AIPL RESEARCH REPORT NM$3 (7-06))	# Net merit as a measure of lifetime profit: 2006 revision

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[2]*Project S-1008, Genetic Selection and Crossbreeding To Enhance Reproduction and Survival of Dairy Cattle*
(collaborative research of the Southern Association of Agricultural Experiment Station Directors)

The 2006 revision of net merit (**NM$**) includes an improved definition of productive life (**PL**) and new genetic evaluations for service sire and daughter stillbirth. Because calving ease and stillbirth are correlated, economic values for these traits are combined and included in NM$ via a calving ability index (**CA$**) that is not published separately. Economic values of other traits also have been updated. Milk component prices were revised to make NM$, cheese merit (**CM$**) and fluid merit (**FM$**) useful for more producers. The indexes each estimate lifetime profit based on incomes and expenses obtained in cooperation with Project S-1008, *Genetic Selection and Crossbreeding To Enhance Reproduction and Survival of Dairy Cattle*, collaborative research of the Southern Association of Agricultural Experiment Station Directors.

Updated economic values

New economic values for each unit of predicted transmitting ability (**PTA**) and relative economic values of traits will be implemented with August 2006 evaluations:

Trait	Units	Standard deviation (SD)	Value ($/PTA unit)			Relative value (%)		
			NM$	CM$	FM$	NM$	CM$	FM$
Protein	Pounds	22	3.55	5.73	0	23	28	0
Fat	Pounds	30	2.70	2.70	2.70	23	18	23
Milk	Pounds	780	0	-.067	.106	0	-12	24
PL	Months	2.1	29	29	29	17	13	17
Somatic cell score (**SCS**)	Log	.20	-150	-150	-150	-9	-7	-9
Udder	Composite	.78	28	28	28	6	5	6
Feet/legs	Composite	.88	13	13	13	3	3	3

Trait	Units	Standard deviation (SD)	Value ($/PTA unit)			Relative value (%)		
			NM$	CM$	FM$	NM$	CM$	FM$
Body size	Composite	.94	-14	-14	-14	-4	-3	-4
Daughter pregnancy rate (**DPR**)	Percent	1.4	21	21	21	9	7	8
Calving ability	Dollars	20	1	1	1	6	4	6

The SDs listed above are for true transmitting abilities (**TA**s) in a hypothetical unselected population. The SDs of TAs for NM$, CM$, and FM$ are all estimated to be $163. An economic value is the added profit caused when a given trait changes by one unit and all other traits in the index remain constant. For example, an economic value for protein is determined by holding pounds of milk and fat constant and examining the increase in price when milk contains an extra pound of protein. The genetic merit for each trait of economic value ideally should be predicted from both direct and indirect measurements, but multitrait methods currently are used only for conformation traits and for PL. The economic value of a trait may change when other correlated traits are added to the index. Selection of animals to be parents of the next generation is most accurate when all traits of economic value are included in NM$.

Relative values for each trait expressed as a percentage of total selection emphasis are obtained by multiplying the economic value by the SD for true TA and then dividing each individual value by the sum of the absolute values. Currently stillbirth evaluations are computed only for Holsteins. The Brown Swiss CA$ includes only SCE and DCE. For the remaining breeds, relative values of the other traits in NM$ each increase by a factor of 1.06 because the 6% of emphasis on CA$ is excluded. A corresponding increase of 1.04 applies to the relative weights in CM$ for the other breeds.

NM$ calculation

Calculation of NM$ and reliability (**REL**) of NM$ can be demonstrated using the following example Holstein:

Trait	PTA	REL (%)
Protein	+70	90
Fat	+80	90
Milk	+2,000	90
PL	+2.5	60
SCS	2.95 (-3.00)	75
Udder	+1.5	80

Trait	PTA	REL (%)
Feet/legs	+.5	75
Body size	-1.0	85
DPR	+.3	55
CA$	+30	90

The PTAs for each trait are multiplied by the corresponding economic value and then summed. An average of 3 must be subtracted from PTA for SCS for all breeds. After subtraction, the NM$ for this example animal is +$643, CM$ is $662, and FM$ is $607. Calculation of NM$ also can be expressed in matrix form:

$$\mathbf{NM\$ = a'u},$$

where **a** contains the economic values for the 10 PTA traits and **u** contains the trait evaluation. The average of 3.00 for SCS is removed from the corresponding element of **u**. Calculations are the same for males and females with one exception: CA$. Cow PTA for CA$ are not available because a sire-maternal grandsire (**MGS**) model (instead of an animal model) is used for CA$ evaluations. Therefore, a pedigree index (.5 sire PTA + .25 MGS PTA + .125 maternal great grandsire PTA, etc.) is substituted for PTA for all generations of the maternal line, with breed average replacing any unknown ancestors.

The REL of NM$ can be approximated as the REL of yield multiplied by .85 plus the REL of PL multiplied by .15. For the example Holstein, NM$ REL is: 90%(.85) + 60%(.15) = 86%. Actual REL of NM$ is computed using matrix algebra from REL of the 10 traits and genetic correlations among those traits. The NM$ REL is the variance of predicted NM$ divided by the variance of true NM$:

$$\text{REL NM\$} = \mathbf{r'Gr/v'Gv},$$

where **r** contains the relative economic values multiplied by the square root of REL for each PTA trait, **G** contains the genetic correlations between the 10 PTA traits, and **v** contains the relative economic values for the traits. For bulls born from 1997 to 2000, NM$ REL will drop from 84 to 81%. Even though NM$ will be more accurate, its REL will be lower because some important economic factors previously had not been given full weight.

Trait parameters

Correlations among yield, PL, SCS, DPR, and linear type composites were estimated from Holstein data by Tsuruta *et al.* (2004, *Journal of Dairy Science* 87:1457) and by VanRaden *et al.* (2006, *Journal of Dairy Science* 89(Suppl. 1):in press), and compromise estimates were used. Genetic correlations among the 3 type composites were calculated from official Holstein genetic correlations for linear type traits (Misztal et al., 1992, *Journal of Dairy Science* 75:544). The remaining correlations for CA$ were obtained from correlations among PTA of bulls with high REL because REML estimates were not available. Genetic correlations are above the diagonal, phenotypic correlations are below the diagonal, and heritabilities are on the diagonal for each of the 10 PTA traits and composites:

PTA trait	PTA trait									
	Milk	Fat	Protein	PL	SCS	Body size	Udder	Feet/legs	DPR	CA$
Milk	**.30***	.45	.81	.08	.20	-.10	-.20	-.02	-.32	.15
Fat	.69	**.30**	.60	.08	.15	-.09	-.20	-.02	-.33	.11
Protein	.90	.75	**.30**	.10	.20	-.10	-.20	-.02	-.35	.16
PL	.15	.14	.17	**.08**	-.38	-.16	.30	.19	.51	.40
SCS	-.10	-.10	-.10	-.15	**.12**	-.11	-.33	-.02	-.30	-.08
Body size	.06	.06	.06	.03	-.11	**.40**	.26	.22	-.08	-.24
Udder	-.10	-.10	-.10	.10	-.33	.26	**.27**	.10	.03	.06
Feet/legs	.01	.01	.01	.19	-.02	.22	.10	**.15**	-.04	-.04
DPR	-.10	-.10	-.10	.20	-.05	.00	.00	.00	**.04**	.34
CA$	.02	.02	.02	.10	-.03	-.07	.00	-.02	.09	**.07**

*Holstein heritabilities in **blue** on diagonal; heritabilities for other breeds are the same except for size (.35), udder (.20), and, for Jerseys and Brown Swiss, yield traits (.35).

Expected genetic progress

Correlations of PTAs for each trait with NM$, FM$, and CM$ were obtained from progeny-tested Holstein bulls born from 1997 through 2000. Bulls were required to have an REL of at least 80% for milk yield and an evaluation for each trait in the index. Correlations with NM$ based on the 2003 formula are shown for comparison:

PTA trait	Correlation of PTA with index				Expected genetic progress from NM$	
	2003 NM$	2006 NM$	2006 CM$	2006 FM$	PTA change/year	Breeding value change/decade
Protein	.74	.62	.62	.58	2.6	52
Fat	.67	.66	.65	.62	3.8	76
Milk	.58	.54	.45	.64	86	1720
PL	.58	.67	.65	.67	.30	6.0
SCS	-.38	-.37	-.36	-.37	-.017	-.34
Udder	.22	.17	.17	.16	.04	.80
Feet/legs	.16	.13	.13	.12	.03	.60

PTA trait	Correlation of PTA with index				Expected genetic progress from NM$	
	2003 NM$	2006 NM$	2006 CM$	2006 FM$	PTA change/year	Breeding value change/decade
Body size	-.10	-.17	-.16	-.16	-.04	-.80
DPR	.15	.27	.27	.26	.07	1.4
CA$	.23	.34	.32	.36	1.3	25

The new indexes are more correlated than 2003 NM$ with PL, body size (negatively), DPR, and CA$ but give less progress for protein yield and for udder traits. Expected PTA progress was obtained as the correlation of PTA with NM$ multiplied by the SD of PTA multiplied by .25, which is the annual trend in SD of NM$. Previously the annual trend was estimated to be .34 SD, but that was with most selection on more heritable traits. The SD of PTA (not shown) generally are lower than the SD of true TA shown in the first table because of selection and because REL are less than one. Genetic trend (change in breeding value) equals twice the expected progress for PTA. Thus, multiplication of annual PTA gain by 20 gives expected genetic progress per decade.

Derivation of economic values

The following sections explain the derivation of economic values. Traits CA$ and PL that were added or modified since the last revision are described first. Changes in values for yield traits are described next. Economic values for SCS, DPR, and type composites were revised slightly since the last NM$ revision.

Calving ease and stillbirth (CA$)

Calves that die or are born with difficulty reduce dairy farm profit. In the 2003 revision of NM$, calf death losses were indirect expenses correlated with calving ease. In the 2006 revision, evaluations for stillbirth (Cole et al., 2006, *Proceedings of the 8th World Congress on Genetics Applied to Livestock Production*, accepted) allow calf loss to be separated from remaining expenses. Because calving ease and stillbirth effects from the service sire and the dam differ, CA$ can include 4 traits: service sire calving ease (**SCE**), daughter calving ease (**DCE**), service sire stillbirths (**SSB**), and daughter stillbirths (**DSB**). Many other countries use the terms direct and maternal or paternal and maternal instead of service sire and daughter. Comparisons of evaluations can be confusing because of terminology, direction of scales, and evaluation of pure maternal effects by several countries with an animal model instead of a sire-MGS model.

Proposed economic values for stillbirths of Holsteins were derived as follows. Value of 2-day-old calves was assumed to be $150 for bulls and $450 for heifers as compared with $100 for bulls and $150 for heifers for 2003 NM$. Some recent prices have been higher, but in the near future additional females may be produced for <$400 from sexed semen. Stillbirth evaluations are the percentage of calves that die as a difference from a base of 8%. Lifetime value of a 1% decrease in DSB is 2.8 lactations multiplied by average calf value: 2.8($150 + $450)/2(100) = $8.40. For SSB, this value must be halved because SSB measures the full effect of the service sire, whereas DSB measures only half of the dam's effect. Other breeds had insufficient data to begin stillbirth evaluations because only one dairy records processing center (DRMS, Raleigh) is supplying a substantial number of records at this time.

The value of DCE includes $70 per difficult birth (score 4 or 5) for farm labor and veterinary charges, and a 1.5% increased probability of cow death multiplied by $1,800. Those expenses are multiplied by 2 because scores 2 and 3 contribute additional smaller effects that occur more frequently. Difficulty in later parities is 0.3 as great, which results in a lifetime incidence of 1 + .3(1.8) = 1.5. Total value of DCE is [$70 + .015($1,800)]2(1.5)/100 = $2.91. Calving ease costs are based primarily on research by Dematawewa and Berger (1997 *Journal of Dairy Science* 80:754).

The value of SCE also includes losses in the bull's mates of $100 for yield and $75 for fertility and longevity. Difficult births reduce 305-day milk yield by 700 pounds and delay the bull's mates from becoming pregnant again by 20 days on average. Such losses are not charged to DCE because the bull's daughter evaluations for yield, fertility, and longevity already account for them. The value of SCE must be halved, as with SSB. This step was done incorrectly in 2003 (DCE value was doubled instead of halving the SCE value). Total value of SCE is [$50 + .015($1,800) + $100 + $75]2(1.5)/2(100) = $3.78. Values were then rounded to $4 for SCE, $3 for DCE, $4 for SSB, and $8 for DSB. The units of CA$ are the lifetime dollar value that the calving traits contribute to NM$. Calculation requires subtracting trait means, multiplying by economic values, and reversing direction to obtain net benefit instead of net cost:

CA$ = -4 (SCE - 8) - 3 (DCE - 8) - 4 (SSB - 8) - 8 (DSB - 8)

The CA$ index has a genetic correlation of .85 with the combined SCE and DCE values in 2003 NM$ and .77 with DCE in TPI. Thus, stillbirth evaluations can provide additional value beyond that of calving ease. A preliminary study (Berger *et al.*, 1998, *Interbull Bulletin* 18:28) reported less benefit because only service sire effects were examined. For Brown Swiss, economic values are -6 for SCE and -8 for DCE because separate stillbirth evaluations are not available and calving ease values include the correlated response in stillbirth. Standard deviations of true transmitting abilities are 1.7 for SCE, 1.4 for DCE, 1.0 for SSB, and 1.7 for DSB with corresponding relative emphasis of 25%, 15%, 15%, and 45% in CA$. The SD of the index is $21 and the relative emphasis on calving traits in NM$ increases to 6%.

Mating programs should assign bulls with low and high PTA for service sire effects to heifers and to cows, respectively. The economic value used in NM$ is a weighted average of losses for cows and heifers. Thus, when ranking sires for heifer use, another $4 should be subtracted from NM$ for each percentage of SCE, and $2 for each percentage of SCE should be added back to NM$ when ranking service sires for cows. These minor adjustments for the differing economic values in heifer vs. cow matings can be handled with computerized mating programs.

Productive life

In the 2006 revision of productive life (PL), cows get credit for continuing in milk after day 305 of lactation and after 84 months of age. Previously, credits were limited to the first 10 months of each lactation because longer lactations had not been stored in the AIPL database. Credits now are based on standard lactation curves, with highest credits at the peak of lactation and diminishing credits across the remainder of lactation. The standard is set such that a second lactation cow with 305 days in milk gets 10 months credit. First lactations get less credit and later lactations slightly more credit in proportion to average production. Lactation curve credits ensure that cows with multiple lactations get more total credit than cows with just 1 long lactation.

The economic value of PL is large because multiple lactations are needed to cover the cost of raising the cow. The value of PL has increased since the 2003 revision because the price of replacement heifers has increased to an estimated $1800 and because the standard deviation of PL was previously underestimated. The genetic SD is now 1.43 times larger due to additional credits for production after 305 days and after 84 months of age. The economic value of PL also increased because cows currently have only 2.8 calves vs 3.0 calves assumed previously. The value of a 1500 pound cull cow was estimated to be $675 or $.45 per pound. Previously death losses were ignored but a death loss of 4% per lactation is now accounted for. The difference between replacement and salvage values largely determines the economic value of PL.

Many traits affect PL and also the incomes and expenses within lactations. Evaluations for PL are enhanced with correlated information from DPR, SCS, type, yield, and calving ease evaluations. See "Multitrait Productive Life" [VanRaden and Wiggans, 2000, *AIPL Research Report* PL1(11-00)] for further information on calculation methods. Previously some of the economic value of PL was shifted to individual traits such as fertility, but more emphasis on PL now is justifed because DPR and calving ease are included in the multi-trait prediction of PL since November 2003. The reliability of PL will decline a few percent because predictions are to an endpoint that is further away.

Yield traits

A base price of $13.20 was assumed for milk containing 3.5% fat, 3% true protein, and 350,000 somatic cells / ml before deducting hauling and promotion charges. Hauling charges have averaged $.20 in Wisconsin but $.60 or higher in some western states (Freije, 2005, Werner, 2005) and are increasing due to fuel costs. An average of $.50 was assumed; actual costs for hauling milk are about $.005 per hundred pounds per loaded mile. The milk price after hauling charges was equal to $12.70. Component prices follow, along with marginal feed costs and health costs required for higher yield with the non-yield traits in NM$ held constant. Values in the volume column are computed as (milk value) - 3.5(fat value) - 3(protein value) divided by 100.

Index	Milk $/100 lbs	Fat $/lb	Protein $/lb	Volume $/lb
NM$	12.70	1.50	1.95	.016
CM$	12.70	1.50	2.80	-.010
FM$	12.70	1.50	.57	.057
Feed cost	3.93	.35	.50	.012
Exra health cost	.96	.10	.07	.004

Feed costs equal 31% of the milk price. The cost for milk volume accounts for the $.20 required to produce a pound of lactose in each 20 pounds of milk. A cost of $.002 for bulk tank, equipment, and electricity costs to cool and store each pound of milk also is included in the feed cost. Feed cost for protein was that estimated by Dado et al. (1994, *J. Dairy Sci.* 77:598), and lower values were obtained in some other studies.

Extra health costs equal 8% of the milk price based on a literature review conducted by Tony Seykora. The other traits in NM$ such as PL and DPR account for replacement costs and some but not all health costs. SCS and udder composite account for about half of the mastitis and discarded milk costs. The residual antagonistic genetic correlations between milk and health traits should be used to account for health expenses until direct evaluations of health traits become available. Examples of research studies that estimated costs of health traits and correlations with production are Dunklee et al (1994 J. Dairy Sci. 77:3683), Jones et al (1994 J. Dairy Sci. 77:3137), Simianer et al (1991 J. Dairy Sci. 74:4358), Uribe et al. (1995 J. Dairy Sci. 78:421), Van Dorp et al (1998 J. Dairy Sci. 81:2264), and Zwald, et al (2004 J. Dairy Sci. 87:4295). The studies indicate that higher milk yield is more correlated than fat or protein yield to increased health costs and also to poorer heat tolerance (Bohmanova et al, 2005 Interbull Bulletin 33:160)

Correlations of merit indexes based on recent, progeny tested bulls were .99 for NM$ with CM$, .97 for NM$ with FM$, and .91 for FM$ with CM$. The FM$ index before 2003 included a protein price of 0, but many producers receive a blend price for milk or at least hope to receive some protein premium within 5 years. Inclusion of a small protein premium equal to feed cost plus health cost may make FM$ more acceptable as a breeding goal and results in no selection for or against protein in the FM$ index. Producers that expect future premiums of <$1.20/lb of protein should select on FM$; those that expect premiums of >$2.30/lb of protein should select on CM$. Most U.S. producers are likely to expect protein premiums between $1.20 and $2.30 and should select on NM$.

The value of milk, fat, and protein is converted from a lactation basis to a net lifetime basis by subtracting feed and health costs and then multiplying by the number of records as compared to second lactation, 305-day equivalent. For Holsteins, the average number of record equivalents is 2.57 and the lifetime value of PTA protein in NM$ is (1.95 - .57) (2.57) = $3.55. Yield traits together account for 46% of total selection emphasis in NM$.

Prices for milk, fat, and protein are difficult to predict because they vary widely by use of milk and across time. Average prices for milk in federal order markets are available from the USDA Agricultural Marketing Service. Actual prices since 2000 for Class III milk used in cheese making are given below.

Year	Milk $/100lb	Fat $/lb	Protein $/lb	Volume $/lb	SCC* $/double
2000	9.74	1.25	1.69	.0030	-.14
2001	13.10	1.85	1.96	.0075	-.17
2002	10.42	1.19	1.97	.0035	-.14
2003	11.42	1.21	2.38	.0005	-.16
2004	15.39	2.05	2.60	.0042	-.20
2005	14.05	1.71	2.46	.0053	-.18

*A doubling of somatic cell count (SCC) results in a one unit increase in SCS. See the section on SCS for fuller explanation of penalties.

During the last 6 years, protein prices paid by cheese plants averaged $2.18 and butterfat prices averaged $1.54, with an upward trend for both. The predicted values in CM$ of $2.80 and $1.50 assume that an upward trend will continue for protein but not for fat. Currently about 50% of U.S. milk is used to make cheese (vs 25% in 1979), about 30% used for fluid (vs 50% in 1979), 15% for soft or frozen products, and 5% for powdered milk. Thus, cheese consumption has increased and fluid consumption has decreased, with market shares of 60% for cheese and 20% for fluid possible in the future. World prices for butterfat tend to be lower than U.S. prices. Premiums for SCS are discussed in the somatic cell section below.

Fluid milk processors often pay no premium for extra protein because grocery store milk is not labelled or priced by protein content, and this situation is not expected to change during the next decade. California processors often pay premiums based on solids-not-fat (SNF) content instead of protein because fluid milk in California is fortified to a minimum SNF rather than protein standard. Ice cream, yogurt, and powder processing plants currently pay premiums of about $.75 per pound of SNF rather than protein because protein is not more valuable than lactose or mineral in many products. Dried whey became a more valuable by-product recently with a price of $.25 or more per pound. Lactose and SNF yields are more correlated to milk yield than to protein yield (Welper and Freeman, 1992 J. Dairy Sci. 75:1342).

The value of protein in NM$ represents an average across the expected future uses of milk, or $2.80 (.60) + $.75 (.20) + $.57 (.20) = $1.95. This same approach was used when the Milk-Fat-Protein Dollars (MFP$) index was first introduced (Norman, 1979 USDA Prod. Res. Report 178). The following historical table shows the component prices used since 1977 to calculate Net Merit $ and MFP$. Prior to 1997, component prices were previous year average prices. Crude protein prices reported prior to 2000 were converted to true protein prices by multiplying by 1.064.

Year	Milk	Fat	True Protein	Volume
1977	12.30	1.48	1.24	0.034
1978	12.23	1.51	1.18	0.034
1979	12.25	1.52	1.21	0.033
1980	12.32	1.61	1.26	0.029
1981	12.35	1.63	1.28	0.028
1982	12.24	1.64	1.30	0.026
1983	12.34	1.70	1.33	0.024
1984	12.32	1.75	1.33	0.022
1985	12.26	1.72	1.28	0.024
1986	12.35	1.85	1.29	0.020
1987	12.28	1.74	1.23	0.025
1988	12.26	1.68	1.26	0.026
1989	12.31	1.46	1.50	0.027
1990	12.33	1.13	1.39	0.042
1991	12.23	1.12	1.47	0.039
1992	12.29	0.79	1.54	0.049

Year	Milk	Fat	True Protein	Volume
1993	12.33	0.70	1.66	0.049
1994	12.24	0.58	1.57	0.055
1995	12.29	0.72	1.69	0.047
1996	12.27	0.89	1.65	0.042
1997-99	12.30	0.80	2.12	0.031
2000-03	12.68	1.15	2.55	0.010
2003-06	12.70	1.30	2.30	0.013
2006-	12.70	1.50	1.95	0.016

Milk prices paid to producers have not increased while much inflation has occurred in labor and some other input prices during this time. Thus, health and fertility conditions requiring individual cow attention are becoming relatively more expensive to treat. Additional history on economic indexes is provided at the end of this document.

Somatic cell score

Selection for lower SCS reduces the labor, discarded milk, antibiotic, and other health costs associated with clinical mastitis. Lower PTA SCS also leads to higher milk prices in markets where quality premiums are paid. Fetrow et. al (2000, *Proceedings of the 39th Annual Meeting of the National Mastitis Council*, p. 3-47) surveyed price premiums and penalties across the nation and found an average price decrease of $.20 for each unit of PTA SCS (a doubling of somatic cell count). Since 2000, SCS premiums in the federal milk marketing orders have steadily increased to about $.18 per double. Somatic cell premiums are expressed and paid in federal orders as a linear function of the cell count difference from 350,000 per 1000 cells, but that value per 1000 cells can be converted to value per double by dividing by .0041, which is the difference between log base 2 of 351,000 and log base 2 of 350,000. Actual value of PTA SCS is higher for herds with more mastitis and lower for herds with less mastitis because payments are linear with SCC rather than with SCS.

The value of PTA SCS per lactation was set at -$58, which includes a lost premium of $42 plus $16 for labor, drugs, discarded milk, and milk shipments lost due to antibiotic residue. Larger economic losses caused by reduced milk yield are not included in the SCS value because these already are accounted for in PTA milk. The economic value results in assigning 9% of emphasis in NM$ to lower SCS. PTA SCS includes an average of 3 which is subtracted when including PTA SCS in the merit indexes.

Daughter pregnancy rate

Cow fertility is a major component of PL and is important in that sense. Additional benefits associated with DPR that are not included in PL are additional calves produced, decreased units of semen needed per pregnancy, decreased labor and supplies for heat detection, inseminations, and pregnancy checks, and higher yields because more ideal lactation lengths are achieved. Semen price ($15/unit) and insemination labor costs ($5/unit) were multiplied by .025 units/day open to estimate a cost of $.50/day open. Heat detection labor and supplies ($20/lactation) multiplied by .5% increase/day open resulted in a cost of $.10/day open. Labor costs for pregnancy checks ($10/exam) were multiplied by .012 exams/day open for a cost of $.12/day open. Reduced profit from lactations longer or shorter than optimum was estimated to be $.75/day open.

The loss of about $1.50/day open is converted to a lifetime value by multiplying by 2.6, which assumes that cows have 2.8 lactations, no breedings are attempted for half of the cows during their final lactation, and heifer fertility is also included with a correlation of .3 to cow fertility (2.6 = 3.0 - .5 + .3). This economic loss for 1 day open is then converted to DPR by multiplying by -4, which results in a DPR value of $16/PTA unit. Also, with the new definition of PL, number of calves born increase with both DPR and PL. At a constant PTA PL, 1% higher DPR results in about 1% more calves per lifetime with an average value of ($150 + $450)/2, resulting in an extra $3/PTA unit of DPR. Poor fertility is correlated with other unmeasured health expenses, and $2 was added to account for these for a total value of $21. With an SD of 1.4 for true transmitting ability, DPR will receive 9% of the relative emphasis in NM$.

The assumed costs may differ greatly across farms or countries. Hansen et al. (1983, *Journal of Dairy Science* 66:306) obtained expected responses to index selection for a wide range of economic values. McAllister (2000, *Proceedings of the Conference on Managing Reproduction in Southeastern Dairy Herds*) provided a more recent summary of selection for fertility. Research from Australia (Morton, 2002) indicates that fertility may be 3 times more important in herds with seasonal calving than those that calve year-round.

Yield trait data are adjusted by the Animal Improvement Programs Laboratory (**AIPL**) for days open during the previous lactation but not the current lactation. Adjustments for current days open were developed as part of a test-day model [Wiggans et al., 2002, *Journal of Dairy Science* 85:(Jan.)] but have not been implemented. Inclusion of PL in NM$ since 1994 and adjustment of yield traits for previous days open since 1995 already have prevented much of the correlated decline in cow fertility that would have resulted from selecting for increased yield. Actual selection decisions of breeders may not have emphasized PL as much as recommended in previous NM$ formulas. The Holstein genetic trend for DPR has stopped declining since 1995, but the environmental trend continues downward.

Further details regarding the calculation of DPR are provided by "Daughter pregnancy rate evaluation of cow fertility" [VanRaden et al, 2003, *AIPL Research Report* DPR1(11-02)].

Conformation composites

Linear type traits provide additional information about incomes and expenses. Instead of directly using PTAs for all 17 type traits, composites are used in NM$. For Holsteins, the Udder Composite, Feet and Legs Composite, and Body Size Composite Indexes are calculated by Holstein Association USA (2000, *Holstein Type-Production Sire Summaries, August*, p. 12). For other breeds, published PTAs for linear traits are converted to standardized transmitting abilities (**STA**s) by dividing by SD of true transmitting ability and then are combined into composites that are not published. Because rear legs (rear view) and feet-and-legs score in the Holstein Feet and Legs Composite are traits that are not available for other breeds, STA for foot angle and rear legs (side view) are included in the feet/legs composite for those breeds. Relative values of udder and feet/leg traits for Jerseys and Brown Swiss were obtained from the official Functional Trait Indexes (FTI) and Functional Udder Index (FUI) of those 2 breed associations. The Jersey values equal 3 FTI + FUI and the resulting values are applied to Ayrshires, Guernseys, and Milking Shorthorns instead of the Holstein values used previously. Relative values were negative for fore udder, rear udder height, and teat placement in the official Guernsey FTI and thus that index was not used here. Breed association FTI formulas were obtained from correlations with productive life, but partial regressions are difficult to estimate in small populations with many traits. Relative values of body size traits are the same for all breeds except Jersey, where body depth is no longer evaluated and its value was assigned to strength instead.

Udder trait	Relative value (%)		
	Holstein	Brown Swiss	Jersey and other breeds
Fore udder	16	21	20
Rear udder height	16	6	18
Rear udder width	12	1	8
Udder cleft	10	2	3
Udder depth	30	35	26
Teat placement	16	11	7
Teat length		-24	-18
Udder composite	100	100	100

Relative values of traits in the feet/legs composite follow:

Foot or leg trait	Relative value (%)		
	Holstein	Brown Swiss	Jersey and other breeds
Rear legs (side view)	-8	-32	-30
Rear legs (rear view)	18	. . .	. . .
Foot angle	24	68	70
Feet and legs score	50	. . .	. . .
Feet and legs composite	100	100	100

Relative values of traits in the size composite follow:

Size trait	Relative value (%)	
	Holstein and other breeds	Jersey
Stature	50	50
Strength	25	40
Body depth	15	. . .
Rump width	10	10
Size composite	100	100

Estimated genetic standard deviations for each trait and breed follow. SD are 1.0 for Holsteins because their linear trait evaluations are published as STAs.

Trait	Genetic Standard Deviation for Each Breed					
	Ayrshire	Brown Swiss	Guernsey	Holstein	Jersey	Milking Shorthorn
Stature	1.8	1.0	1.8	1.0	1.3	1.6
Strength	0.8	0.7	0.9	1.0	0.8	0.9
Body depth	1.0	0.8	1.1	1.0	1.0	1.1
Dairy form	0.9	0.7	1.4	1.0	1.1	1.0
Rump angle	0.8	1.0	1.3	1.0	1.0	0.9
Thurl width	1.0	0.6	1.2	1.0	0.7	0.8
Rear legs (side view)	0.6	0.7	0.7	1.0	0.7	0.4
Rear legs (rear view)	0.0	0.0	0.0	1.0	0.0	0.0
Foot angle	0.7	0.6	0.5	1.0	0.7	0.6
Foot and leg score	0.0	0.0	0.0	1.0	0.0	0.0
Fore udder	0.7	1.0	1.4	1.0	1.1	1.0
Rear udder height	0.9	0.9	1.5	1.0	1.2	0.9
Rear udder	0.8	0.7	1.4	1.0	1.1	0.7

Trait	Genetic Standard Deviation for Each Breed					
	Ayrshire	Brown Swiss	Guernsey	Holstein	Jersey	Milking Shorthorn
width						
Udder cleft	0.7	0.9	1.0	1.0	0.8	0.6
Udder depth	0.9	1.0	1.6	1.0	1.5	1.1
Teat placement	0.8	0.8	1.2	1.0	1.1	1.1
Teat length	1.2	1.1	1.3	1.0	0.9	1.3

The emphasis placed on udder composite in NM$ is similar to that proposed by Rogers (1993, *Journal of Dairy Science* 76:664; 1998, *Proceedings of the 1998 U.S. National Dairy Genetics Workshop, Orlando, FL*, p. 5-11). Selection for higher udders is important when also selecting against large body size. Positive selection for PTA feet/legs and negative selection for PTA size also are included. Compared with a value of $11 per lactation for udder traits, the value of PTA feet/legs is set at $5 per lactation based on research by Rogers (1993, *Journal of Dairy Science* 76:664).

Large cows and bulls were favored by dairy cattle breeders for many years. Research studies (VanRaden, 1988, *Journal of Dairy Science* 71:Suppl. 1:238; Metzger et al., 1991, *Journal of Dairy Science* 74:Suppl. 1:262) that were funded by Holstein Association USA at the Universities of Wisconsin and Minnesota concluded that cow size should have negative value in an index because milk income already was accounted for but feed costs were not. Within each breed, the larger cows tend to eat more feed and are less efficient (Dickinson et al., 1969, *Journal of Dairy Science* 52:489).

Body size expenses include the increased cost of feed per lactation that is eaten by heavier cows for body maintenance [$.18/pound of cow weight based on findings by the National Research Council (2001, *Nutrient Requirements of Dairy Cattle*, 7th rev. ed.), Yerex et al. (1983, *Journal of Dairy Science* 66:Suppl. 1:115), and Metzger et al. (1991, *Journal of Dairy Science* 74:Suppl. 1:262) plus increased housing costs [$.03/pound of cow weight based on Bath et al. (1985, *Dairy Cattle: Principles, Practices, Problems, Profits*, 3rd ed.) and Etgen et al. (1987, *Dairy Cattle Feeding and Management*, 7th ed.)] minus income from heavier calf weights ($.06/pound of cow weight). Mature cow weight in pounds is obtained by multiplying PTA size by 24 based on Holstein data from the University of Minnesota size-selection herd. The net lactation expense equals $.15/pound of cow weight, and the beef price for cull cows is much lower than the cost of growing replacements. The calculated value of body size was then reduced slightly as compared to 2000 NM$ because inclusion of calving ease in the index places additional emphasis on small size. The direct selection emphasis in NM$ is now 4% against large body size.

Lifetime profit

The NM$ index is defined as the expected lifetime profit as compared with the breed base cows born in 2000. Incomes and expenses that repeat for each lactation are multiplied by the cow's expected number of lactations. This multiplication makes the economic function a nonlinear function of the original traits. For official NM$, a linear approximation of this nonlinear function is used as recommended by Goddard

(1983, *Theoretical and Applied Genetics* 64:339). The linear function is much simpler to use and was correlated with the nonlinear function by .999.

Index selection based on computer calculation is efficient, and computer mating programs that account for inbreeding using complete pedigrees also should be used. Selection and mating programs both can have large, nearly additive effects on future profit. Gains from mating programs do not accumulate across generations, whereas gains from selection do. Cows and bulls within each breed are ranked with the same NM$ even though the timing of gene expression differs with gender.

NM$ measures additional lifetime profit that is expected to be transmitted to an average daughter, but does not include additional profit that will be expressed in granddaughters and more remote descendants. Gene flow methods and discounting of future profits could provide a more complete summary of the total profit from all descendants. Animal welfare may be a goal of society but is not assigned a monetary value in NM$. Healthier cows can make dairying a more enjoyable occupation, and traits associated with cow health may deserve more emphasis as labor costs increase. Production of organic milk with fewer treatment options could require cows with more natural ability to resist disease and remain functional.

The profit function approach used in deriving NM$ lets breeders select for many traits by combining the incomes and expenses for each trait into an accurate measure of overall profit. Averages and SDs of the various traits in the profit function may differ by breed, but official NM$ is calculated by using Holstein values instead of having a slightly different NM$ formula for each breed. Producers should use the lifetime merit index (NM$, CM$, or FM$) that corresponds to the market pricing that they expect a few years in the future when buying breeding stock and 5 years in the future when buying semen.

History of NM$

The August 2006 NM$ index is correlated by .975 with the 2003 NM$ formula for recent progeny-tested bulls. About half the changes are caused by the PTA PL revision and the rest from addition of stillbirth and updates of trait economic values. An increase in genetic progress worth $6 million per year is expected on a national basis, which assumes that all of the three changes are improvements.

In the August 2003 revision, cow fertility and calving ease were incorporated into NM$. In the August 2000 revision, type traits were included along with yield and health traits using a lifetime profit function described in based on research of scientists in the S-284 Health Traits Research Group. In 1994, PL and SCS were combined with yield traits into NM$ using economic values that were obtained as averages of independent literature estimates (VanRaden and Wiggans, 1995 Journal of Dairy Science 78:631). In the 1980's as part of Project NC-2 of the North Central Regional Association of Agricultural Research Experiment Station Directors, researchers developed a profit function to compare genetic lines in their experimental herds:

lifetime profit = milk value + salvage value + value of calves
- rearing cost - feed energy - feed protein - health cost - breeding cost.

Relative net income also was developed to measure profit from field data, with adjustment for opportunity cost to more fairly compare short- and long-term investments (Cassell et al 1993 76:1182). The main difference between NM$ and the profit function approaches is that a PTA is calculated for each evaluated trait and then combined instead of combining each cow's phenotypic data directly. The PTA approach is more accurate because heritabilities of traits differ, genetic correlations are not the same as phenotypic correlations, and all phenotypes are not available at the same time.

In 1984 and 1977, economic index formulas based on cheese yield price (**CY$**) and protein price (**MFP$**), respectively, were introduced. In 1971, AIPL introduced its first economic index called Predicted Difference Dollars (**PD$**), which combined only milk and fat yield. The 3 different milk pricing formulas continued to be published until 1999 when these were replaced by the more complete merit indexes CM$, NM$, and FM$, respectively. See the Yield Traits section for a history of milk price formulas.

A history of the main changes in AIPL indexes and the percentage of relative emphasis on traits included in indexes follows:

Traits included	**USDA economic index (and year introduced)**						
	PD$ (1971)	**MFP$ (1976)**	**CY$ (1984)**	**NM$ (1994)**	**NM$ (2000)**	**NM$ (2003)**	**NM$ (2006)**
Milk	52	27	-2	6	5	0	0
Fat	48	46	45	25	21	22	23
Protein	. . .	27	53	43	36	33	23
PL	. . .	. . .	. . .	20	14	11	17
SCS	. . .	. . .	. . .	-6	-9	-9	-9
Udder composite	. . .	. . .	. . .	. . .	7	7	6
Feet/legs composite	. . .	. . .	. . .	. . .	4	4	3
Body size composite	. . .	. . .	. . .	. . .	-4	-3	-4
DPR	. . .	. . .	. . .	. . .	. . .	7	9
Service sire calving difficulty	. . .	. . .	. . .	. . .	. . .	-2	. . .
Daughter calving difficulty	. . .	. . .	. . .	. . .	. . .	-2	. . .
CA$	. . .	. . .	. . .	. . .	. . .	. . .	6

Emphasis on yield traits has declined as other fitness traits were introduced. As protein yield became more important, milk volume became less important because of the high correlation of those 2 traits. A more complete history and comparisons with selection indexes used by other countries are available (Shook, 2006, *Journal of Dairy Science* 89:1349; VanRaden, 2002, *Proceedings of the 7th World Congress on Genetics Applied to Livestock Production* 29:127; VanRaden, 2004, *Journal of Dairy Science* 87:3125).

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