Improving dairy cattle replacement and insemination decision-making: A complex problem

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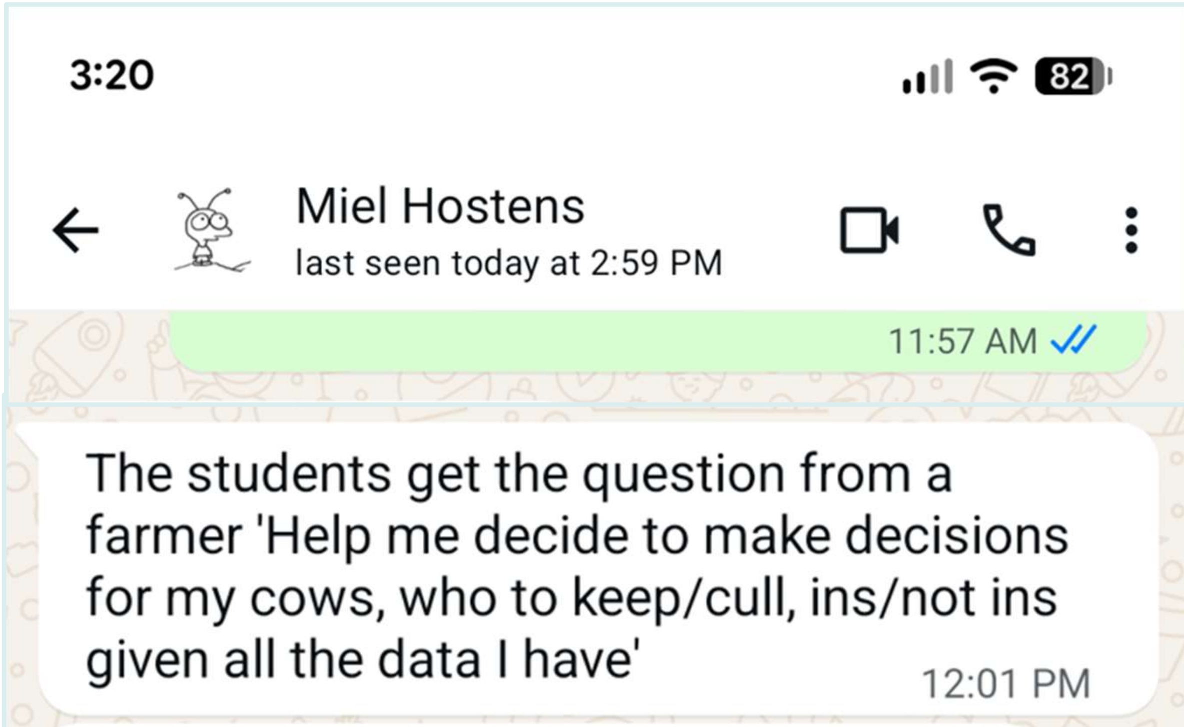
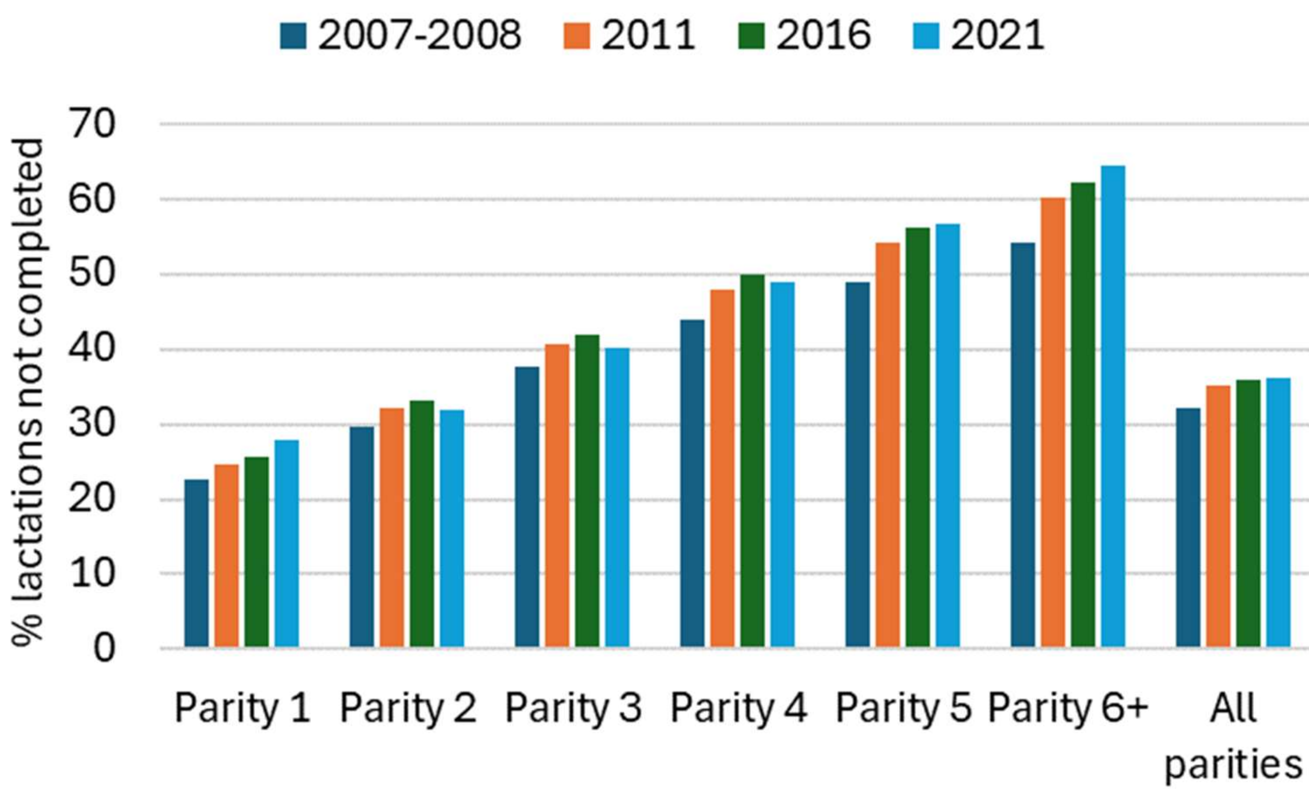
Guest lecture, *ANSC 4040 Data Science Applications in Agriculture*, Cornell University, February 9, 2026


3:20
82
Miel Hostens
last seen today at 2:59 PM
11:57 AM
The students get the question from a farmer 'Help me decide to make decisions for my cows, who to keep/cull, ins/not ins given all the data I have'
12:01 PM

% cows not reaching next lactation (DHI)



≈35% of cows are replaced every year

1/35% = 2.9 yr productive life

≈ 3 million records/year

Source: https://queries.uscdcb.com/publish/dhi/cull.html

Cows that survive

HOARD'S DAIRYMAN INTEL Feb. 3 2025 08:02 AM

9 Total Shares

Create the invisible cow

BY REAGAN BLUEL, UNIVERSITY OF MISSOURI EXTENSION

- 4 events per lactation:
  - 1 calving
  - 1 breeding
  - 1 pregnancy diagnosis
  - 1 dry off

- Risk factors for culling: sick, lame, not-pregnant, poor conformation, bad temperament, low milk yield, …

Reviewed in: De Vries and Marcondes (2020). Animal 14(S1):s155-s164 https://www.agproud.com/articles/59714-developing-a-productive-sustainable-life-for-dairy-cows

Calf & Heifer Health

Getty Images.

Developing a productive, sustainable life for dairy cows

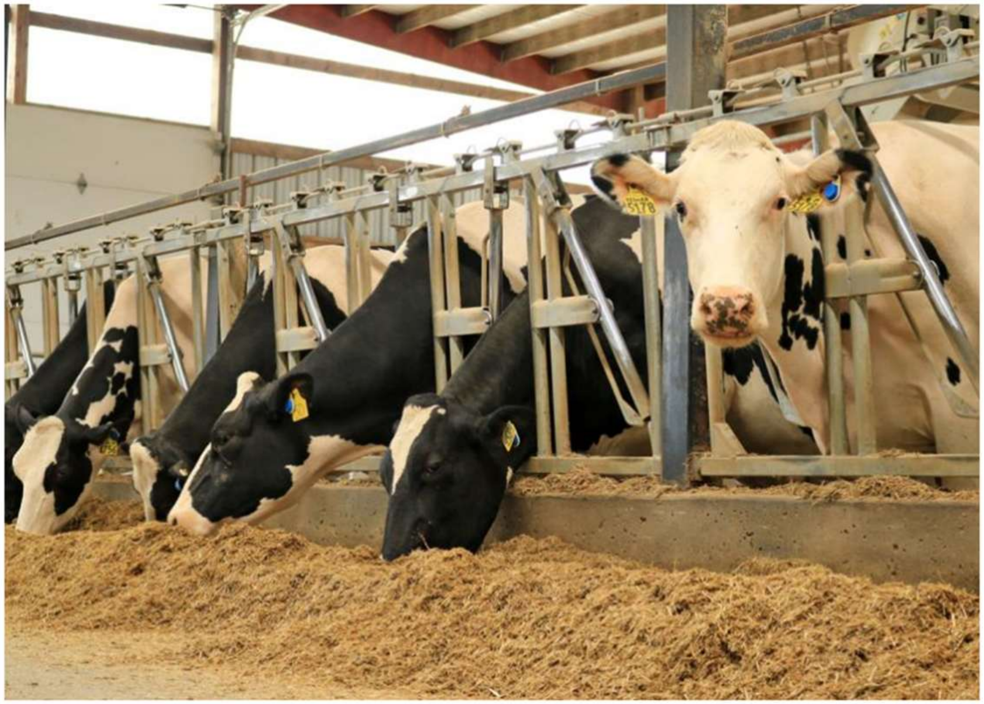
Gavin Staley June 5, 2024

In order to become more economical and sustainable, dairies should focus on increasing the productive life of their animals. This also meets consumer demands for transparency and animal care.

https://www.dairyherd.com/news/dairy-production/longevity-cowherd

NEWS / DAIRY PRODUCTION

Longevity in the Cowherd



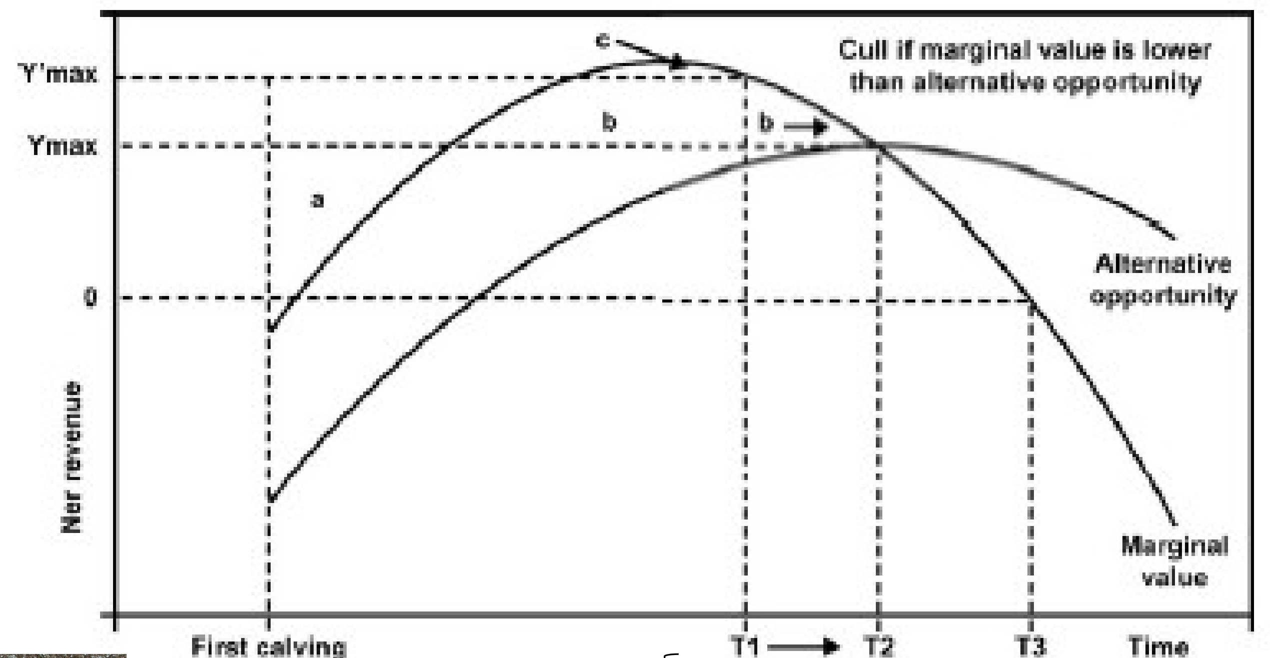
"What happens when a new heifer enters the herd? You have the luxury of finding the least profitable cow, the least healthy cow, and replacing her." —Steve Eicker, DVM
(Taylor Leach)

By RHONDA BROOKS July 17, 2024

Animal Replacement Problem: Principles

- Competition for a slot in the herd
- Most profitable cows stay
- Complication: herd constraints (cow interdependence)
- Needed:
    1. Predict future animal performance; cow + replacement heifers
    2. Make most profitable decisions

Asset Replacement Theory: replace sooner if *challenger* is technically better than *incumbent*



Replacement heifer:

T1: better

T2: identical

T3: not available

Groenendaal et al. (2004) J. Dairy Sci. 87:2146

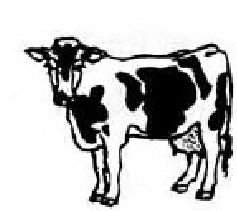
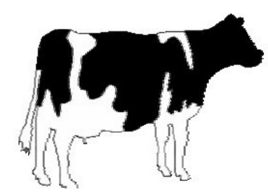
Optimal replacement decisions (theory)

Compare future cash flows of incumbent and challenging cow(s)

- Consider **opportunity cost** = cost sacrificed on an average challenging cow by keeping the incumbent cow in the herd *(Van Arendonk, 1991)*

NPV[Future cash flow of incumbent] Keep
– NPV[Future cash flow of challenger] Replace

= Keep – Replace = Retention pay-off (RPO) = Keep value

y = f(x):  **or**  **?**

Dynamic programming, *example*

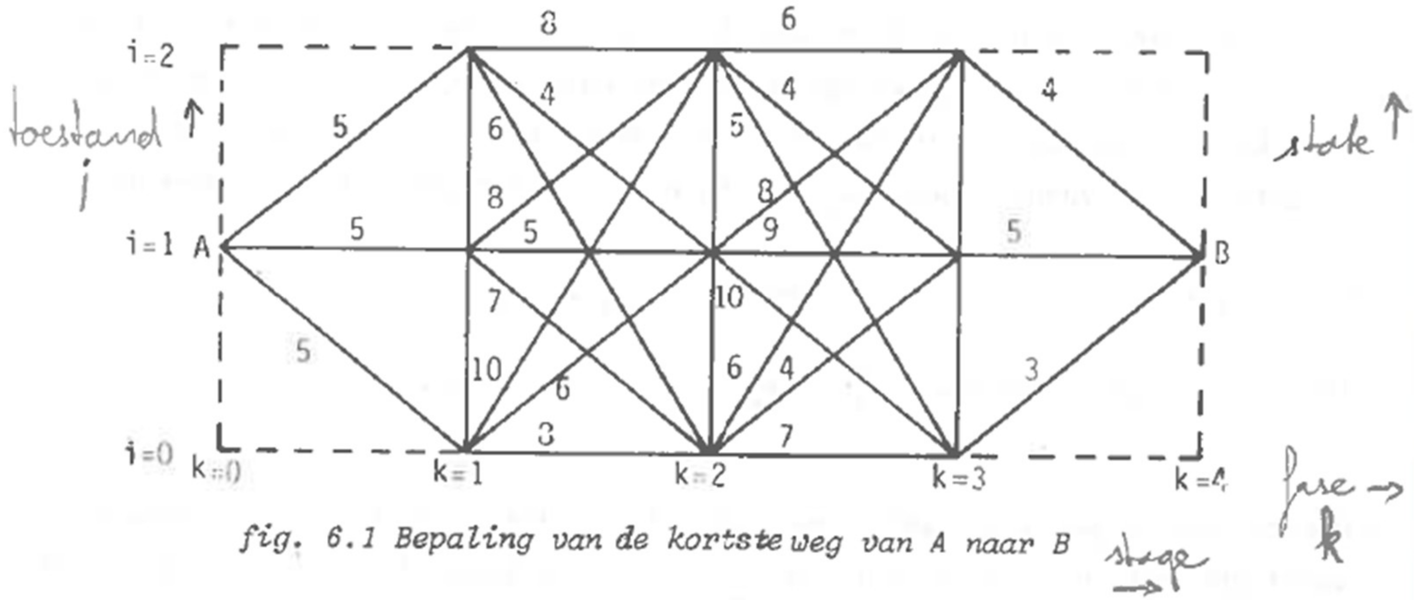


fig. 6.1 Bepaling van de kortste weg van A naar B

Objective: find cheapest path from A to B

Finding solution

$V_4(0) = \infty$

→ $V_4(1) = 0$ $\min\{V_4(0), V_4(1), V_4(2)\} = V_4(1)$

$V_4(2) = \infty$

$V_3(0)$ ... $V_3($ ... $V_3($ ...

$V_2(0$ ... $V_2(1$ ... $V_2(2$ ...

$V_1(0)$ ... $V_1(1)$ ... $V_1(2$ ...

cheapest route: $V_4(1)$, $V_4(1)$, $V_4(1)$, $V_3(1)$, $V_3(2)$, $V_3(1)$, $V_2(0)$, $V_2(0), V_2(2)$, $V_2(0)$, $V_1(2)$

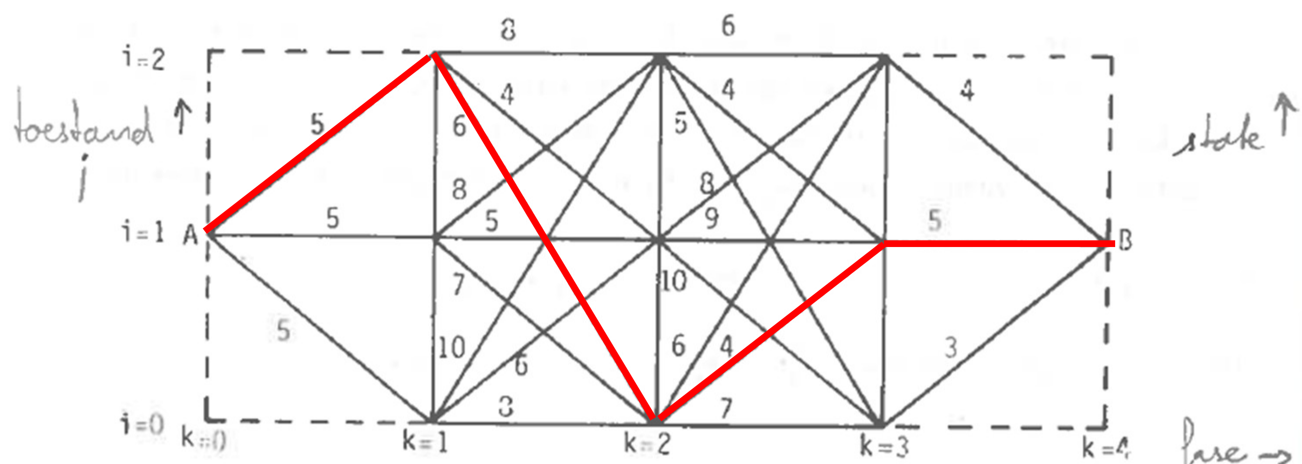


fig. 6.1 Bepaling van de kortste weg van A naar B

$V_0(1) = \min\{5 + V_1(0), 5 + V_1(1), 5 + V_1(2)\} = \min\{22, 21, 20\} = 20$

Cheapest route: $A = V_0(1) \to V_1(2) \to V_2(0) \to V_3(1) \to V_4(1) = B$ $5+6+4+5=20$

Some examples of the *optimal cow replacement problem* in the literature

66–8314

GIAEVER, Harald Birger, 1927–
OPTIMAL DAIRY COW REPLACEMENT POLICIES.

University of California, Berkeley, Ph.D., 1966
Economics, agricultural

Livestock Production Science, 13 (1985) 333—349
Elsevier Science Publishers B.V., Amsterdam — Printed in The Netherlands

STUDIES ON THE REPLACEMENT POLICIES IN DAIRY CATTLE. III. INFLUENCE OF VARIATION IN REPRODUCTION AND PRODUCTION

J.A.M. VAN ARENDONK[1,2] and A.A. DIJKHUIZEN[2]

Acta Agric. Scand. 39: 311–318, 1989

Optimal Replacement and Ranking of Dairy Cows under Milk Quotas

ANDERS R. KRISTENSEN

Department of Animal Science, The Royal Veterinary and Agricultural University, Roligedsvej 23, DK-1958 Frederiksberg C, Copenhagen, Denmark

J. Dairy Sci. 94:4476–4487
doi:10.3168/jds.2010-4123

The cost and management of different types of clinical mastitis in dairy cows estimated by dynamic programming

E. Cha,*[1] D. Bar,† J. A. Hertl,* L. W. Tauer,‡ G. Bennett,§ R. N. González,§ Y. H. Schukken,§ F. L. Welcome,§ and Y. T. Gröhn*
*Section of Epidemiology, Department of Population Medicine and Diagnostic Sciences, College of Veterinary Medicine, Cornell University, Ithaca, NY 14853
†SCR Engineers Ltd., 6 Haomanut St., Poleg, Industrial Zone, Netanya 42504, Israel
‡Charles H. Dyson School of Applied Economics and Management, College of Agriculture and Life Sciences, and
§Quality Milk Production Services, Department of Population Medicine and Diagnostic Sciences, College of Veterinary Medicine, Cornell University, Ithaca, NY 14853

Cash flow predictions (≥2020)

- Future cash flow affected by value of keeping cow in the herd (vs. replace) and value of calf

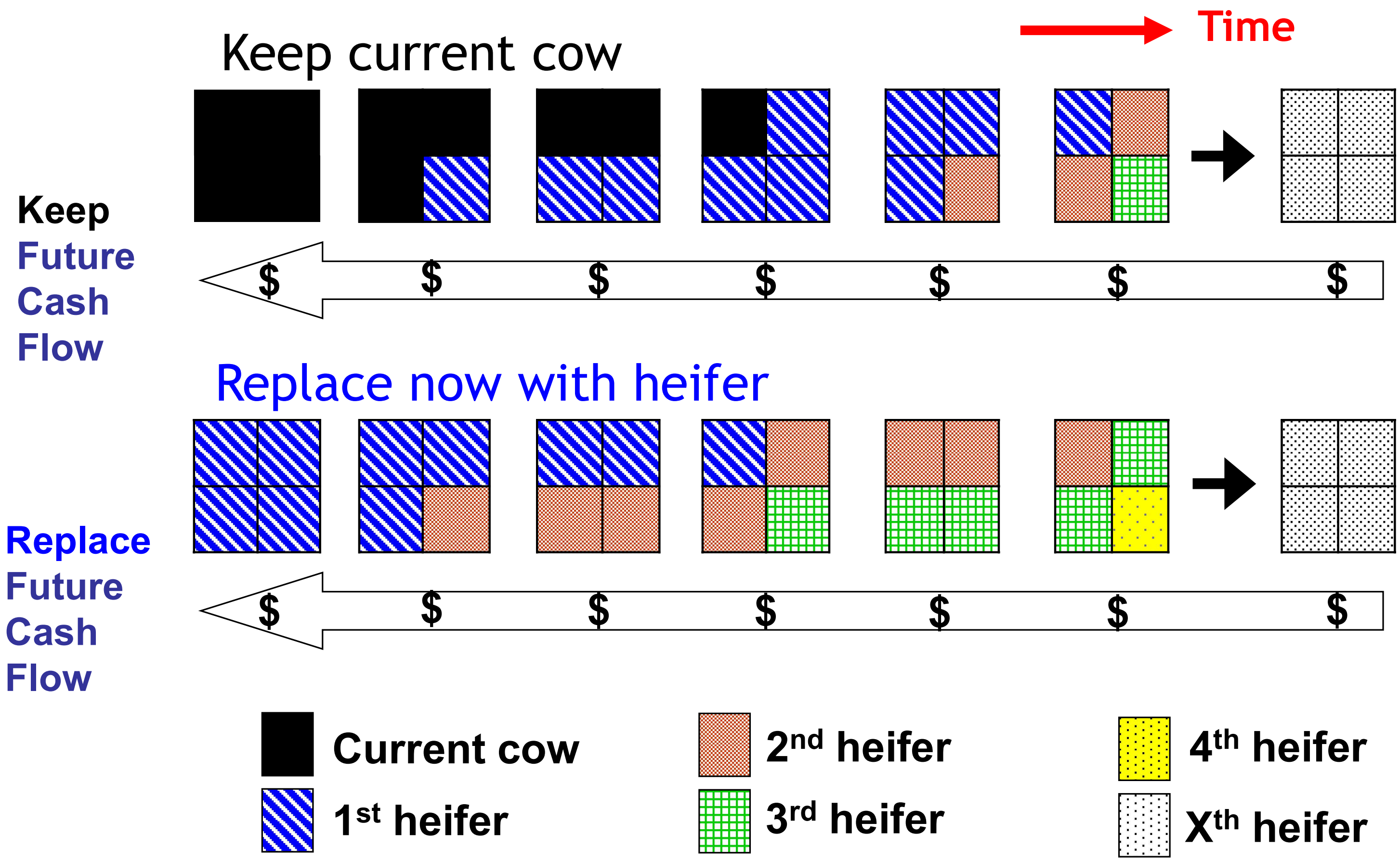
Attributes:

- Dam: Lactation, DIM, fertility, milk production, genetic merit, …
- Sire: Semen type, breed, price, sire conception rate, risk of abortion, genetic merit, …
- Mating: Dam + Sire (+ inbreeding + …)

Dynamic programming to calculate future cash flows

Keep/replace decision: Prediction future cash flows for a slot

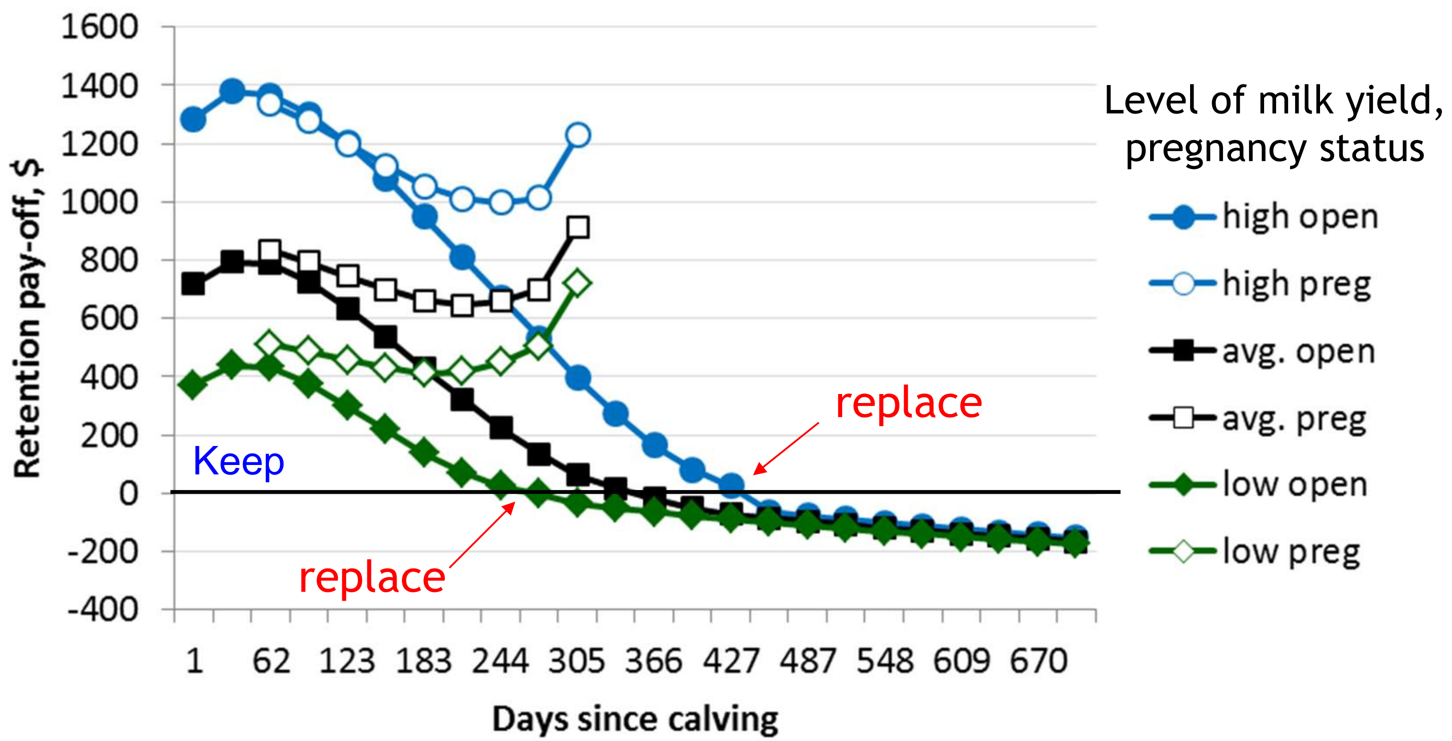
mixture of cash from current cow and replacement heifers



Adapted from: Eicker, S., and J. Fetrow. 2003. “New tools for deciding when to replace used dairy cows”

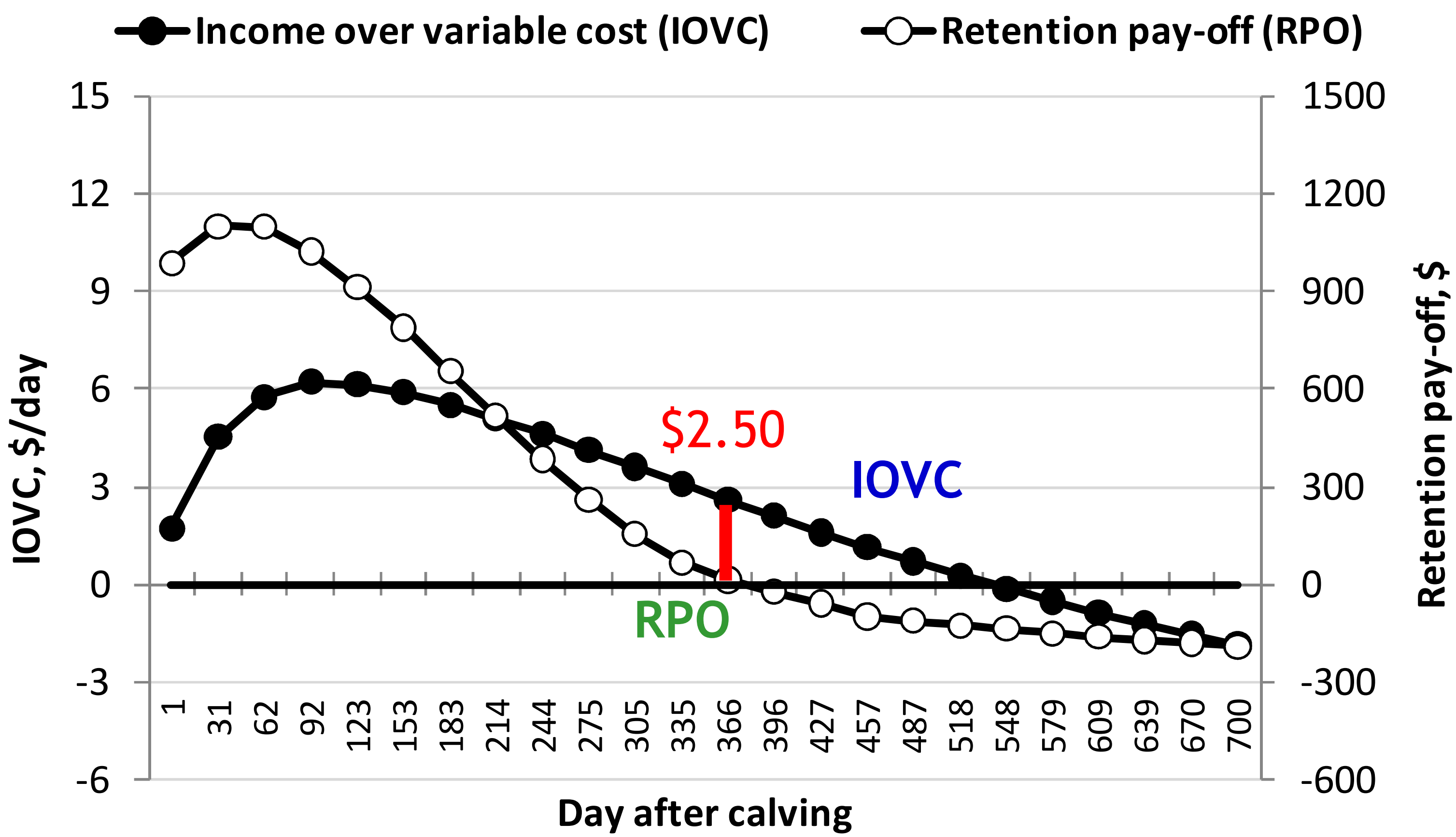
Value of keeping the cow in the herd

Compared to immediate replacement with a heifer



Higher milk yield and pregnancy protect against culling

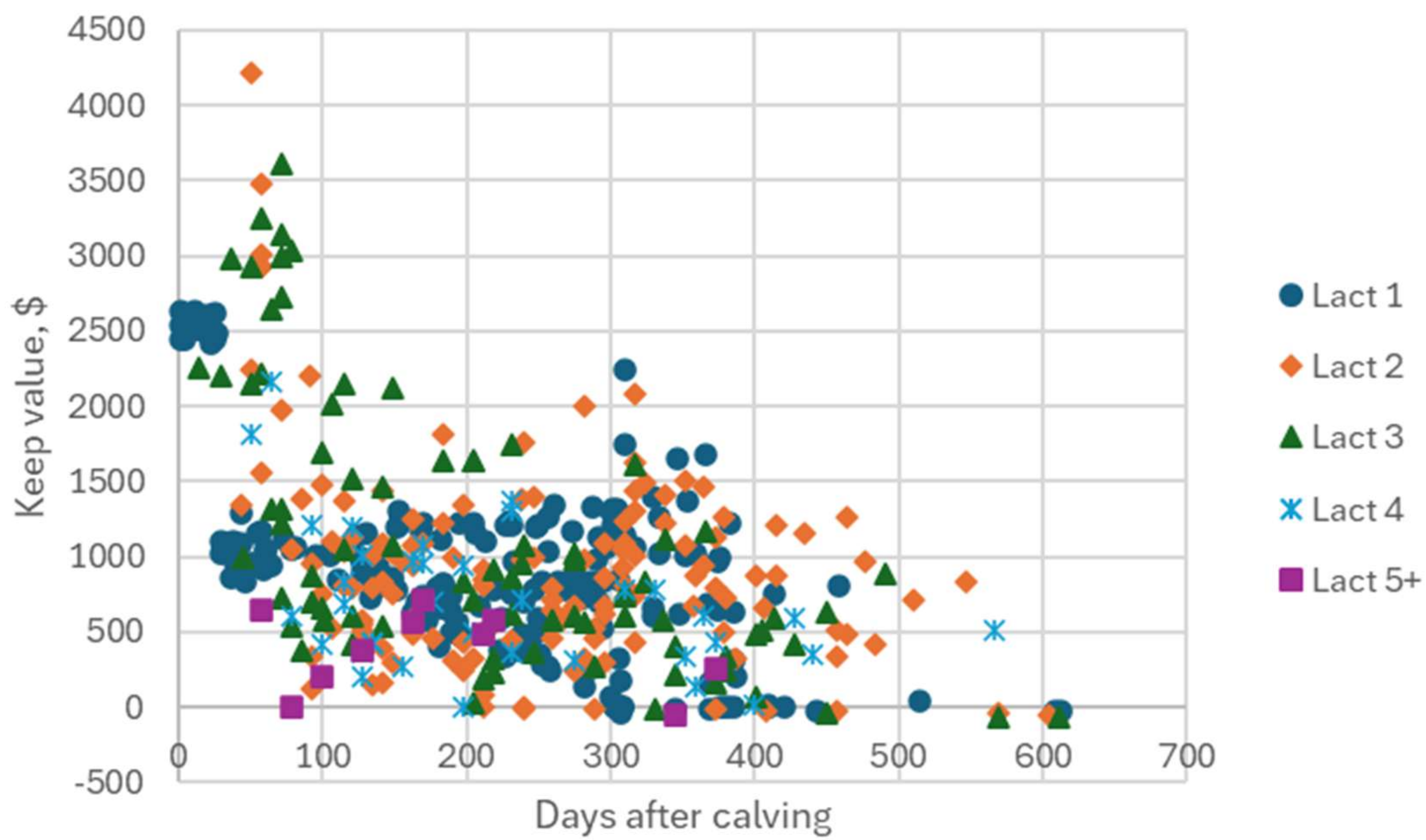
2 criteria for culling: cull when cow still makes you money



Parity 1, milk price $0.19/lbs

old slide

Keep values for 460 cow herd



ID=11002, 8/31/2024

LACT	2
DIM	261
PEN	6
KEEP$	1293
CWVAL	1200
PGVAL	1199
RPRO	PREG
DCC	198

ID=11004, 8/31/2024

LACT	3
DIM	41
PEN	7
KEEP$	742
CWVAL	-574
PGVAL	349
RPRO	FRESH
DCC	0

How to best to predict daily milk in the remainder of the current lactation?

Extension factors
Wiggans and Dickinson, 1985

Table 2. Projection factors for Holsteins in the northern United States.

		Milk				Fat			
		Sample day		Factor/herd average		Sample day		Factor/herd average	
Calving season	Days in milk	Intercept	Slope	Intercept	Slope	Intercept	Slope	Intercept	Slope
				First lactation					
December-February	7- 55	.453	.00296	1.314	−.01538	.316	.00340	1.536	−.01149
	56-105	.570	.00085	.599	−.00238	.412	.00166	1.170	−.00483
	106-155	.536	.00117	.787	−.00416	.453	.00126	1.064	−.00383
	156-205	.547	.00148	4.866	−.03418	.399	.00209	.495	−.00226
	206-255	.376	.00232	9.545	−.05700	.361	.00228	.665	−.00309
	256-305	.502	.00182	−8.621	.01424	.485	.00179	.165	−.00113
March-May	7- 55	.367	.00364	1.487	−.01787	.272	.00334	1.623	−.01157
	56-105	.511	.00101	.578	−.00134	.361	.00174	1.146	−.00291
	106-155	.355	.00250	.981	−.00518	.138	.00386	1.783	−.00897
	156-205	.420	.00219	12.811	−.06840	.444	.00208	.701	−.00337
	206-255	.314	.00271	14.562	−.07694	.470	.00195	.599	−.00288
	256-305	.797	.00082	−10.551	.02154	.656	.00122	−.033	−.00040
June-August	7- 55	.437	.00312	1.268	−.01269	.328	.00308	1.529	−.00817
	56-105	.466	.00260	.844	−.00499	.323	.00316	1.511	−.00784
	106-155	.583	.00149	.699	−.00360	.455	.00190	1.241	−.00527

Best Prediction
VanRaden, 1997

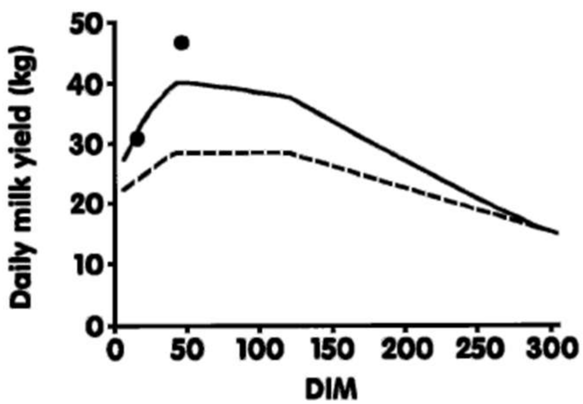
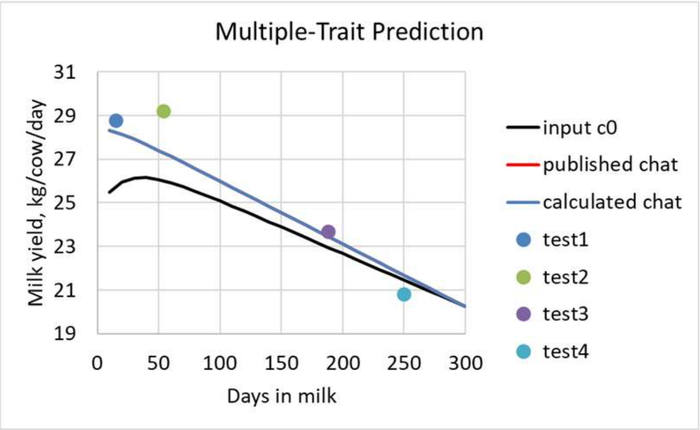


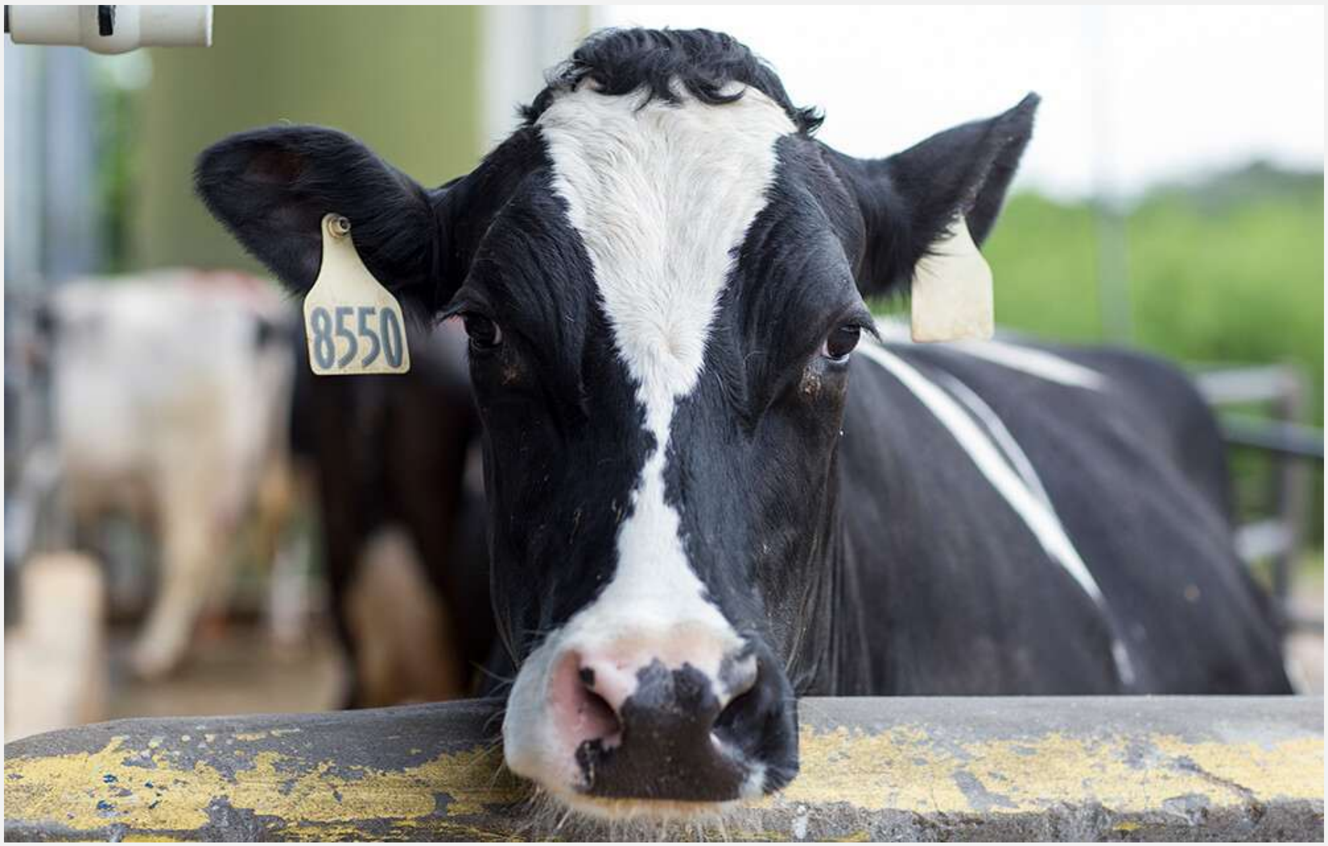
Figure 3. Example lactation in progress plotted by best prediction (———) and compared with contemporary mean (– – –) where ● = supervised milk weight.

Multiple-Trait Prediction
Schaeffer and Jamrozik, 1996



Or (better yet), artificial intelligence based predictions?

On-farm insemination decisions



Planning number of dairy heifers to make

	A–D	E	F	G	H	I	J	K–N
1		inputs		results	results	results	11/27/2026	expected 1st calving date
2	Cow herd size	500		year	month	week	months from today	
3	Cow annual replacement rate	35%	==>	175	15	**3.4**	33	heifers calving to replace culled cows
4	Buffer (surplus heifers)	5%	1.05	184	15	**3.5**	33	heifers actually calving
5	Non-complete heifers	20%	1.25	230	19	**4.4**	9	heifer calves born alive
6	Dead on arrival, heifer calves	2%	1.02	235	20	**4.5**	9	heifer calves born, including DOA
7	%females in sexed dairy semen	90%	1.11	261	22	**5.0**	9	calves born to sexed semen (male and female)
8	New pregnancies not resulting in calving	13%	1.15	300	25	**5.8**	1	new pregnancies diagnosed to sexed semen
9	Conception rate	47%	2.15	645	54	**12.4**	0	sexed semen inseminations (heifers + cows)
10							2/28/2024	today

- Sexed semen if:
  - Lact = 0 & TBRD ≤ 2 & gNM$ > XXX
  - Lact = 0 & TBRD = 0 & gNM$ = 0 (missing)
  - Lact ≤ 2 & TBRD ≤ 2 & gNM$ > XXX
  - Lact = 3 & TBRD ≤ 1 & gNM$ > XXX
- Beef semen otherwise (≈50%)

vary gNM$ XXX weekly (?)
to get desired
#sexed semen inseminations

Cow synch and TAI program

PEN	ID	DIM	LACT	TBRD	WMLK1	GNM$	SYP	SDESC	TAI
3	10946	166	2	3	101	0	R	GNRH/TAI	SLICK
7	10802	61	3	0	128	601	D	GNRH/TAI	BEEF
7	11119	63	2	0	142	0	D	GNRH/TAI	BEEF
7	11194	60	2	0	145	697	D	GNRH/TAI	SEXED
9	11379	162	1	2	111	703	R	GNRH/TAI	SEXED
9	11422	129	1	0	108	761	D	GNRH/TAI	SEXED
9	11427	113	1	1	128	636	R	GNRH/TAI	BEEF
9	11448	124	1	1	116	605	R	GNRH/TAI	BEEF
9	11511	115	1	1	106	658	R	GNRH/TAI	SEXED
10	10364	130	4	2	135	382	R	GNRH/TAI	BEEF
10	10648	313	3	7	104	539	R	GNRH/TAI	BEEF
10	10713	221	3	4	77	344	R	GNRH/TAI	BEEF
10	10756	66	3	0	166	496	D	GNRH/TAI	BEEF
10	10987	207	2	3	38	802	R	GNRH/TAI	BEEF
10	11160	99	2	1	125	748	R	GNRH/TAI	SEXED
13	11068	191	2	0	91	637	D	GNRH/TAI	BEEF
13	11182	96	2	1	46	390	R	GNRH/TAI	SLICK
13	11348	80	1	0	102	539	D	GNRH/TAI	SLICK
13	11539	80	1	0	82	661	D	GNRH/TAI	SEXED
13	11553	75	1	0	97	542	D	GNRH/TAI	BEEF
13	11562	74	1	0	108	725	D	GNRH/TAI	SEXED

Total: 21

UF Dairy Unit
2/29/2024
Timed AI list cows
Dairycomp

$761

$344

$802

$761 - $344
= $417

Lifetime
Profit
Difference
Of daughter,
If bred to
Sexed semen

Insemination values, multiple sires

Estimate net present value (NPV) of future cash flows following each insemination opportunity, given optimal future decisions:

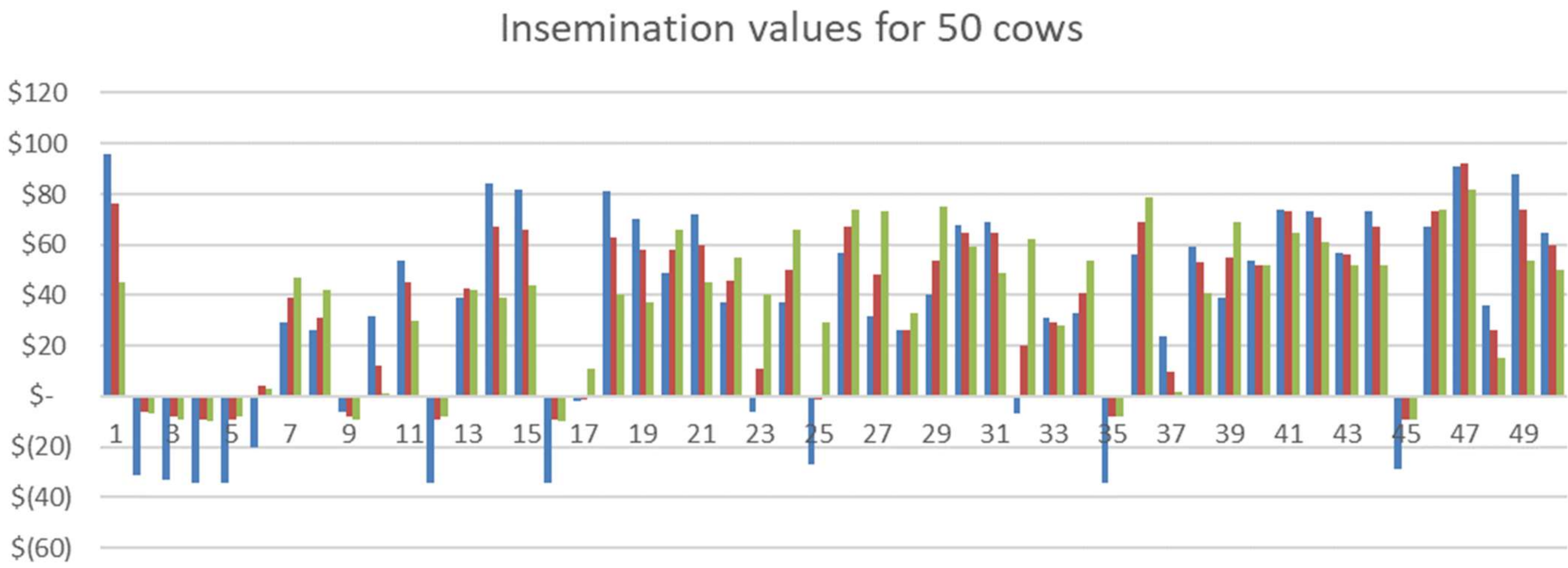
NPV(future cash flow (insemination, sire A))
– NPV(future cash flow (delay insemination))

= Insemination value (sire A)

Sexed-over-beef value (SOB$) =

insemination value (sexed dairy) – insemination value (conventional beef)

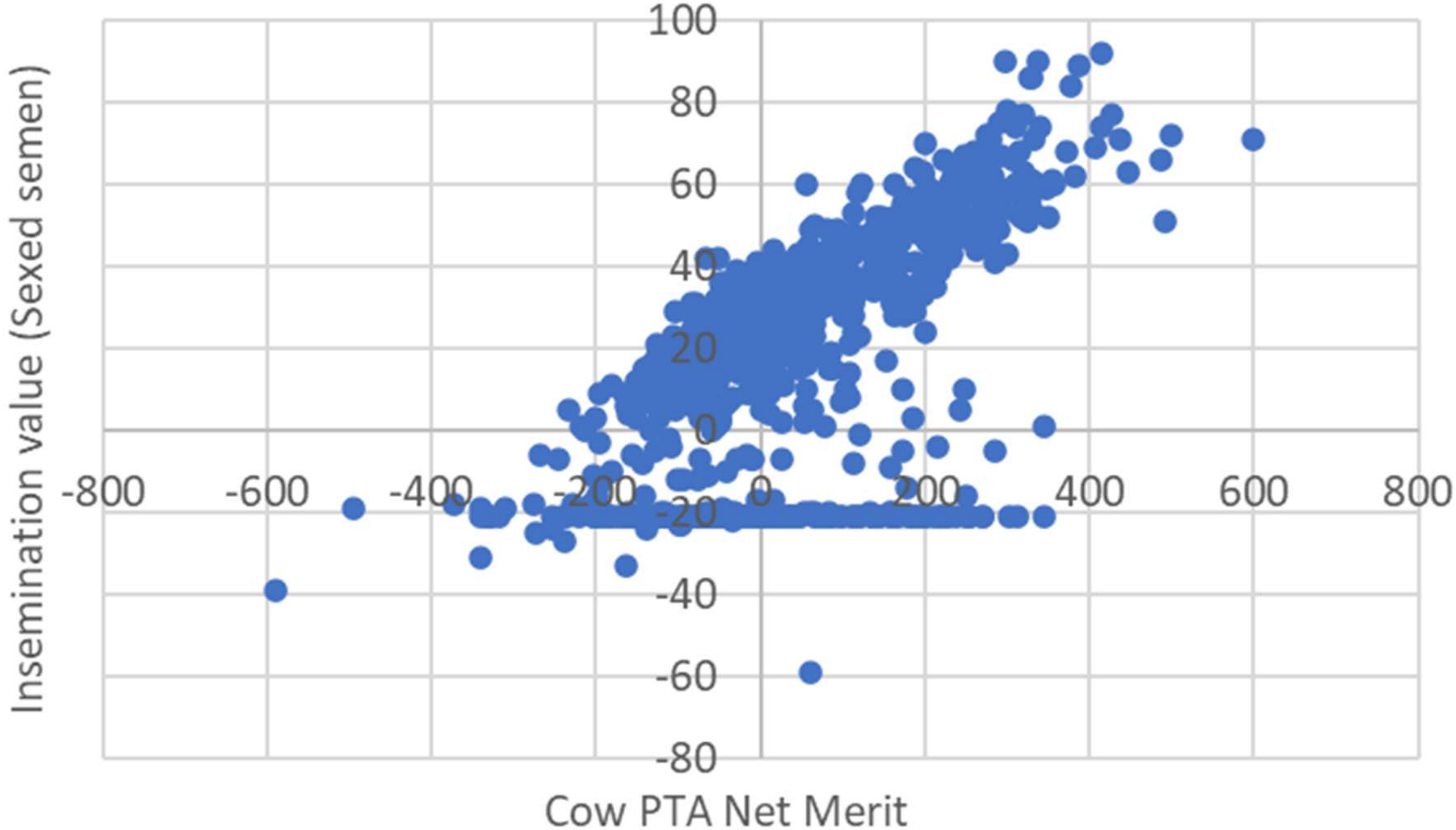
Illustration: 50 cows - 3 semen choices



Semen choices: sexed conventional beef

P(female dairy calf): 90% 50% 0%

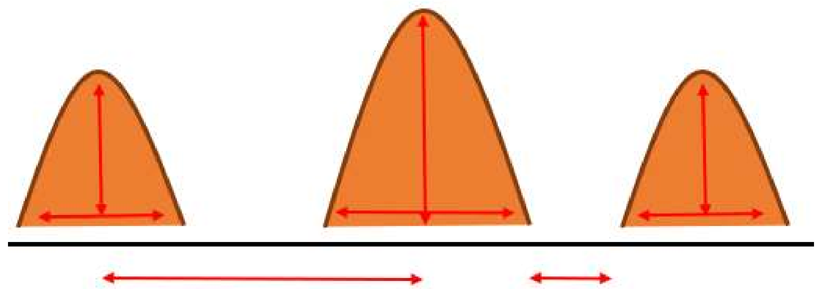
Insemination values (sexed semen) vs cow genetic merit



Insemination values more accurate through …

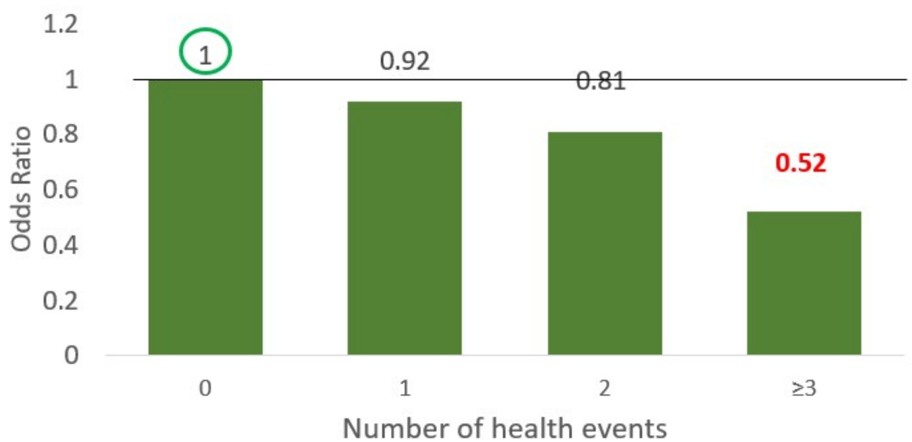
- Better prediction fertility
- Better prediction milk yields, health, dry matter intake, bodyweight, BCS, …
- Use all past relevant data
- Data silos

Quantifying estrous behavior



Ronaldo Cerri, UBC, Canada

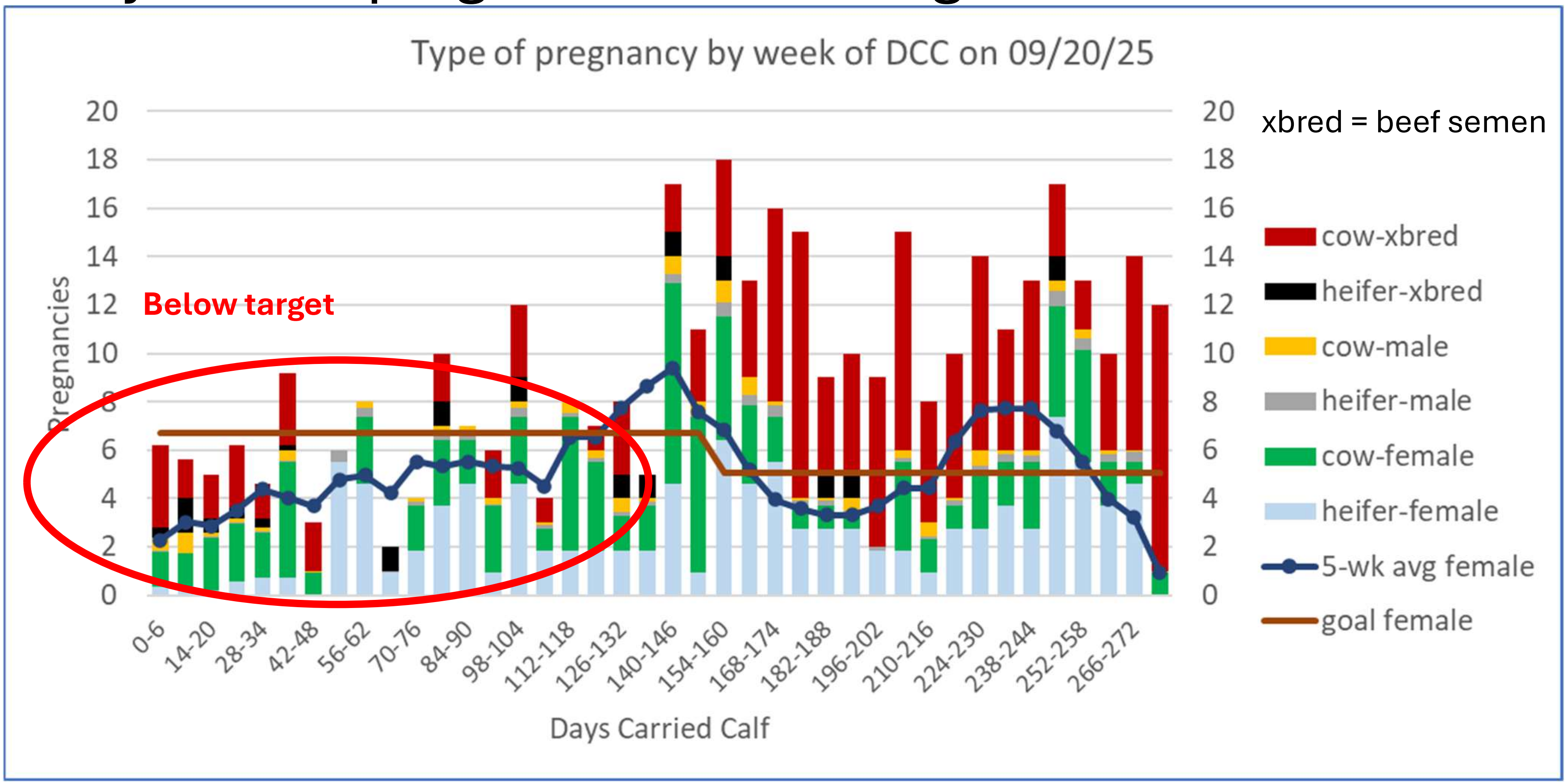
Odds ratio for pregnancy at first AI



Pablo Pinedo, CSU, USA

Example 450-cow dairy farm

How best to **adjust** breeding decisions when number of dairy female pregnancies is off target?



	A	B	C	D	E	F	G	H	I	J	K	L
1			compare 2 breeding scenarios. Imagine 2 idential cows that we are breeding with either scenario A or B									
2			red numbers you may change, black numbers are formulas you should not change									
3												
4					description	4		sire A	sire B			
5					conclusion	5		$ 12	$ -	**scenario A is best value**		
6					sire or scenario	6		A	B	A-B		
7					semen cost/unit current breeding	7		$ 28	$ 20	$ 8		
8					PTA NM$ sire current breeding	8		$ 1,100	$ 1,000	$ 100		
9					PTA NM$ dam current breeding	9		$ 300	$ 300	$ -		
10					PTA NM$ female calf current breeding	10		$ 700	$ 650	$ 50		
11					conception rate	11		50%	30%	20%		
12					probability abortion	12		8%	8%	0%		
13					probability of pregnancy (after abortion)	13		46%	28%	18%		
14					#pregnancies current breeding	14		0.460	0.276	0.184		
15					probability female calf	15		90%	90%	0%		
16					#female calves current breeding	16		0.414	0.248	0.166		
17					#male calves current breeding	17		0.046	0.028	0.018		
18					value male calf	18		$ 400	$ 400	$ -		
19					breeding value female calf	19		$ 1,400	$ 1,300	$ 100		
20					corrected value female calf	20	$ 700	$ 700	$ 600	$ 100		
21					#not pregnant after current breeding	21		0.540	0.724	-18%		
22						22				A-B		
23					semen cost/unit future breedings	23		$ 25	$ 25	$ -		

Semenvalue calculator