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Net merit as a measure of lifetime profit: 2010 revision

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Updated economic values || Net merit calculation || Trait parameters || Expected genetic progress || Derivation of economic values || Yield traits || Somatic cell score || Body size composite || Lifetime profit || History of net merit || Acknowledgments

The 2010 revision of net merit (**NM$**) updates a number of key economic values as well as milk utilization statistics. Feed costs have dramatically risen since the 2006 revision, which affects a number of traits in the index. Different somatic cell score (**SCS**) premiums are now applied to NM$, cheese merit (**CM$**), and fluid merit (**FM$**). New heifer and cow conception rate traits were not added to the indexes but could be included in the near future. Compared with the 2006 formulation of NM$, less weight is placed on fat and protein yields and calving ability (**CA$**, an index that includes sire calving ease, daughter calving ease, sire stillbirth, and daughter stillbirth), and more emphasis is placed on productive life (**PL**), SCS, udder composite, feet/legs composite, body size (favoring smaller cows), and daughter pregnancy rate (**DPR**). Members of Project S-1040, *Genetic Selection and Crossbreeding To Enhance Reproduction and Survival of Dairy Cattle*, provided updated incomes and expenses used to estimate lifetime profit.

This document describes changes made for the 2010 revision of NM$. Further details regarding the calculation of NM$ and component traits are provided by VanRaden and Multi-State Project S-1008 [2006, *AIPL Research Report* NM$3(7-06)].

Updated economic values

New economic values for each unit of predicted transmitting ability (**PTA**) and relative economic values of traits will be implemented with January 2010 evaluations:

Trait	Units	Standard deviation (SD)	Value ($/PTA unit)			Relative value (%)		
			NM$	CM$	FM$	NM$	CM$	FM$
Protein	Pounds	19	3.41	7.52	0	16	25	0
Fat	Pounds	27	2.89	2.89	2.89	19	13	20
Milk	Pounds	723	0.001	−0.119	0.107	0	−15	19
PL	Months	2.5	35	35	35	22	15	22
SCS	Log	0.23	−182	−235	−91	−10	−9	−5
Udder	Composite	0.90	32	32	32	7	5	7
Feet/legs	Composite	1.03	15	15	15	4	3	4
Body size	Composite	1.03	−23	−23	−23	−6	−4	−6
DPR	Percent	1.70	27	27	27	11	8	12
CA$	Dollars	20	1	1	1	5	3	5

The SDs listed above are for true transmitting abilities (**TTA**s) in a hypothetical unselected population. The SDs of TTAs for NM$, CM$, and FM$ are all estimated to be $198. An economic value is the added profit caused when a given trait changes by 1 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 measures, but multitrait methods currently are used only for conformation traits and 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 the index.

Relative values for each trait expressed as a percentage of total selection emphasis are obtained by multiplying the economic value by the SD for TTA 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 sire calving ease and daughter calving ease. For the remaining breeds, relative values of the other traits in NM$ and FM$ each increase by a factor of 1.05 because the 5% emphasis on CA$ is excluded. A corresponding increase of 1.03 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
Feet/legs	+0.5	75
Body size	−1.0	85
DPR	+0.3	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 +$685, CM$ is $735, and FM$ is $653. Calculation of NM$ also can be expressed in matrix form:

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$. Cow PTAs for CA$ are not available because a sire-maternal grandsire (**MGS**) model (instead of an animal model) is used for evaluation of CA$ traits. Therefore, a pedigree index (0.5 sire PTA + 0.25 MGS PTA + 0.125 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 0.85 plus the REL of PL multiplied by 0.15. For the example Holstein, NM$ REL is [90%(0.85) + 60%(0.15)] = 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$:

REL NM$ = **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.* (2004, *Journal of Dairy Science* 87:2285), 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 PTAs of bulls with high REL because restricted maximum-likelihood 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:

PTA trait	PTA trait									
	Milk	Fat	Protein	PL	SCS	Body size	Udder	Feet/legs	DPR	CA$
Milk	**0.30**[1]	0.45	0.81	0.08	0.20	−0.10	−0.20	−0.02	−0.32	0.15
Fat	0.69	**0.30**	0.60	0.08	0.15	−0.09	−0.20	−0.02	−0.33	0.11
Protein	0.90	0.75	**0.30**	0.10	0.20	−0.10	−0.20	−0.02	−0.35	0.16
PL	0.15	0.14	0.17	**0.08**	−0.38	−0.16	0.30	0.19	0.51	0.40
SCS	−0.10	−0.10	−0.10	−0.15	**0.12**	−0.11	−0.33	−0.02	−0.30	−0.08
Body size	0.06	0.06	0.06	0.03	−0.11	**0.40**	0.26	0.22	−0.08	−0.24
Udder	−0.10	−0.10	−0.10	0.10	−0.33	0.26	**0.27**	0.10	0.03	0.06
Feet/legs	0.01	0.01	0.01	0.19	−0.02	0.22	0.10	**0.15**	−0.04	−0.04
DPR	−0.10	−0.10	−0.10	0.20	−0.05	0.00	0.00	0.00	**0.04**	0.34
CA$	0.02	0.02	0.02	0.10	−0.03	−0.07	0.00	−0.02	0.09	**0.07**

[1]Holstein heritabilities in **blue** on diagonal; heritabilities for other breeds are the same except for size (**0.35**), udder (**0.20**), and Jersey and Brown Swiss yield traits (**0.35**).

Expected genetic progress

Correlations of PTAs for each trait with NM$, FM$, and CM$ were obtained from progeny-tested Holstein bulls born from 2000 through 2003. 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 2006 formula are shown for comparison:

PTA trait	Correlation of PTA with index				Expected genetic progress from NM$	
	2006 NM$	2010 NM$	2010 CM$	2010 FM$	PTA change/year	Breeding value change/decade
Protein	0.52	0.45	0.43	0.49	2.1	43
Fat	0.62	0.56	0.54	0.57	3.8	76
Milk	0.44	0.38	0.24	0.52	69	1,374
PL	0.72	0.78	0.76	0.74	0.5	10
SCS	−0.35	−0.39	−0.41	−0.30	−0.02	−0.45
Udder	0.15	0.17	0.15	0.16	0.04	0.8
Feet/legs	0.14	0.15	0.13	0.15	0.04	0.8
Body size	−0.16	−0.19	−0.21	−0.18	−0.05	−0.98
DPR	0.35	0.41	0.41	0.37	0.17	3.5
CA$	0.30	0.30	0.28	0.30	1.5	30

The new indexes are more correlated than 2006 NM$ with PL, SCS (negatively), udder composite, feet/legs composite, body size (negatively), and DPR but result in less progress for milk, fat, and protein yields. Expected PTA progress was obtained as the correlation of PTA with NM$ multiplied by the SD of PTA multiplied by 0.25, which is the annual trend in SD of NM$. Previously the annual trend was estimated to be 0.34 SD, but that was with most selection on more heritable traits. The PTA SDs (not shown) generally are lower than the TTA SDs shown in the first table because of selection and because RELs are less than 1. 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 derivation of economic values is shown below for yield traits, SCS, and body size composite; economic values for PL, udder and feet/legs composites, DPR, and CA$ were derived as described in VanRaden and Multi-State Project S-1008 [2006, *AIPL Research Report* NM$3(7-06)] for the 2006 net merit index.

Yield traits

A base price of $14.93 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 $0.40 in California (California Department of Food and Agriculture, 2009), $0.28 in the Upper Midwest Marketing Order (Freije, 2008), and $0.73 in New York (State of New York Department of Agriculture and Markets, 2008) and are increasing because of fuel costs. An average of $0.57 was assumed; actual costs for hauling milk are about $0.0057/100 pounds/loaded mile. The milk price after hauling charges was equal to $14.36. Component prices follow, along with marginal feed costs and health costs required for higher yield with the nonyield traits in NM$ held constant; values in the volume column are computed as (milk value) − 3.5(fat value) − 3(protein value) divided by 100:

Index	Milk ($/100 pounds)	Fat ($/pound)	Protein ($/pound)	Volume ($/pound)
NM$	14.36	1.63	1.94	0.0286
CM$	14.36	1.63	3.35	−0.0138
FM$	14.36	1.63	0.77	0.0636
Feed cost	6.01	0.53	0.70	0.0206
Extra health cost	1.15	0.11	0.07	0.0056

Feed costs have averaged 41% of the milk price over the last 4 years (Gould, 2009; R.E. Pearson, 2009, personal communication). The cost for milk volume accounts for the $0.20 required to produce a pound of lactose in each 20 pounds of milk. A cost of $0.002 for bulk tank, equipment, and electricity costs to cool and store each pound of milk also is included in the feed cost. Feed costs for fat and protein were calculated using the approach of Dado et al. (1994, *Journal of Dairy Science* 77:598) with an additional multiplier to account for increased feed prices. The feed cost for fat also now reflects the increased price of corn relative to soybean meal, resulting in similar feed costs per pound of fat and protein produced.

Extra health costs equal 8% of the milk price based on a literature review conducted by A.J. Seykora (2006, personal communication). The other traits in NM$ such as PL and DPR account for replacement costs and some (but not all) health costs. Somatic cell score 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, *Journal of Dairy Science* 77:3683), Jones et al. (1994, *Journal of Dairy Science* 77:3137), Simianer et al. (1991, *Journal of Dairy Science* 74:4358), Uribe et al. (1995, *Journal of Dairy Science* 78:421), Van Dorp et al. (1998, *Journal of Dairy Science* 81:2264), and Zwald et al. (2004, *Journal of Dairy Science* 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 0.97 for NM$ with CM$, 0.97 for NM$ with FM$, and 0.89 for FM$ with CM$. The FM$ index before 2003 included a protein price of 0, but many producers receive a blend price for milk. A small protein premium equal to feed cost plus health cost was included to 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 less than $1.35/pound of protein should select on FM$; those that expect premiums greater than $2.65/pound of protein should select on CM$. Most U.S. producers are likely to expect protein premiums between $1.35 and $2.65 and should select on NM$.

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 2.92, and the lifetime value of PTA protein in NM$ is (1.94 − 0.77)2.92 = $3.41. Yield traits together account for 35% of total selection emphasis in NM$.

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 USDA's Agricultural Marketing Service. Actual prices since 2006 for class III milk used in cheese making are shown below:

Year	Milk ($/100 pounds)	Fat ($/pound)	Protein ($/pound)	Volume ($/pound)	SCC ($/double)[1]
2006	11.89	1.33	2.09	0.0097	−0.15
2007	18.04	1.47	3.51	0.0024	−0.21
2008	17.44	1.57	3.89	0.0028	−0.23
2009	10.29	1.20	1.99	0.0012	−0.15
Average	14.42	1.39	2.87	0.0040	−0.19

[1]A doubling of somatic cell count (SCC) results in a 1-unit increase in SCS. See the section on SCS for a fuller explanation of penalties.

During the last 4 years, protein prices paid by cheese plants averaged $2.87 and butterfat prices averaged $1.39, with prices peaking in 2008 and decreasing in 2009. The predicted values in CM$ of $3.35 and $1.63 assume a modest upward trend in minimum Federal milk order class prices through 2014 (Food and Agricultural Policy Research Institute, 2009) for both protein and fat. Based on utilization statistics from USDA's Agricultural Marketing Service, the California Department of Food and Agriculture, and the University of Idaho, about 40% of U.S. milk is used for cheese (compared with 25% in 1979), about 31% for fluid (50% in 1979), 24% for soft or frozen products, and 5% for powdered milk. Utilization of milk for hard cheese has decreased, and fluid consumption has increased. The 2006 version of NM$ assumed that 60% of milk would be used to make cheese, 20% for fluid consumption, 15% for soft and frozen products, and 5% for powdered milk. The change in expected utilization contributes to the decreased value of protein in NM$ because less milk now goes to make cheese. Premiums for SCS are discussed in the SCS section below.

Fluid milk processors often pay no premium for extra protein because grocery store milk is not labeled 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 have paid premiums averaging $1.16/pound of SNF from 2006 to 2009 rather than protein because protein is not more valuable than lactose or mineral in many products. Dried whey became a more valuable byproduct recently with a price of $0.25/pound or higher. Lactose and SNF yields are more correlated to milk yield than to protein yield (Welper and Freeman, 1992, Journal of Dairy Science 75:1342).

The value of protein in NM$ represents an average across the expected future uses of milk (hard cheese, soft/frozen products, and fluid milk): $3.35(0.40) + $1.16(0.29) + $0.86(0.31) = $1.94. That same approach was used when the milk-fat-protein dollars (MFP$) index was first introduced (Norman et al., 1979, USDA Production Research Report 178). The following historical table shows the component prices used since 1977 to calculate NM$ 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
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
2006–09	12.70	1.50	1.95	0.016
2010–	14.36	1.63	1.94	0.029

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 in the History of NM$ section below.

SCS

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 $0.20/unit of PTA SCS (a doubling of SCC). Since 2006, SCS premiums in Federal milk orders have steadily increased to about $0.27/double. Somatic cell premiums are expressed and paid in Federal orders as a linear function of the cell count difference from 350,000/1,000 cells, but that value per 1,000 cells can be converted to value per double by dividing by 0.0041, 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.

A different premium for SCS is now applied in each index. The full class III premium of $0.24 is applied to SCS in CM$ because manufacturing plants typically provide incentives for improved milk quality. A premium of $0.17 is used for NM$ on the assumption that 70% of the milk will be sold in blend markets that are paid the class III premium [$0.35(0.70) = $0.17]. Some producers in fluid markets receive a small premium for improved milk quality, but estmates of those payments were difficult to find. A premium of $0.05 was assigned to SCS in FM$, but the actual premium paid will vary somewhat from market to market.

The value of PTA SCS per lactation in NM$ was set at −$62, which includes a lost premium of $44 plus $18 for labor, drugs, discarded milk, and milk shipments lost because of antibiotic residue. The value of SCS is greater for CM$ (−$80) and less for FM$ (−$31). Larger economic losses caused by reduced milk yield are not included in the SCS value because those already are accounted for in PTA milk. The economic value results in assigning 10% of emphasis in NM$ to lower SCS. The PTA SCS includes an average of 3, which is subtracted when including PTA SCS in the merit indexes.

Body size composite

Linear type traits provide additional information about incomes and expenses. Instead of directly using PTAs for all 17 type traits, composite indexes are used in NM$. For Holsteins, the udder, feet/legs, and body size composites are calculated by Holstein Association USA (2009, *Total Performance Index Sire Summaries, August*, p. 16). For other breeds, published PTAs for linear traits are converted to standardized transmitting abilities (**STA**s) by dividing by SD of TTA and then combining into composites that are not published. Because rear legs (rear view) and feet-and-legs score in the Holstein feet/legs composite are traits that are not available for all 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/legs traits for Jerseys, Guernseys, and Brown Swiss were obtained from the official Functional Trait Indexes or Functional Udder Indexes of those 3 breed associations. The Jersey values are applied to Ayrshires and Milking Shorthorns. Breed association Functional Trait Index formulas were obtained from correlations with PL, 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 and Brown Swiss, where body depth is no longer evaluated and its value was assigned to strength instead.

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). In 2006, feed costs were 31% of the cost of producing a hundredweight of milk. Those costs rose dramatically between 2006 and 2009 and now average 47% of production costs. The cost of feed, particuarly corn, is expected to decrease slightly over the next few years.

Body size expenses include the increased cost of feed per lactation that is eaten by heavier cows for body maintenance {$0.20/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 [$0.03/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 based on Holstein data from the University of Minnesota size-selection herd. The net lactation expense equals $0.41/pound of cow weight, and the beef price for cull cows is much lower than the cost of growing replacements. The direct selection emphasis in NM$ is now 6% against large body size.

Lifetime profit

The NM$ index is defined as expected lifetime profit as compared with the breed base cows born in 2005. 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 0.999.

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 by sex.

The 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 January 2010 NM$ index is correlated by 0.99 with the 2006 NM$ formula for recent progeny-tested bulls. The 2010 changes are caused by updated trait economic values, SDs of TTAs, and milk utilization statistics. No new traits were added to NM$ in 2010, but heifer and cow conception rate may be added in the near future. The price of feed has increased dramatically in the last 2 years; although prices are expected to decrease slighty over the next few years, they will remain high. The value of heifer calves has decreased substantially and is now consistent with historical trends that valued heifer and bulls calves similarly. That decrease had little effect on the indexes because most of the cost of raising replacements is in feed rather than calf cost; however, it did increase the value of longevity.

The 2006 NM$ index was correlated by 0.975 with the 2003 NM$ formula for recent progeny-tested bulls. About half the changes were 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/year was expected on a national basis, which assumed that all of the 3 changes were improvements.

In the 2003 NM$ revision, cow fertility and calving ease were incorporated into NM$. In the 2000 NM$ revision, type traits were included along with yield and health traits using a lifetime profit function 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 1980s 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, *Journal of Dairy Science* 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, USDA introduced its first genetic-economic index called Predicted Difference Dollars (**PD$**), which combined only milk and fat yield. The 3 different milk pricing formulas (Norman, 1986, *National Cooperative Dairy Herd Improvement Program Handbook* Fact Sheet H-1) continued to be published until 1999 when they were replaced by the more complete merit CM$, NM$, and FM$ indexes, respectively (see the Yield Traits section for a history of milk price formulas).

A history of the main changes in USDA genetic-economic indexes for dairy cattle and the percentage of relative emphasis on traits included in the indexes follow:

Traits included	USDA genetic-economic index (and year introduced)							
	PD$ (1971)	MFP$ (1976)	CY$ (1984)	NM$ (1994)	NM$ (2000)	NM$ (2003)	NM$ (2006)	NM$ (2010)
Milk	52	27	−2	6	5	0	0	0
Fat	48	46	45	25	21	22	23	19

Protein	…	27	53	43	36	33	23	16
PL	…	…	…	20	14	11	17	22
SCS	…	…	…	−6	−9	−9	−9	−10
Udder composite	…	…	…	…	7	7	6	7
Feet/legs composite	…	…	…	…	4	4	3	4
Body size composite	…	…	…	…	−4	−3	−4	−6
DPR	…	…	…	…	…	7	9	11
Service sire calving difficulty	…	…	…	…	…	−2	…	…
Daughter calving difficulty	…	…	…	…	…	−2	…	…
CA$	…	…	…	…	…	…	6	5

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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