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Application of Expected Income-Variance Frontier Based Sire Selection Methodology to Optimize Young Dairy Sire Use

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ABSTRACT. *A net income and risk-based optimization procedure was used to determine the optimum proportion of young sire matings that would maximize 95% guaranteed future income for a given a pool of Holstein sires in the United States. Expected income from a sire was defined as the total discounted revenue (from milk production) minus total discounted cost (for feed, housing, etc.) associated with his daughter from her birth to the end of three lactations. Risk was the variance of future income of a sire, a function of his reliability estimates. A set of 36 sires (18 young, 18 progeny tested) from the current U.S. Holstein population was considered. Four reliability levels (0.3 and 0.5 for young, and 0.7 and 0.9 for proven sires) and breeding value estimates for four traits (milk yield, fat %, protein %, and dystocia) differentiated the sires.*

On average, young sires were superior to proven sires by $30.65 in predicted transmitting ability for dollars. A total of 100 daughters was expected to be produced by the whole set of sires. The quadratic programming procedure applied, determined the best set of sires (and the optimum number of daughters to be produced by each sire) that minimizes risk at a user specified expected income. Lower 95% confidence intervals (95% reliability margin) were constructed for the expected income–variance frontier of the sires. The optimum set of sires to be selected (and optimum number of matings) was defined as the one that maximizes the 95% reliability margin. Resulting optimum proportion of matings to young sires was approximately 34%.

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INTRODUCTION

Dairy breeders in the United States are provided with many information on the genetic potential of available sires for sire selection. Breeders often face difficulty in combining all of the information such as breeding values and reliabilities of milk, fat and protein yields, productive life, somatic cell scores and dystocia optimally in selecting the best sires. Most often relative weights given to breeding values and reliabilities in selecting sires are arbitrary.

Selection between pedigree–tested young sires (with low reliability) and progeny–tested proven sires (with high reliability) is another common problem. Greater use of young sires is encouraged as it leads to higher rate of genetic progress (Freeman, 1975; Hunt *et al.*, 1974; White, 1975). But most young sires have reliabilities in the range from 0.1 to 0.5 (McCraw *et al.*, 1980; Henderson, 1964) as their theoretical maximum is 0.71 (Lush, 1945). Hence they are riskier to use than proven sires whose reliability may approach 1.0. Consequently, semen price of young sires in the USA is also lower. At the same level of predicted breeding value, a young sire with low semen cost can generate a higher expected income than a proven sire (Loyd and Hargrove, 1991; McMahon *et al.*, 1985). The producer's dilemma is whether to use a young sire with higher expected income, accepting higher risk, or to use a proven sire with a relatively low yet reliable expected income (Meinert and Pearson, 1992). Dematawewa *et al.* (1998) proposed an optimization method for sire selection based on both income and risk. This method determines the best set of sires from a given pool of sires that would maximize a 95% guaranteed future income regardless of the utility function of the producer.

The objective of this study was to extend the procedure developed by Dematawewa *et al.* (1998) to determine the optimum proportion of young sire use, that maximizes a 95% guaranteed future income, when a set of young and proven sires is given.

MATERIALS AND METHODS

Resource pool of sires

An empirical set of 36 sires was defined as the resource pool of sires based on the distribution of breeding values for milk yield, fat percentage, protein percentage, and dystocia of the current United States Holstein population. The selected pool consisted of two sub–populations, proven (progeny tested) and young (pedigree tested), 18 sires each (Table 1). Averages of proven sire population for milk yield, fat percentage, protein percentage and expected progeny difference for dystocia (EPD) were considered to be 8172 kg, 3.6%, 3.2%, and 0.0, respectively. Due to the occurrence of annual genetic gain (Norman and Powell, 1992), the young sire population was on average, superior to proven sire population in predicted transmitting ability (PTA) for milk yield by 113.5 kg. Dystocia was included as a critical trait because potential dystocia problems with young sires is a reason for breeders in the United States to use fewer young sires. Sires of each sub–population were consisted of two groups (9 sires each) based on reliability of their breeding value estimates. For the four traits considered, the reliability estimates of the two groups (High– and Low–reliability groups) of proven sires were 0.9 and 0.7, respectively. The two young sire groups had reliability estimates of 0.5 and 0.3, respectively. A four letter identification code was used to differentiate the sires as in Table 1. The Average sire had breeding values for all four traits similar to the averages of their respective sub–population. Other sires were similar to the Average sires of their respective groups in breeding values for all traits except for their coded trait. The definition of sires is given in Table 1. Genetic standard deviations (used to define the sires) for milk yield, fat percentage, and protein percentage for the Holsteins in the United States were 765.54 kg, 0.2258%, and 0.101%, respectively (Welper and Freeman, 1992). Genetic standard deviation for dystocia for Holsteins was 0.3904 standard deviation units (Djemali *et al.*, 1987). Genetically superior sires transmit their superior genes to their daughter cows to produce high milk, fat and protein yields. The income realized from milk yield of the daughter cows is considered in this study as the only revenue that can be derived from the AI sires. The United States Department of Agriculture developed the following formula (PTA$ index) to calculate the revenue ($) that can be realized from a superior AI sire (compared with an average sire) through milk, fat and protein production of a daughter cow during a lactation (H.D. Norman, 1995, personal communication):

$$\text{PTA\$} = \$0.120396\ \text{PTAmilk} + \$1.2775\ \text{PTAfat} + \$3.23789\ \text{PTAprotein} \qquad [1]$$

where, PTAmilk, PTAfat and PTAprotein are the predicted transmitting abilities of a bull for milk, fat and protein yields (*i.e.* milk, fat protein yields of a daughter cows in a lactation relative to the population average) and PTA$ provides the total revenue ($) of the sire (per daughter and

Table 1. Profile of breeding values of the sires in the resource pool.

Sires[1]	Yield	Predicted Transmitting Ability (PTA)[2,3,4]			EPD for Dystocia[5]	PTA$
	Category	Milk Yield (kg)	Fat %	Protein %		
Proven sires						
OHAV, OLAV	Average	0	0	0	0	0.00
OHHM, OLHM	High-milk	σ^2_M	0	0	0	103.21
OHLM, OLLM	Low-milk	$-\sigma^2_M$	0	0	0	-103.21
OHHF, OLHF	High-fat	0	$2\sigma^2_F$	0	0	23.57
OHLF, OLLF	Low-fat	0	$-2\sigma^2_F$	0	0	-23.57
OHHP, OLHP	High-protein	0	0	$2\sigma^2_P$	0	26.73
OHLP, OLLP	Low-protein	0	0	$-2\sigma^2_P$	0	-26.73
OHHD, OLHD	High-dystocia	0	0	0	σ^2_D	0.00
OHLD, OLLD	Low-dystocia	0	0	0	$-\sigma^2_D$	0.00
Young sires[6]						
YHAV, YLAV	Average	ΔG	0	0	0	30.65
YHHM, YLHM	High-milk	$\Delta G+\sigma^2_M$	0	0	0	133.86
YHLM, YLLM	Low-milk	$\Delta G-\sigma^2_M$	0	0	0	-72.57
YHHF, YLHF	High-fat	ΔG	$2\sigma^2_F$	0	0	54.55
YHLF, YLLF	Low-fat	ΔG	$-2\sigma^2_F$	0	0	6.74
YHHP, YLHP	High-protein	ΔG	0	$2\sigma^2_P$	0	57.74
YHLP, YLLP	Low-protein	ΔG	0	$-2\sigma^2_P$	0	3.55
YHHD, YLHD	High-dystocia	ΔG	0	0	σ^2_D	30.65
YHLD, YLLD	Low-dystocia	ΔG	0	0	$-\sigma^2_D$	30.65

[1] Sire code: First letter: O = proven, Y = young; Second letter: H = high reliability, L = low reliability, Last two letters: AV = average, HM = high-milk, LM = low-milk etc., with F, P, and D for fat %, protein %, and dystocia, respectively.
[2] σ^2_M = 0.5*genetic standard deviation for milk yield.
[3] σ^2_F = 0.5*genetic standard deviation for fat percentage.
[4] σ^2_P = 0.5*genetic standard deviation for protein percentage.
[5] σ^2_D = 0.5*genetic standard deviation for dystocia.
[6] ΔG = difference in PTAmilk between the averages of the proven and young sire population.

per lactation) relative to an average sire. The PTA$ values (commonly called Predicted Transmitting Ability for Dollars) for the 36 sires (Table 1) were obtained using the above index. A daughter cow of an average proven sire in the population was assumed to produce a milk yield of 8172 kg per lactation with 3.6% fat and 3.2% protein hence, the revenue of an average proven sire in the proven sire population ($\overline{EI}$) was estimated to be \$2206.44. Formula [1] above provided the revenue of a sire (from one lactation of a daughter) relative to the average revenue ($\overline{EI}$) of the population. Thus the actual revenue of a sire is the PTA\$ value of the sire (from formula [1]) plus ($\overline{EI}$). The estimated value of expected income for the young sire population was \$30.65 superior to that of the proven sire population (Table 1).

Expected income of sires

A planning period of six years (from the conception of a daughter to the completion of three lactations) was considered in deriving the expected income of sires. Expected income was defined as the total discounted net income realized over the six years. The cost component included semen cost at insemination, cost of dystocia at birth of the daughter, all fixed and variable costs associated with raising heifer and production and maintenance of the cow. Revenue was realized from milk, fat and protein production of the daughter through three lactations. The following semen price prediction formula was used to obtain the semen price of the proven sires considered:

$$SMP_i = -0.08077 - 0.01162\ PTA\$_i + 0.00014\ PTA\$_i^2 + 5.51019\ R_i \qquad [2]$$

where, SMP_i = predicted semen price of the i^{th} sire,
R_i = reliability of PTA\$ values of the i^{th} sire.

The formula [2] was derived based on 540 active Holstein AI sires from five major AI organizations. The minimum semen prices for the two reliability groups ($R_i = 0.9$ and $R_i = 0.7$) were set as \$4.64, and \$3.53, respectively. Thus, an average semen price of \$3.00 was assigned to all young sires following the practice of the five AI companies considered here. Five services (inseminations) per conception of a daughter was assumed based on Schneeberger *et al.* (1982a and b). The cost of semen was obtained by multiplying the semen price by the number of services per conception. Costs associated with dystocia of sires with different EPD estimates were obtained based on the following EPD\$ index formula derived by Dematawewa (1992) and Dematawewa and Berger (1995):

$$EPD\$_i = 25.16 + 38.79 * EPD_i \qquad [3]$$

where EPD_i and $EPD\$_i$ are the EPD estimates for dystocia and the cost associated with dystocia for the i^{th} sire, respectively.

According to Lawrence and Judd (1995), the cost associated with raising a heifer up to the beginning of her first lactation (heifer cost) was \$900. Using the average input and output prices of the Midwestern region of the USA for 1995, and following the procedure of Lawrence and Judd (1995), the following cow cost prediction formula was derived:

$$\text{Cow cost}_{it} = \$790.545 + \$0.371288\,[\,\alpha_t\,(PTA\$_i + \overline{EI})] \qquad [4]$$

where, Cow cost_{it} is the cost for maintenance and production of the daughter of the i^{th} sire, in her t^{th} lactation, α_t is the mature equivalent conversion factor for t^{th} lactation. Following Schneeberger *et al.* (1982a and b) the mature equivalent factors considered for the first three lactations were 0.81, 0.89 and 0.96, respectively. A 3% risk free real discount rate was used based on USDA Agriculture Statistics (1967 and 1982) and Wilcox *et al.* (1984). When all the information are combined, expected income of a sire becomes:

$$E(I)_i = -\frac{5{*}SMP_i}{(1+0.03)^0} - \frac{[25.16 + 38.79\widehat{EPD}_i]}{(1+0.03)^{3/4}} - \frac{900}{(1+0.03)^2}$$

$$-\,(790.545)\left[\frac{1}{(1+0.03)^3} + \frac{1}{(1+0.03)^4} + \frac{1}{(1+0.03)^5}\right]$$

$$+\,(1 - 0.371288)\,[\widehat{PTA\$}_i + \overline{EI}\,]\left[\frac{0.81}{(1+0.03)^3} + \frac{0.89}{(1+0.03)^4} + \frac{0.96}{(1+0.03)^5}\right]$$

where $E(I)_i$ is the expected income of the i^{th} sire, $\widehat{EPD}$ and $\widehat{PTA\$}$ are respective estimates of EPD for dystocia and PTA\$ of the i^{th} sire. The resulting expected incomes of the 36 sires are in Table 2.

Table 2. Expected income ($) of 36 sires.

Sire Category	Expected Income ($) Proven sires High reliability	 Low reliability	 Young sires High reliability	 Low reliability
Average	276.79	282.29	330.56	330.56
High-milk	427.60	434.57	484.03	484.03
Low-milk	123.33	128.83	177.09	177.09
High-fat	311.83	317.34	366.10	366.10
Low-fat	241.75	247.25	295.01	295.01
High-protein	316.52	322.02	370.84	370.84
Low-protein	237.06	242.56	290.27	290.27
High-dystocia	269.39	274.89	323.16	323.16
Low-dystocia	284.20	289.70	337.97	337.97

Variance of income of sires

Variance of future income of the ith sire, $V(I)_i$ was defined as the variance of discounted net (future) income of a sire given its estimated genetic merit. Under a constant input and output regime, the conditional variance of future income of the ith sire given his expected (estimated) income is a function of his reliability estimates of the traits considered (Dematawewa *et al.*, 1998). For an estimated population variance of EPD of 0.0381 in standard units (Djemali *et al.*, 1987) and an estimated population variance of PTA$ values of 8834.02 $\$^2$ (Welper and Freeman, 1992) with the mature equivalent and discount factors considered, variance of income of a sire for a 6 year investment period can be simplified to:

$$V(I)_i = 54.84\,(1 - r_i) + 19450.52\,(1 - R_i) \qquad [6]$$

where r_i and R_i are reliabilities of EPD and PTA$ estimates of the ith sire, respectively. The details of the standard simplification procedure generalized for any value of variance and discount rate are elaborated in Dematawewa *et al.* (1998). Based on Formula 6 the variances of income of sires for the four reliability groups (0.3, 0.5, 0.7, and 0.9) were 13653.752 $\$^2$, 9752.68 $\$^2$, 5851.608 $\$^2$, 1950.536 $\$^2$, respectively.

Finally, the total expected income from the 36 sires, E(I) was derived as

$$E(I) = \sum_{i=1}^{36} n_i \cdot E(I)_i$$

$$= n_{OHAV} \cdot (276.79) + n_{OHHM} \cdot (427.60) + \ldots + n_{YLLD} \cdot (337.97) \qquad [7]$$

where n_i is the number of daughters from the i^{th} sire and the sire code is as in Table 1. Similarly variance of total future income from all 36 sires, V(I) can be simplified to:

$$V(I) = \sum_{i=1}^{36} n_i^2 \cdot V(I)_i$$

$$= n_{OHAV}^2 \cdot (1950.536) + n_{OHHM}^2 \cdot (1950.536) + \ldots$$

$$\ldots\ldots\ldots + n_{YLLD}^2 \cdot (13653.752). \qquad [8]$$

Risk was defined as the variance of total future income of the herd and was expected to be minimized by quadratic programming for a predefined expected income level (K). The 36 sires were expected to produce a total of 100 daughters. Thus the quadratic programming problem was formulated as follows:

$$\text{Minimize: } V(I) = n_{OHAV}^2 \cdot (1950.536) + \ \ldots\ + n_{YLLD}^2 \cdot (13653.752)$$

subject to:

$$E(I) = n_{OHAV} \cdot (276.79) + \ldots\ldots\ldots\ldots + n_{YLLD} \cdot (337.97) \geq K$$

$$\sum_{i=1}^{36} n_i = 100$$

$$n_1, n_2, \ldots\ldots, n_{36} \geq 0. \qquad [9]$$

Under the linear programming framework of LINDO® (Schrage, 1991) used to solve the problem, the quadratic objective function was expressed in linear form with a set of 36 additional first order constraints (Kuhn/Tucker/Karush/LaGrange conditions) one for each sire. The program iterated on n_i values, by assigning different numbers of daughters to be obtained from each sire satisfying a predefined minimum E(I) (*i.e.*, K) and calculated the corresponding V(I) levels. The minimum and maximum possible K values were $12,333, and $48,403, respectively. These were reached by assigning all dams to OHLM sire, and all dams to a combination of YHHM, and YLHM sires, respectively (see Table 1 for sire codes). Expected income-Variance (E-V) frontier was developed for these sires by plotting V(I) for all possible K values within the range (Figure 1).

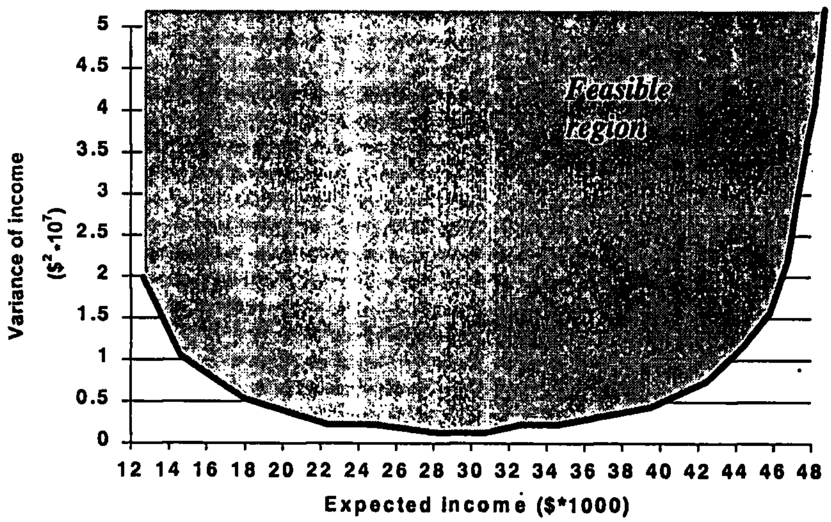

Figure 1. **Expected income variance frontier for the resource pool of 3 sires (solid line).**

Reliability margins

Any single point on the E-V frontier (solid line in Figure 1) shows a possible expected future income and the corresponding variance, which measures the possible variation of actual future income associated with the corresponding expected income. If normality is assumed for the distribution of actual future income given an expected income and variance, lower bound of the true future income for a given probability level can be derived (Dematawewa *et al.*, 1998). For example, 95% lower bound value indicates that only 5% of the time that actual future income will fall below that lower bound value. All of the lower bound points are combined to draw a curve (defined as reliability margin) for a given probability level. Reliability margins corresponding to 90%, 95%, 98.5%, and 99% probability levels were derived for the E-V frontier (Figure 2). The level of E(I) corresponding to the maximum of the 95% reliability margin (K_0 in Figure 2) defined the optimum E(I) to be targeted in sire selection. Thus, the optimum E(I) value maximized the 95% guaranteed future income. For this E(I) level, the quadratic program provided the optimum sire solutions (the optimum number of daughters that should be obtained from individual sires to maximize the 95% guaranteed income). The total number of daughters (out of 100) contributed by the young sires at the optimal solution determined the optimum percentage of young sire usage for this set of sires.

RESULTS AND DISCUSSION

The expected incomes of sires in Table 2 were based on the actual input-output prices and discount factors in the Midwestern region of the United States in 1995. High-milk sires in Table 2 exceeds their corresponding average sires by an income of over $150 while sires in Low-dystocia category, who are one genetic standard deviation superior to their corresponding average sires in EPD estimates, exceeded the average sires in income only by about $7.41. This comparison shows the economic importance of milk yield relative to dystocia as a criterion for sire selection. Although many producers show reluctance to use young sires because of potential calving difficulty problems, this comparison shows that young sires with superior PTA$ should be used more widely by producers instead of giving unnecessary emphasis to possible occurrence of dystocia. Low-reliability proven sires produced higher expected income than High-reliability proven sires (within all nine categories) because of the low semen cost associated with Low-reliability group (Table 2). For young sires, reliability was not a factor affecting semen price. Hence, both reliability groups (High and Low) of young sires had identical expected incomes under each of the nine yield categories.

Although young sires on the average produced higher expected incomes than proven sires, variance of their incomes were also higher. Thus, use of young sires was riskier relative to proven sire use. Similarly, at the same PTA$ and EPD level, Low-reliability-proven sires had higher expected incomes and were associated with higher variances of income compared with High-reliability-proven sires.

The E-V frontier for the 36 sires is in Figure 1. All possible sire combinations satisfying the constraints (minimum E(I), and non-negative number of daughters) fell within the feasible region. The minimum variance combination of sires (and daughters) for each K determined the boundary (frontier). Higher K levels required high-income sires (in general, higher proportions of young sires). This resulted in higher variances. Low E(I) and low V(I) combinations predominantly consisted of proven sires. The lowest possible value of K ($12,333) was determined by obtaining all 100 daughters from OHLM, the sire with the lowest expected income of $123.33 (Table 2). The highest income of $48,403 could be obtained by using the two sires (YHHM, and YLHM) with the highest expected income of $484.03 (Table 2), individually or together. According to formula [8], however, obtaining daughters from both decreases V(I) compared with using only one of the two sires to obtain all 100 daughters. Because of the specific values of reliability (0.5 and 0.3) of the two sires, for the particular expected income level, the minimum V(I) of 56890660 $\$^2$ was reached by using YHHM and YLHM to obtain 58.33% and 41.66% of the daughters, respectively.

The reliability margins developed at each probability level are in Figure 2. The 99% reliability margin of income was lower than the margin of 90% reliability.

Table 3 shows the optimum expected income level corresponding to the maximum of each reliability margin. At 95% probability level, a producer should aim at an expected income level (K_0) of $44440.32. At this level, the producer will be 95% guaranteed to have an income greater than $38783.30. Aiming at any other target level of expected income will result in a 95% guaranteed income lower than $38783.30 and hence will be inefficient at the 95% probability level..

The optimum set of sire solutions corresponding to K_0 was $\{n_{OHHM} = 48.24$, $n_{OLHM} = 17.79$, $n_{YHHM} = 17.98$, $n_{YHHF} = 0.57$, $n_{YHHP} = 1.27$, $n_{YLHM} = 12.84$, $n_{YLHF} = 0.41$, and $n_{YLHP} = 0.90$, with $n_i = 0$ for all other sires$\}$. The sum of the solutions was 100 satisfying the second constraint in [9]. Any other mating assignment for sires increases the risk, and is hence inefficient. The numbers of daughters are percentages based on a total of 100 daughters. If the breeding plan of a herd requires N number of daughters, then the optimum number of daughters for the i^{th} sire is n_i*N/100. Rounding off the final numbers to integers may be done for mating plans without dramatic

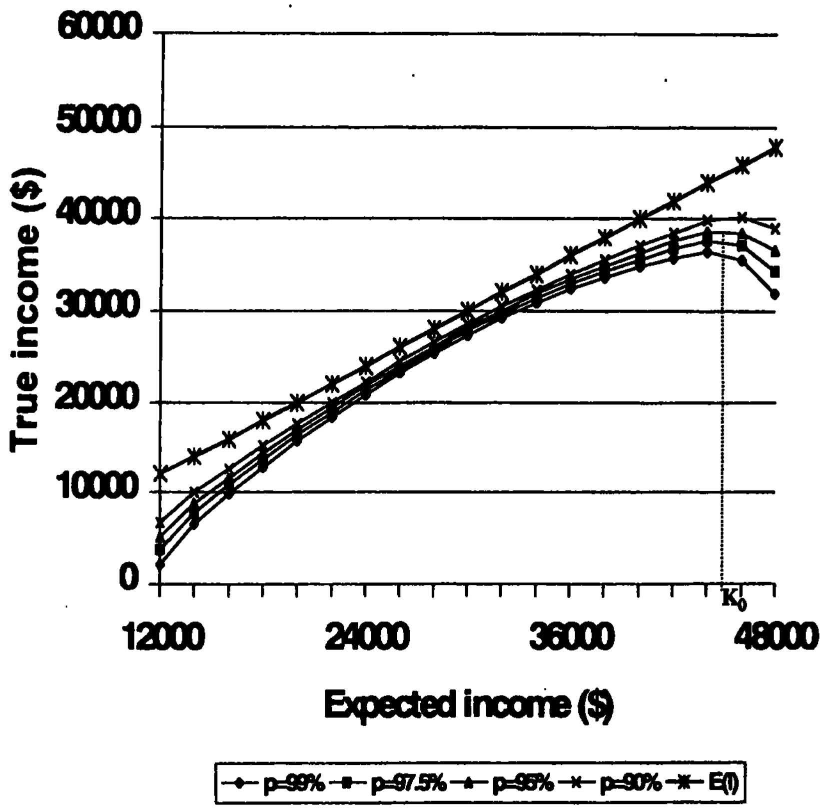

Figure 2. Reliability margins at various probability levels.

increase in risk. Sum of the solutions over all young sires provided the optimum percentage of daughters to be obtained from young sires of the given pool. According to the optimum solution set, the optimum percentage of young sire use was about 34%, at the 95% probability level (Table 3). At a lower probability level of guaranteed income, such as 90%, about 43% of the dams should be bred to young sires however, 95% was considered as the appropriate probability level for sire selection.

Accuracy and applicability of the procedure for a different country, region or time depend on the use of relevant and accurate input and output prices and discount rates. When applying to a country such as Sri Lanka, the economic indexes used here should be replaced by appropriate indexes

Table 3. **Optimum expected income and proportion of young sire use that maximizes guaranteed income.**

	Percentage of income guarantee			
	90%	95%	98.5%	99%
Optimum expected Income $ (target value)	45290.86	44440.32	43927.03	43373.32
Guaranteed income $	40286.60	38783.30	37575.20	36243.60
Optimum percentage of daughters from sires[1]				
OHHM	40.32	48.24	47.02	45.33
OLHM	16.92	17.79	17.03	16.18
YHAV	0.00	0.00	0.00	0.13
YHHM	24.94	17.98	16.01	14.26
YHLD	0.00	0.00	0.00	0.81
YHHF	0.00	0.57	2.20	3.41
YHHP	0.00	1.27	2.76	3.84
YLAV	0.00	0.00	0.00	0.10
YLHM	17.82	12.84	11.44	10.19
YLLD	0.00	0.00	0.00	0.58
YLHF	0.00	0.41	1.57	2.43
YLHP	0.00	0.90	1.97	2.74
Others	0.00	0.00	0.00	0.00
Total	100.00	100.00	100.00	100.00
Optimum percentage of young sire use	42.76	33.97	35.95	38.49

[1] Sire identification code is as in Table 1.

developed based on the specific dairy market system of the country. For example, unlike in the USA, protein content of the milk has no specific market value in many developing countries. Economic value of the dairy sires used should be determined based on the relevant dairy industry and economy of the country. With these appropriate adjustments, the procedure can be readily adopted to any dairy industry in the world.

CONCLUSIONS

Optimization of young sire use requires consideration of net income as well as risk associated with sires because high risk is an integral part of young sires. Quadratic programming based optimization procedures best handle this problem. Risk preference varies with individual breeders. The

95% probability level of guaranteed future income, defines the set of sires and how frequently they should be used in a breeding program in the absence of knowledge about each breeder's preference for risk. Use of all currently available sires in the United States in the model with national average input and output prices and genetic relationship matrix can determine an average optimum proportion of young sire use for the whole population. The procedure can be readily applied to any other country using appropriate input-output prices, discount rates and available sires.

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