them, 1000 for males that can have semen taken, 1 for females that cannot enter a MOET program and 8 for females that can. The figure for dead males might be the number of semen doses available. Minimum numbers can also be set, in two ways: definite minimum use, and minimum use if used (zero use is an accepted value in the latter case).
- ✓ Migration constraints include not permitting young bulls to migrate from herd of birth, and restricting older natural mating bulls to be used in just one herd alone. Quarantine barriers can also be set in a simple manner.
- ✓ Any factor in the MSI can be included as a constraint instead of an index component. For example, long-term inbreeding can be included as a constraint by using a simplified MSI, (MSI = $\frac{x'G}{2M} + \phi F + \chi C - \cos t$) and penalising any mating set for which $\frac{x'Ax}{4M^2} = 2\Delta F$ exceeds a predetermined value. For example, to constrain ΔF to 0.01 per generation, this value should be set at 2 times 0.01 equals 0.02.

To calculate optimal values for MSI index weights χ, ϕ and λ would be a complex undertaking. However, these can be manipulated to give a desire outcome. An example of this is shown in figure 4, where λ is varied in order to give a frontier of outcomes for genetic gain and long-term inbreeding. (see also ‘ Dynamic control of desired outcomes, below).

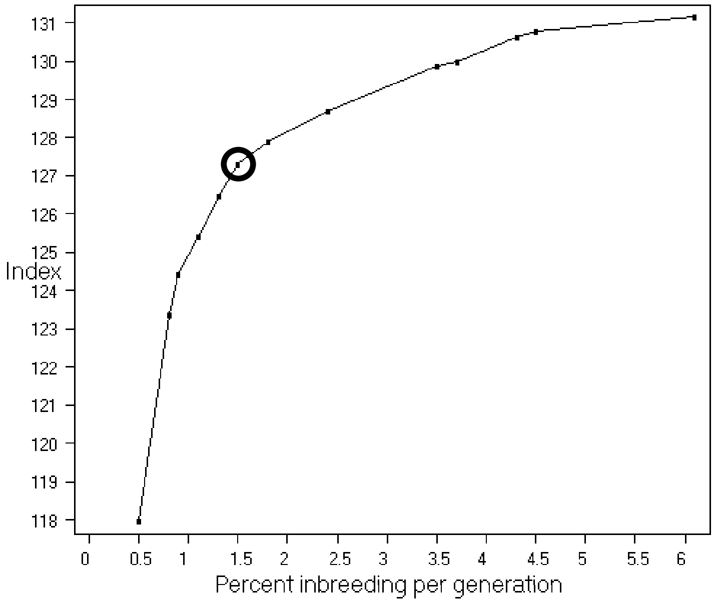

Figure 4. Plot of predicted progeny merit (EBV Index) against mean predicted long-term inbreeding per generation, for 13 alternative mate selection sets generated by using 13 values of λ. The chosen solution is circled.

APPLICATION OF THE MATE SELECTION APPROACH

Inputs: The mate selection approach outlined here has been implemented as Total Genetic Resource Management (TGRM, trademarked to LAMBPLAN). Information to implement TGRM includes parameters that describe conditions and desires (such as number of matings to be made, MSI weights, and constraints to be applied to trait expression) and data on animals (including pedigree, EBV's and candidate status. Candidate status is the maximum number of matings that can be made by the animal, and reflects natural mating versus use of reproductive boosting (AI, MOET etc.). Values are typically higher for males (25 to 1000+) than for females (1 to 8+). Candidate status defines a limit, and does not mean that the animal will automatically be used for that number of matings.

Output and reporting: The mean value of key variables for the chosen mating set is reported, such as predicted genetic merit of progeny, long-term rate of inbreeding, progeny inbreeding, progeny heterosis and program costs. The sires selected are listed together with their number of matings and distribution of these matings across herds. The part of the report to be acted on is the mating list. This lists the male and female to be used for each mating, together with predicted merit, inbreeding etc. for progeny from each mating. This mating list constitutes decisions on all the breeding issues addressed in the mate selection run.

Use over multiple stages: It is possible to carry out mate selection runs to make culling decisions well before joining time. In this way it is possible to undertake, for example, relatively heavy culling by castrating males, at a relatively early stage, while accommodating concerns about (lack of) relevance of early measures of merit, inbreeding, cost savings, etc. A separate run can be made well before mating for the purpose of identifying semen, embryos and seedstock to purchase. A later run for the main mating round will benefit from knowledge of purchases made and any change in the candidate status of other animals. A further run can be made to make backup mating decisions in the light of knowledge of which females did not conceive.

Dynamic control of desired outcomes: As the mate selection analysis is running it is possible to view key aspects of the currently best solution in a visual manner. This means showing predicted progeny trait merit (including trait distributions using histograms), inbreeding, heterosis, costs and structural components, such as the pattern of use of sires over herds, using real-time graphical output. The user can then change weighting factors and constraints during the analysis so that these outcomes change in desired directions. This approach gives great flexibility to learn about the potential outcomes and to optimally balance them, without having to rely on theoretical calculations about what weighting factors to be used *a priori*.

This is similar to the desired gains selection index approach, except that here the index (MSI) covers much more ground than selection alone. It brings the breeder's experience and judgments into the decision-making process, with experience showing this to be a strong educational experience for both scientists and breeders.

DISPERSAL OF BREEDING MALES TO COMMERCIAL UNITS

A mate selection analysis can be run over both commercial and stud operations, such that it solves the problem of dispersal of bulls to commercial units, simultaneously with selection of bulls into the stud(s) (Figure 5). The competition between commercial units for bulls can be handled in a manner that optimises overall profit, in harmony with bull selection for the breeding operation, and all the components in the MSI.

As the value of prospective progeny is calculated specifically for the herds in which they will be born, the benefits will be highest where the commercial units have different breeding objectives, as in figure 5. Moreover, where crossbreeding is practiced in some commercial units, the range of terminal and maternal attributes of candidate sires can be well accommodated via their EBVs and knowledge of their breed genotype, as well as that of their prospective commercial mates. This also holds when the commercial destinations involve different end-uses (eg. fully terminal versus 'daughters may be bred').

This can be done without individual information on commercial cows, by considering each cow herd, or part thereof, as a single group in the analysis - one 'nymphomaniac cow' for each commercial herd.

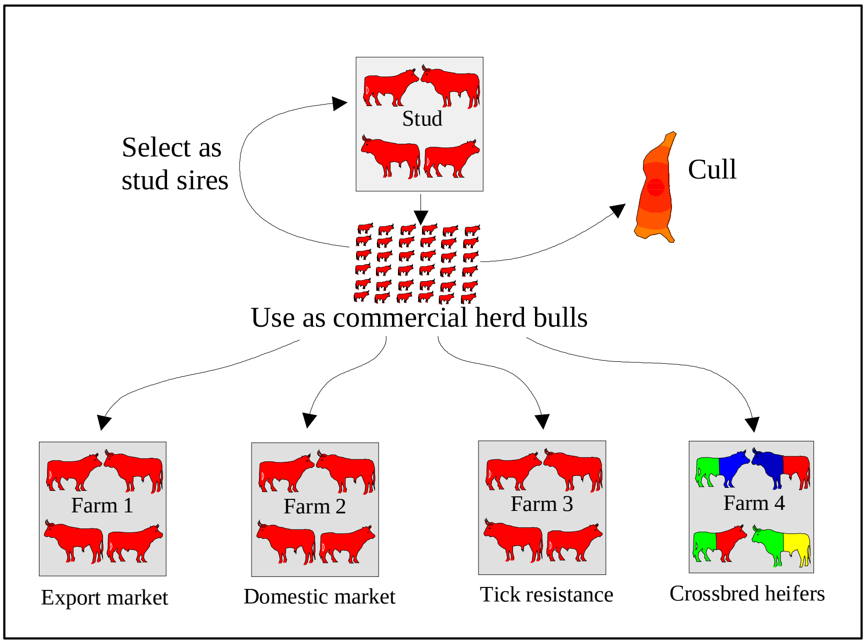

Figure 5. The fate of stud born bulls. Mate selection can be used to make decisions on dispersal of breeding males to commercial units, simultaneously with stud selection decisions.

GETTING THE MOST OUT OF THE TACTICAL APPROACH

The tactical approach to breeding is driven by specifying desired outcomes. Mate selection analysis can be a very powerful computing tool, as the results that it gives are closely aligned to the ‘outcome instructions’ that it receives. This means that the breeder can have a high degree of control, not by specifying which animals should be selected, but by specifying desires in terms of direction of genetic change, maintenance of genetic diversity, limits in money spent, constrains to be satisfied etc. Here are some examples of how we can give mate selection room to maneuver:

- ✓ Pre-culling of animals should be restricted to ‘definite culls’. The mate selection approach will only use competitive animals, but benefits from a bigger pool of candidates.
- ✓ It is worth considering the numerical scoring of important visually classed traits. This will permit the use of information from relatives to make faster progress in these traits and monitor their genetic change. It also gives more opportunity to make corrective matings.
- ✓ Consider a wide range of outside sires. These can help increase gains, lower inbreeding levels, and provide connections to outside seedstock sources that will result in better gains in the longer term.
- ✓ Include all key costs. Limits on finances available can also be set.
- ✓ Make herd size variable. By factoring in the cost of maintaining breeding females, herd size can be an outcome of the analysis. This can provide a way to give controlled reduction of herd size through periods of drought or financial hardship, with parallel accommodation of concerns about genetic gains, inbreeding, etc.
- ✓ Select sires for commercial units as well as breeding units. This is likely to work well in large enterprises in which the breeding objectives differ between commercial units.

- ✓ There is potential for constraining outcomes. For example, it could be declared that all progeny should be expected to be below a given fat thickness.
- ✓ Drive outcomes using a production model, as described below.

FROM TGRM TO TRM - TOTAL RESOURCE MANAGEMENT

Mate selection as implemented in TGRM could usefully be driven by a dynamic production model, rather than static breeding objectives. This means that breeding decisions (including dispersal of young bulls to commercial units) could be based on the optimal production and processing pathway(s) for prospective progeny, as suggested in figure 6. The result would account for eg. animal merit, variance in merit, prevailing feed and market conditions, and options for multiple pathways to multiple product end-points (Kinghorn, 2000).

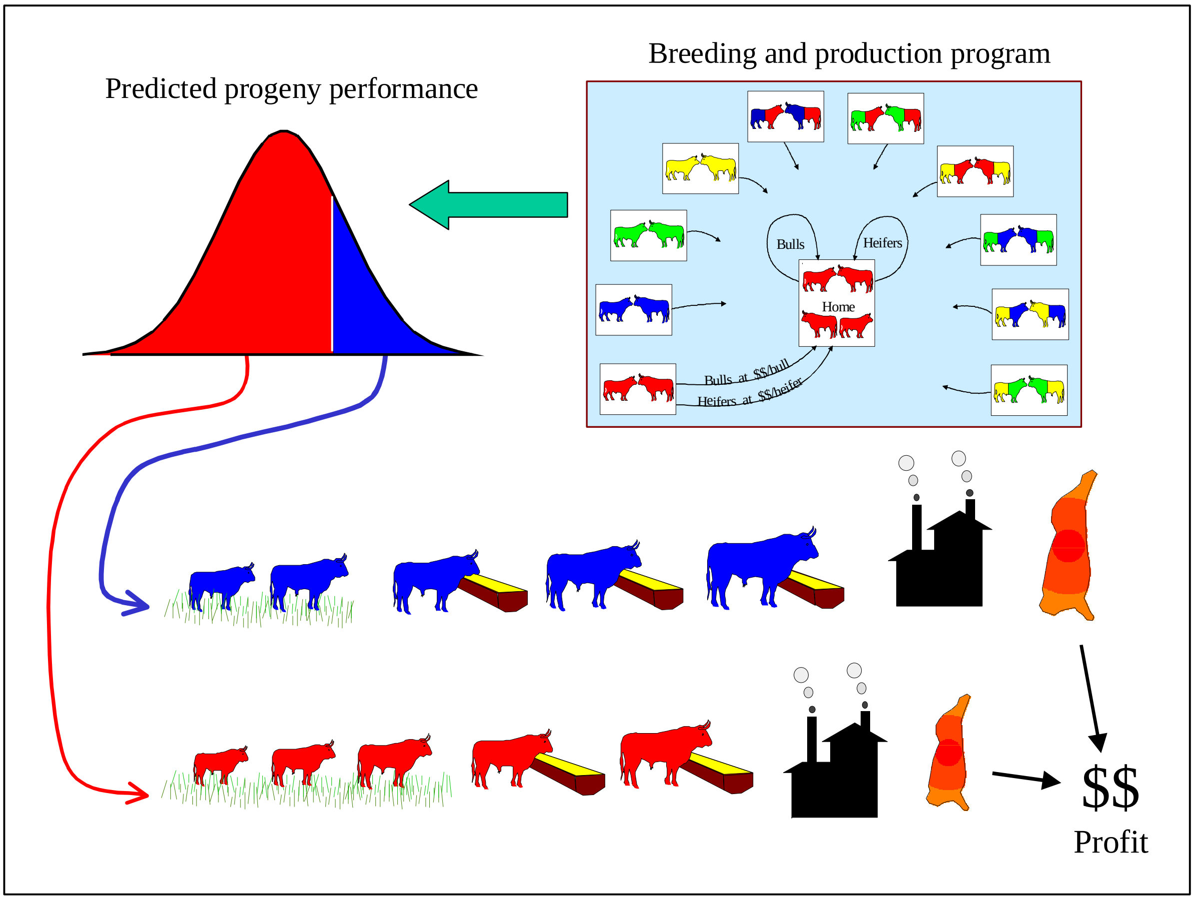

Figure 6. Tactical breeding program design could be extended to the full production system. “Total Genetic Resource Management” becomes “Total Resource Management”.

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