Automated detection of lameness in dairy cows based on day-to-day variation in behaviour

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Presentation

- Material & methods
- Data analysis
  - Modelling
  - Alerts
- Results
  - 2010/2011 Data collection
  - 2012 Live test
    - Procedures
    - Results
- Discussion & conclusions

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Material & Methods

Project goal:

Development of methods to monitor behaviour and health in dairy cows automatically with sensors:

1. Lameness detection with activity sensors?
2. Oestrus and mastitis detection improved with activity sensors?

Application of IceTags for behaviour recording

Data collected at Dairy Campus:

- in 2010/2011: used for model development
- January-April 2012: Live Test of developed model

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M&M: available data

- **Icetags (per cow per day):**
  - number of lying bouts
  - number of standing bouts
  - lying time (part of day)
  - standing time (part of day)
  - maximal length of lying bout
  - maximal length of standing bout
  - minimal length of lying bout
  - minimal length of standing bout
  - motion index
  - number of steps

- **Milk robot data (per visit):**
  - yield (per quarter)
  - electrical conductivity per quarter
  - action: milked or refused

- **Process computer data (per day):**
  - concentrate ration, intake and remainder

- **Milk test data (per test day):**
  - fat & protein percentage

- **Cow data:**
  - calving dates, lactation number
  - cases of oestrus, insemination, diseases
  - locomotion scores, condition scores

M&M: used data (1/2)

■ Icetags (per cow per day), 7 variables:

- number of lying bouts
- ~~number of standing bouts~~ = *number of lying bouts $\pm$ 1*
- lying time (part of day)
- ~~standing time (part of day)~~ = *1 - lying time*
- **logarithm of** maximal length of lying bout = *normally distributed[1]*
- **logarithm of** maximal length of standing bout = *normally distributed[1]*
- ~~minimal length of lying bout~~ =
- ~~minimal length of standing bout~~ =
- ~~motion index~~ = *number of steps * factor[2]*
- **logarithm of** number of steps = *normally distributed[1]*
- **logarithm of average length of lying bout**[3] = *normally distributed[1]*
- **logarithm of average length of standing bout**[4] = *normally distributed[1]*

[1] results from Q-Q plots
[2] results from PCP & scatter plots; other variables have added value
[3] number of lying bouts/ lying time, [4] same for standing

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M&M: used data (2/2)

- **Milk robot data (per visit):**
  - yield ~~(per quarter)~~
  - electrical conductivity per quarter
  - ~~action: milked or refused~~ *not yet used*

- **Process computer data (per day):**
  - concentrate ~~ration, intake and~~ remainder

- **Milk test data (per test day):**
  - ~~fat & protein percentage~~

- **Cow data:**
  - ~~calving dates, lactation number~~ *only in titles of graphs, not in data analysis*
  - cases of oestrus, insemination, diseases *only for analysis of detection results*
  - locomotion scores = *used to define lameness cases*, ~~condition scores~~

Data analysis: Modelling

Dynamic Linear Models (DLM) used to model variables:

- linear: output directly proportional to input
- dynamic: model parameters change in time

Theory & software available

DLMs used to detect:

- outliers: unexpected event is happening
- trend changes: characteristics are changing

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Data analysis: Modelling

DLM for:

- lying time
- number of lying bouts
- maximal lying bout
- average lying bout
- maximal standing bout
- average standing bout
- number of steps

- daily milk yield
- concentrate remainders
- conductivity left front
- conductivity left hind
- conductivity right front
- conductivity right hind

conductivity: linear trend model, gives level & trend
other variables: quadratic trend model, gives level, trend & slope

Data analysis

example:

nine graphs for

cow 612/lactation 3

horizontal axis:

day since 1/1/2010

95 Cow 612 lactation 3 MS1, 213 days with data, calved 10/08/2011 (daynr 587), 0 oestrus, 0 insem., 1 in calf, 2 lame, 0 mastitis, 0 disease
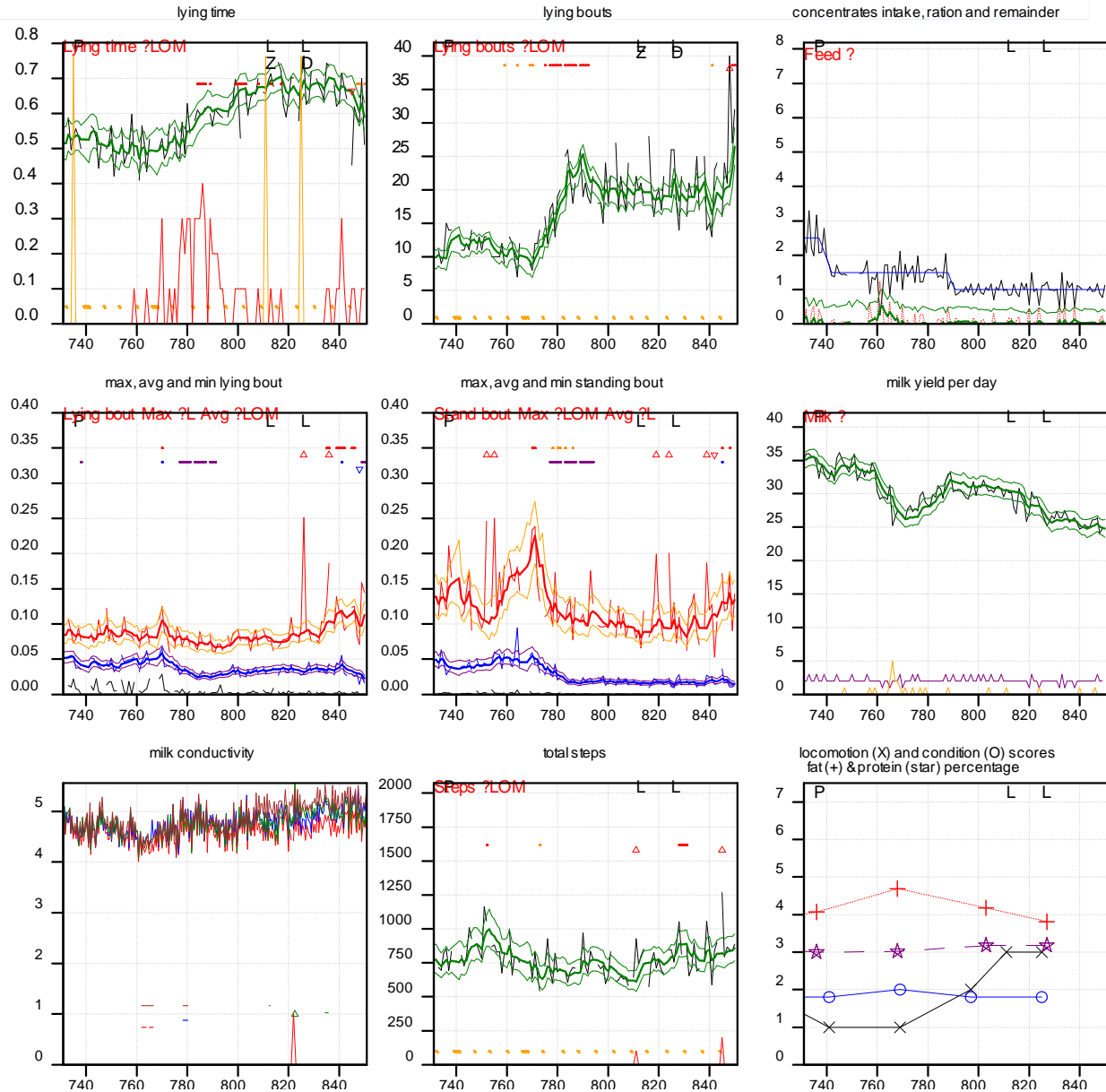
Data analysis: Alerts

Alerts per cow & per day for:

- Lameness

  1. non-zero trend in one or more activity variables (or ≥ 3 outliers in one week)

  2. non-zero trend in concentrate remainder ≥ 3 outliers in milk in one week

- Oestrus

  1. outlier in steps

  2. outliers in other variables

- Mastitis

  1. outlier in (one or more) conductivity

  2. outliers in other variables

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Data analysis: Lameness alerts

variable	direction
lying time	↑
number of lying bouts	↑↓
maximal lying bout	↑
average lying bout	↑
maximal standing bout	↓
average standing bout	↓
number of steps	↓
milk yield	↓
concentrate remainder	↑
~~conductivity~~	

lameness alert in case of a non-zero trend in 2 or more variables

Data analysis: Oestrus alerts

variable	direction
lying time	↓
number of lying bouts	↑↓
maximal lying bout	↓
average lying bout	↓
maximal standing bout	↑
average standing bout	↑
number of steps	↑
milk yield	↓
concentrate remainder	↑
~~conductivity~~	

oestrus alert in case of an outlier in steps (& other variables)

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Data analysis: Mastitis alerts

variable	direction
lying time	↓
number of lying bouts	↑↓
maximal lying bout	↓
average lying bout	↓
maximal standing bout	↑
average standing bout	↑
number of steps	↑
milk yield	↓
concentrate remainder	↑
conductivity left front	↑
conductivity left hind	↑
conductivity right front	↑
conductivity right hind	↑

mastitis alert in case of an outlier in at least one conductivity (& other variables)

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Siivonen et al., 2011

Data analysis: Reference data

- Lameness:
    - locomotion score 3 or more (on a 1-5 scale) and preceding score less than 3
    - claw treatments not used
    - non-lame: locomotion score 1
- Oestrus:
    - observed & recorded cases of oestrus
    - recorded insemination cases
- Mastitis:
    - recorded clinical mastitis cases

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Data analysis: Alerts vs. reference data

Lameness alerts versus lameness cases

alert \ reference	cow is lame	cow is not lame
alert for lameness	True Positive (TP)	False Positive (FP)
no alert for lameness	False Negative (FN)	True Negative (TN)

Same for oestrus and mastitis

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Data analysis: Alerts vs. reference data

- any case is either TP or FN:

  - lameness case is TP if one or more alerts in period since previous locomotion score (but period at least 14 days)

  - oestrus case is TP if one or more alerts on oestrus day or preceding day

  - mastitis case is TP if one or more alerts in week up to mastitis day

- an alert outside these periods can be FP:

  - lameness alert is FP if in period between two locomotion scores 1

  - oestrus alert is FP if not on oestrus or preceding day

  - mastitis alert is FP if not in week up to mastitis case and more than 4 days after any mastitis case

Data analysis: Alerts vs. reference data

Example Cow 938:

Reference =
locomotion score (black)

Lame when 3 or more =
at day 838 (=17-4-2012)

Locomotion scores in 2012 of Cow 938 lactation 1

Days since 1/1/2010

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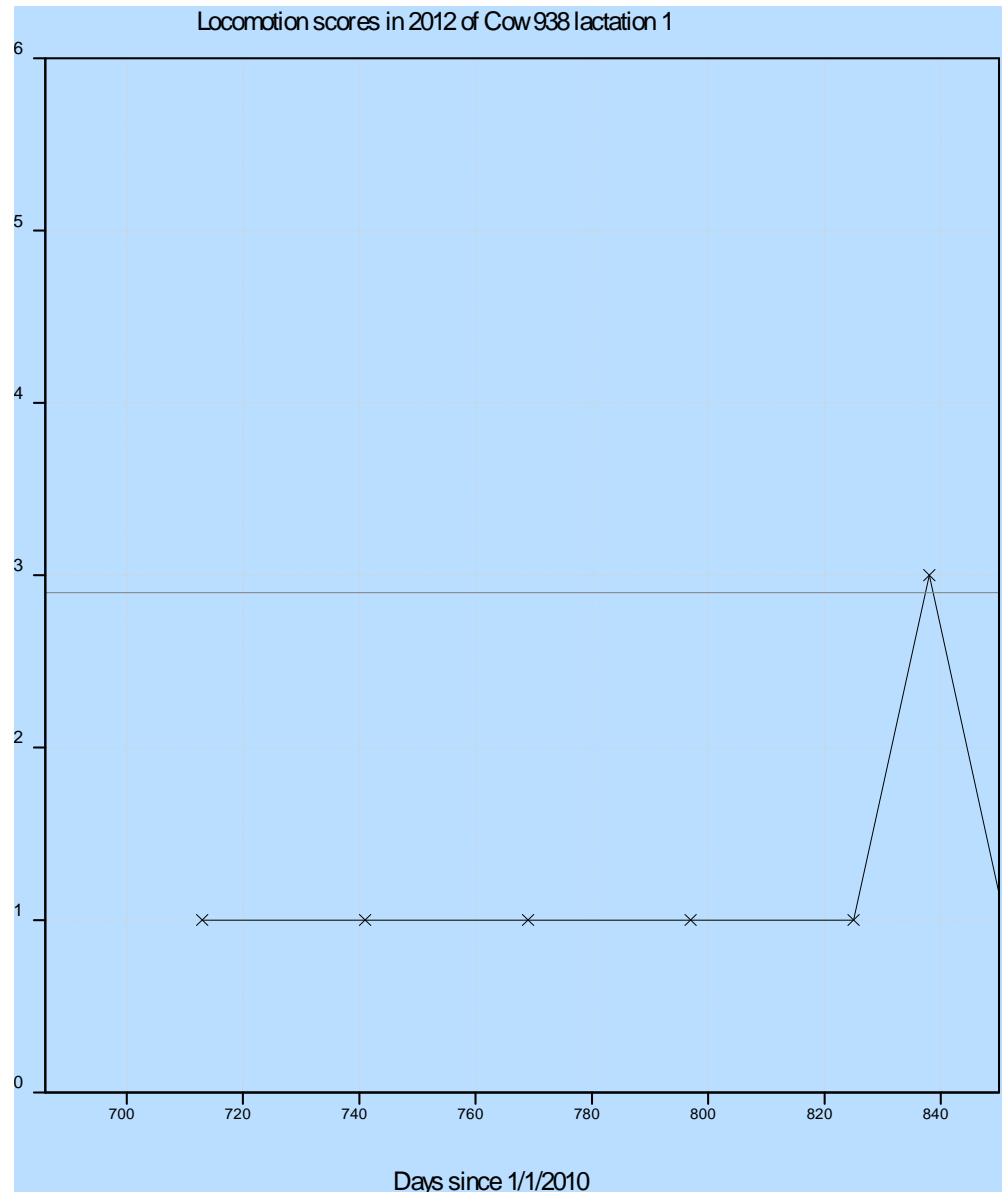
Data analysis: Alerts vs. reference data

Example Cow 938:

Reference =
  locomotion score (black)

Lame when 3 or more =
  at day 838 (=17-4-2012)

Alerts = lameness alerts
  (red striped)

Alert level 2 or more

This lameness case is TP
  level = 6
  number or alerts = 13

FP alerts at day 733-737

Orange dots = missing data

Locomotion scores & lameness alerts in 2012 of Cow 938 lactation 1

Days since 1/1/2010

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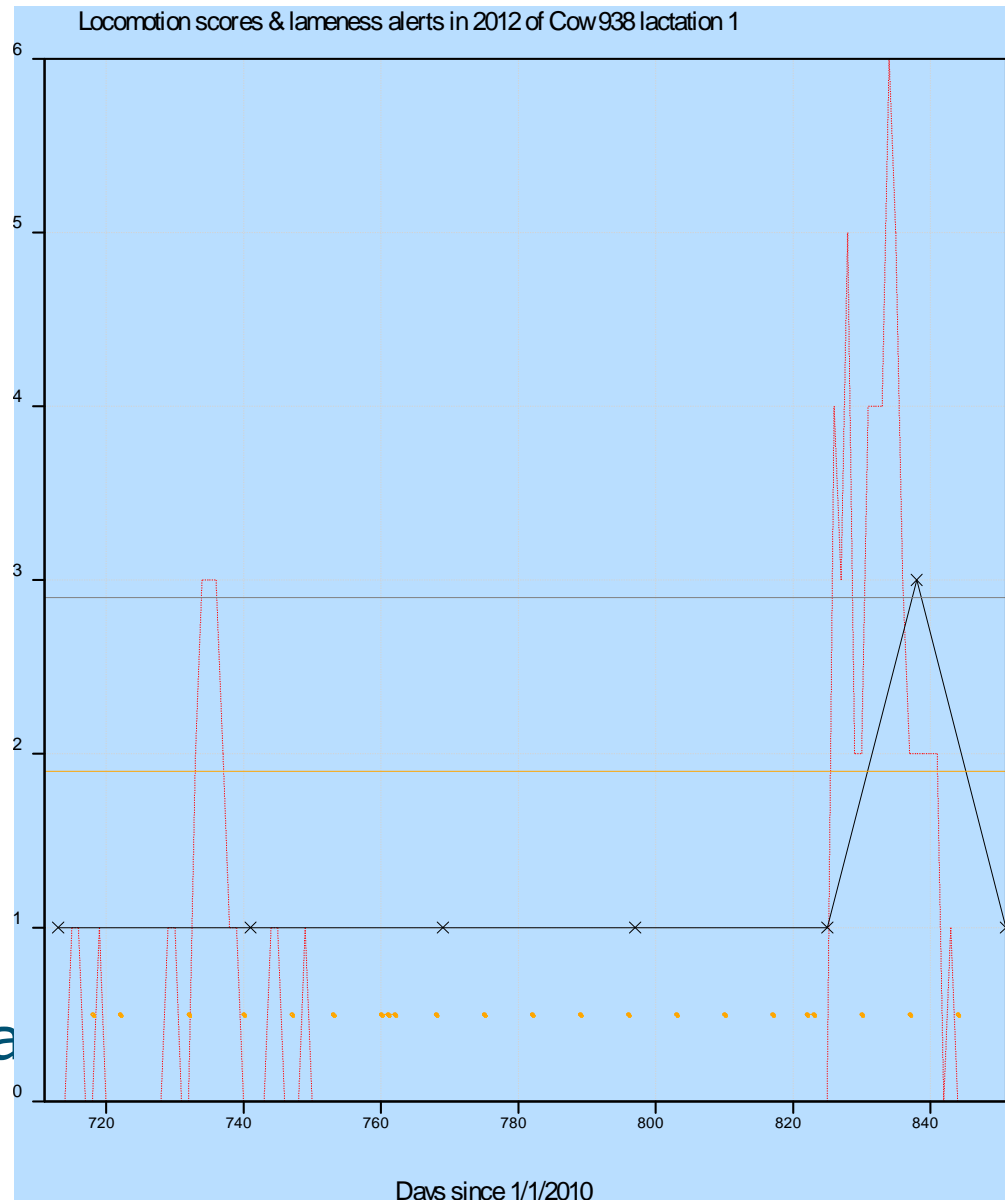
Data analysis: Missing cases

Evaluation of lameness/oestrus/mastitis cases

Cases with too much missing data to be classified when:

- **Lameness:**
  - < 50% of activity data available since preceding locomotion score OR
  - < 50% of activity data available in last week OR
  - < 2 days with activity data available during last 3 days

- **Oestrus:**
  - not all activity data available on oestrus day & preceding day

- **Mastitis:**
  - any missing conductivity on mastitis day or *6* preceding days OR
  - ≤ 2 conductivity data on mastitis day or preceding day OR
  - no activity data on mastitis day

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Results: 2010/2011 data

survey of number of icetags
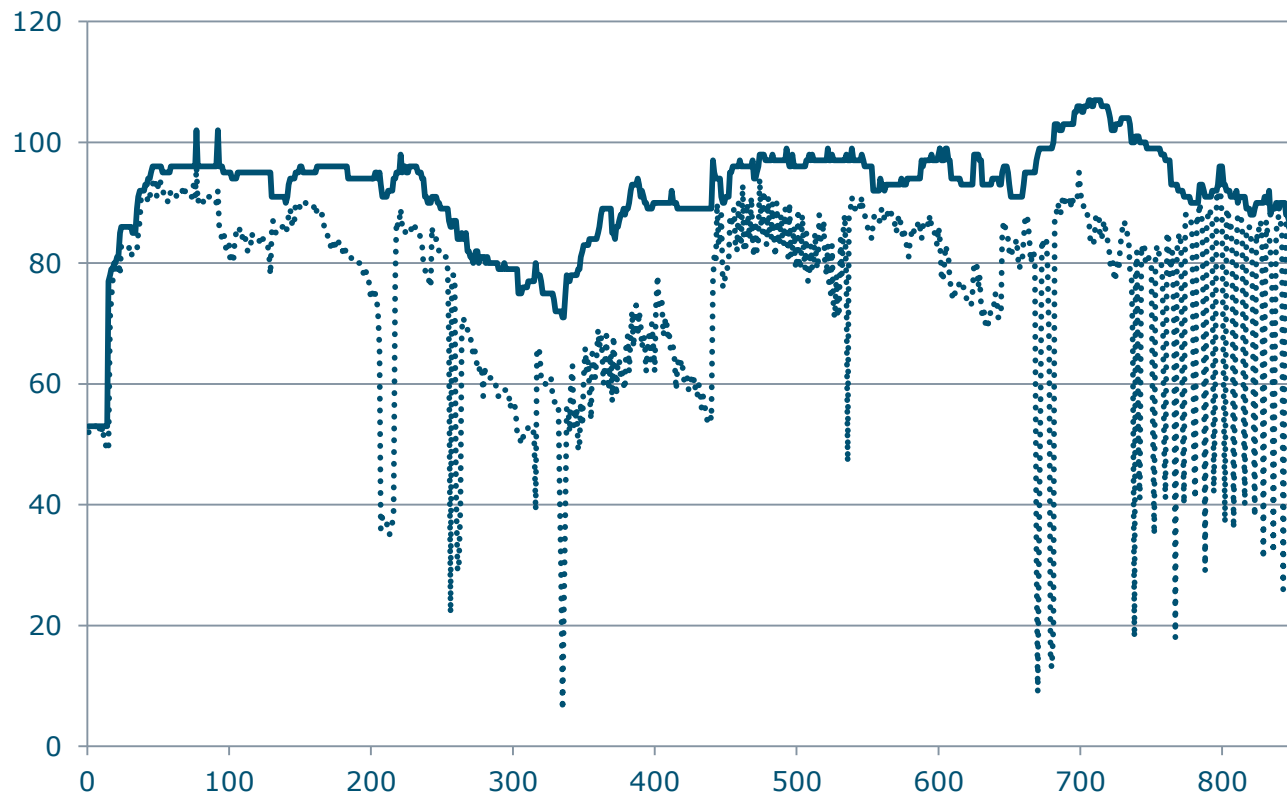
Only data from 1 Feb 2010 till 31 Dec 2011 used

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Results: 2010/2011 data Lameness detection

85 lameness cases → **68** determinable cases → **59** TP cases

68 determinable cases → **9** FN cases

85 lameness cases → **17** indeterminable cases

sensitivity: 87%

average level: 3.54

average number of alerts: 7.07

40,458 non-lameness cow-days → **35,187** determinable cow-days → **31,158** TN cow-days

35,187 determinable cow-days → **4,029** FP cow-days

40,458 non-lameness cow-days → **5,271** indeterminable cow-days

specificity: 88.55%

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Results: 2010/2011 data Lameness detection

Lameness alerts: contribution of each variable

Results: 2010/2011 data Oestrus detection

665 oestrus cases

→ **521** determinable cases
- → **390** TP cases
- → **131** FN cases

→ **144** indeterminable cases

sensitivity: 75%

average level: 2.10

average number of alerts: 1.19

61,000 non-oestrus cow-days

→ **52,506** determinable cow-days
- → **51,406** TN cow-days
- → **1,100** FP cow-days

→ **8,494** indeterminable cow-days

specificity: 97.91%
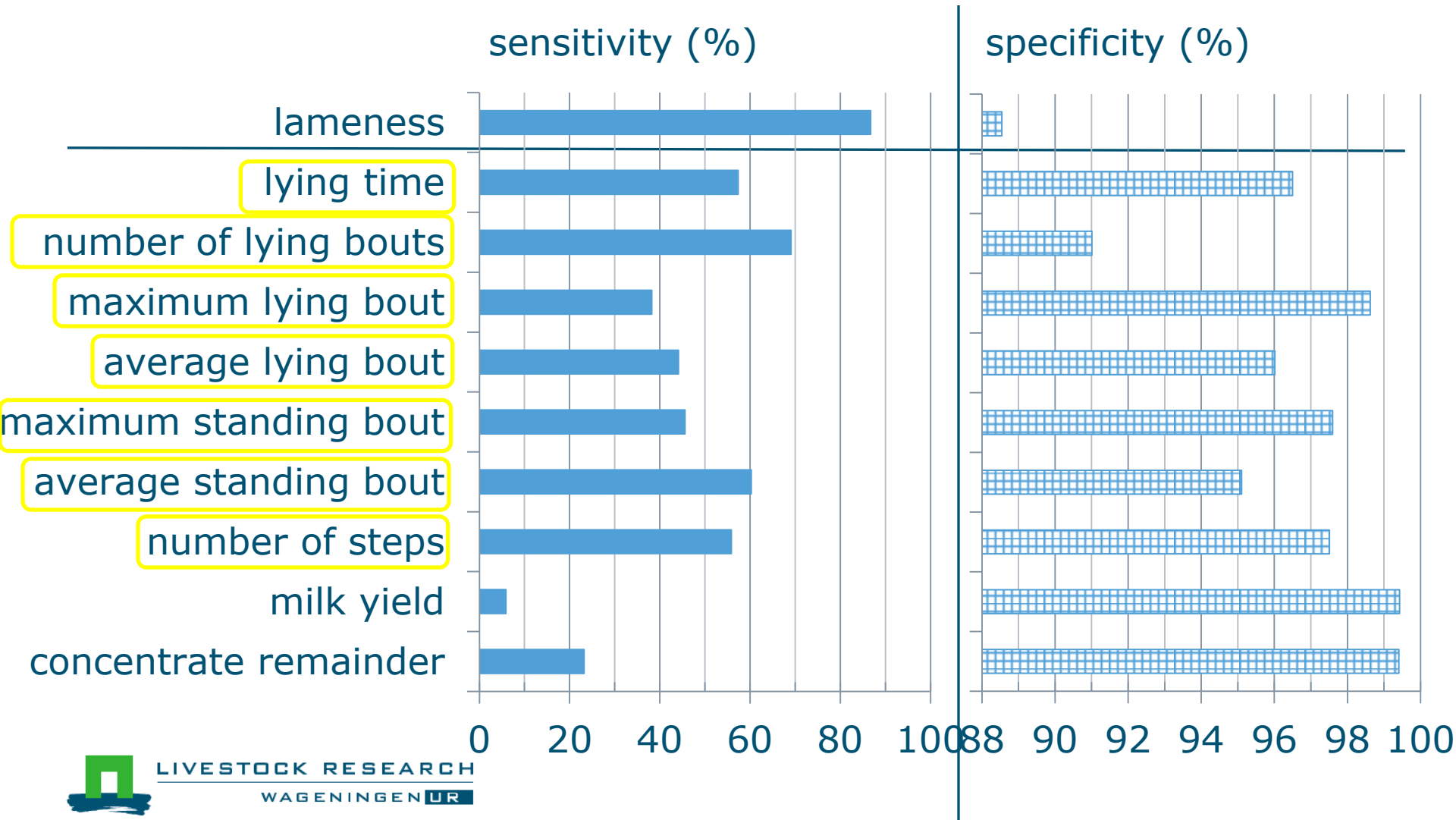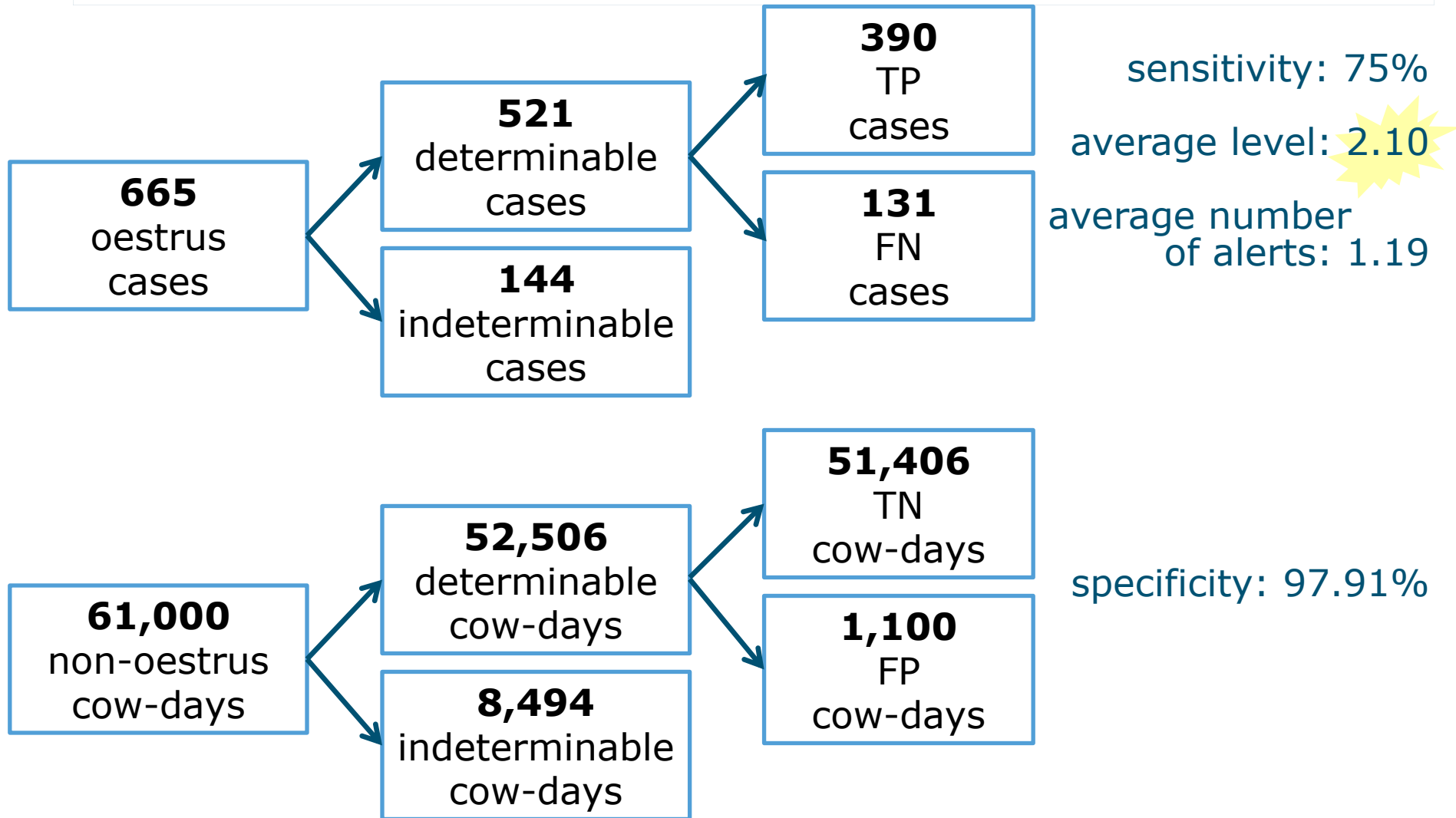
Results: 2010/2011 data Oestrus detection

Oestrus alerts: contribution of each variable

Results: 2010/2011 data Mastitis detection

72
mastitis
cases

→

54
determinable
cases

18
indeterminable
cases

→

48
TP
cases

6
FN
cases

sensitivity: 89%

average level: 2.73

average number
of alerts: 2.38

62,021
non-mastitis
cow-days

→

61,564
determinable
cow-days

457
indeterminable
cow-days

→

59,817
TN
cow-days

1,747
FP
cow-days

specificity: 97.16%

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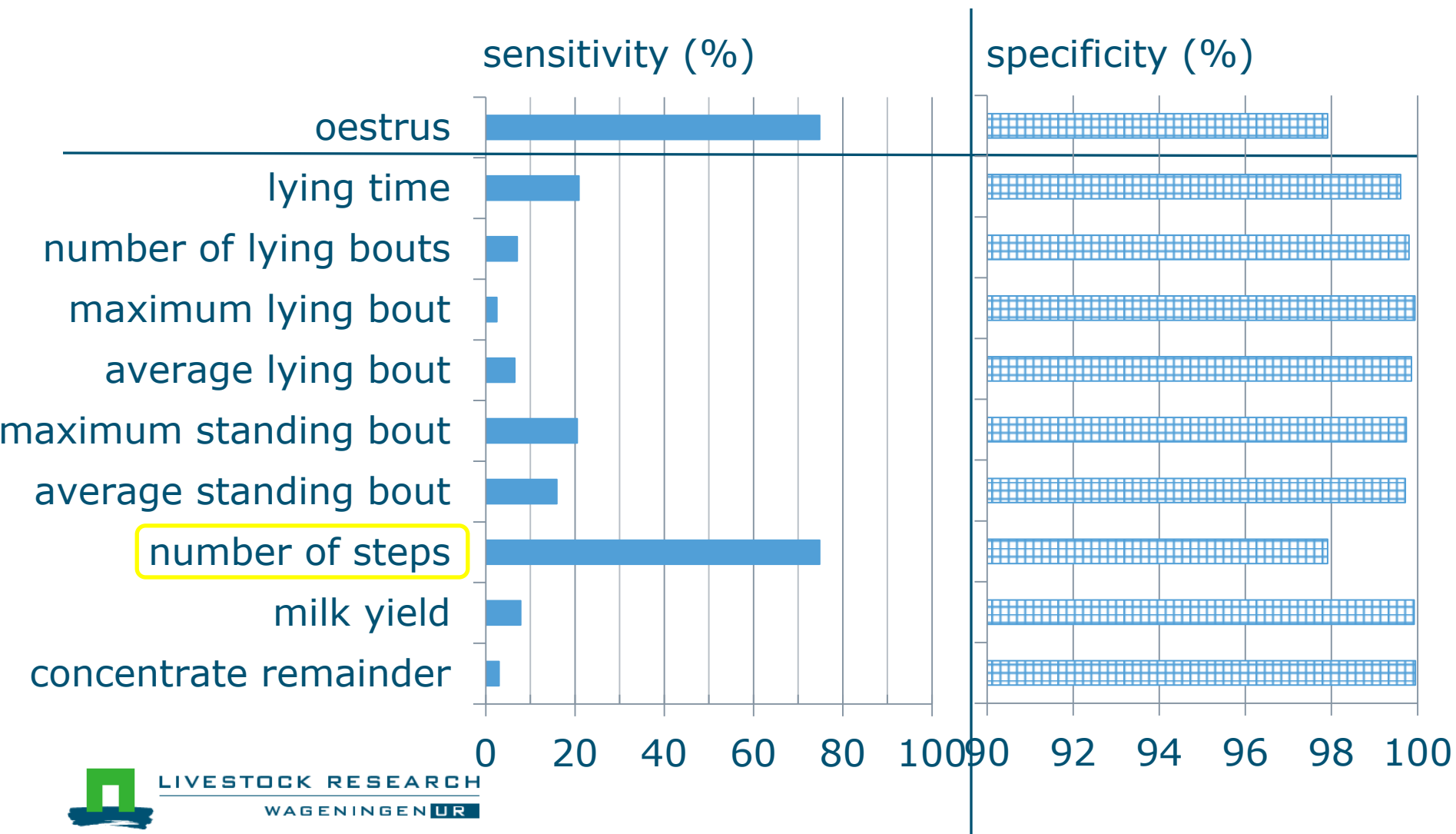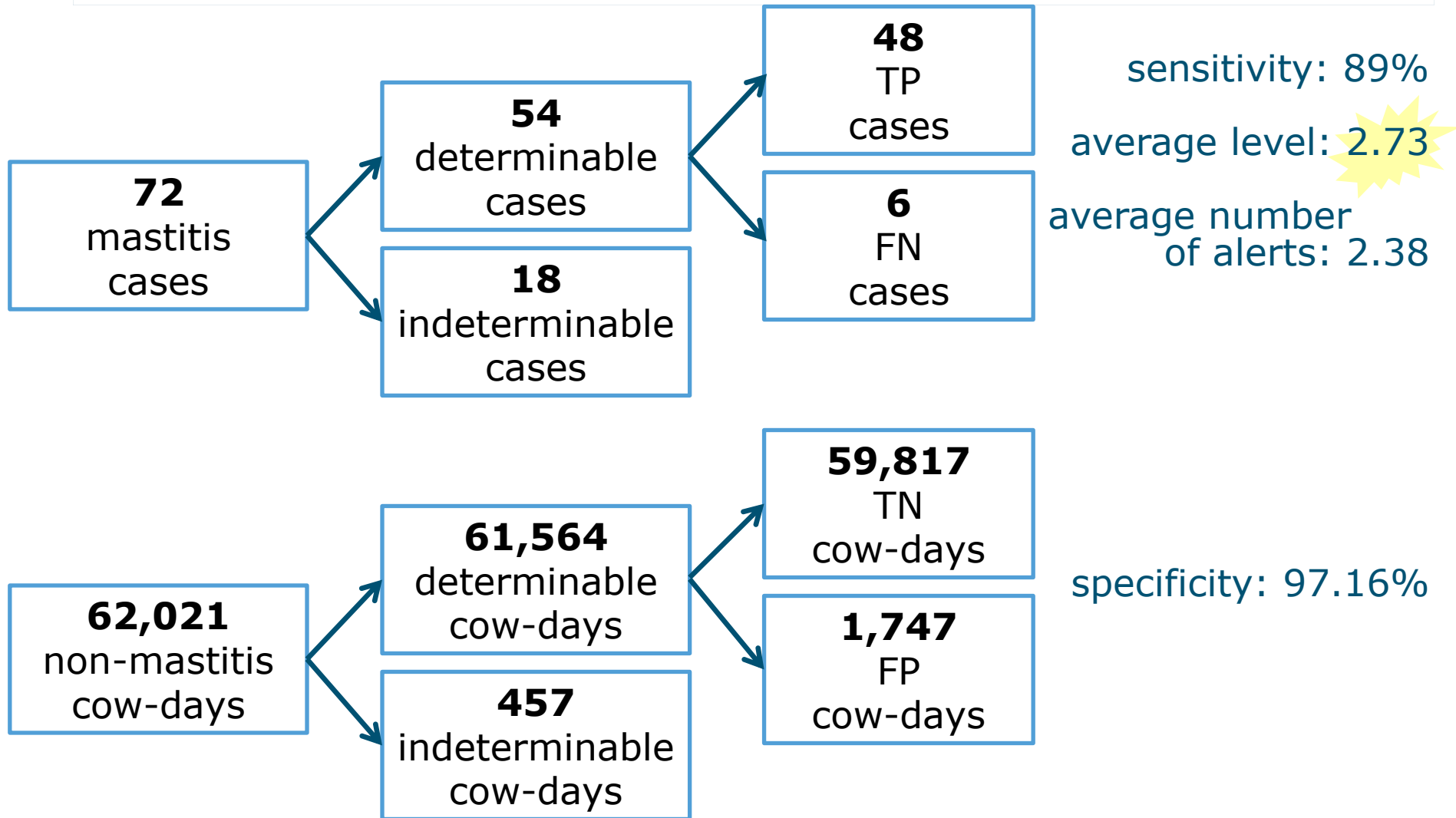
Results: 2010/2011 data Mastitis detection

Mastitis alerts: contribution of each variable

sensitivity (%)   specificity (%)

Variables (top to bottom): mastitis, lying time, number of lying bouts, maximum lying bout, average lying bout, maximum standing bout, average standing bout, number of steps, milk yield, concentrate remainder, conductivity left front, conductivity right front, conductivity left hind, conductivity right hind

Sensitivity axis: 0, 20, 40, 60, 80, 100
Specificity axis: 90, 92, 94, 96, 98, 100

Results Live test: procedures

Live test to check the alerts as if they were available daily

- Every Tuesday in January-April 2012:
  - make data available for software
  - run DLM models
  - generate alert list
  - send alert list to farm

- Every Wednesday:
  - check alerts at the farm:
    - lameness: new locomotion scores for alerted cows
    - oestrus: cow status, last known oestrus case
    - mastitis: check cow

- Every Thursday:
  - return annotated alert list

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Results Live test: example alert list

Per cow and per day alerts for:
- lameness
- mastitis (with quarter)
- oestrus

Attenties project "Verbeteren welzijn melkvee"

periode 24-apr-12 tot en met 30-apr-12

Kreupel Lameness   **Locomotiescore**

Dier	24-apr	25-apr	26-apr	27-apr	28-apr	29-apr	30-apr	Datum	Loc.score	Opmerkingen
346		1	1	1	1	1				
513	1	1	1	1	1					
607		1	1	1	1					
634		1	1	1						
646					1	1				
741	1					1				
812	1	1	1							
823	1	1								
921					1	1				
984	1	1				1				
1001						1	1			

Mastitis Mastitis   **Mastitis ja/nee**

Dier	24-apr	25-apr	26-apr	27-apr	28-apr	29-apr	30-apr	Datum	LV	RV	LA	RA	Opmerkingen
537			RV										
607			RV										
614			RA										
725		LA				LA							
727	LA	LA											
766			LA										
827					RA	RA							
971	RV		LA										

Tocht Oestrus   **Tocht gegevens**

Dier	24-apr	25-apr	26-apr	27-apr	28-apr	29-apr	30-apr	Status	Ltst tcht	Opmerkingen
		0				0	0			
537			1							
612	1									
646					1					
726		1								
802	1									
842				1	1					
867					1					
933	1			1						
935				1	1					
984	1									

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Results Live test: example annotated alert list

every alert: TP or FP

with remarks from

herdsman

Attenties project "Verbeteren welzijn melkvee"

periode 24-apr-12   tot en met 30-apr-12

Kreupel — Lameness

Dier	24-apr	25-apr	26-apr	27-apr	28-apr	29-apr	30-apr	Datum	Loc.score	Opmerkingen
346		1	1	1	1	1		1/5	4	kreupel
513	1	1	1	1	1			"	1	
607		1	1	1	1			"	1	
634		1	1	1				"	1	
646				1	1			"	1	
741	1				1			"	1	
812	1	1	1					"	2	
823	1	1						"	1	
921				1	1			4/5	3	tussenklauw
984	1	1			1			"	1	
1001				1	1			"	1	

Mastitis

Dier	24-apr	25-apr	26-apr	27-apr	28-apr	29-apr	30-apr	Datum	LV	RV	LA	RA	Opmerkingen
537			RV					27/4		H			geen
607			RV					"		N			geen
614			RA					24/4				N	RA Balsem
725		LA			LA			24/4			N		Balsem
727	LA	LA						24-25/4			N		Balsem
766		LA						26/4				N	geen
827				RA	RA			28-29/4				N	geen
971	RV		LA					24/4 . 26/4			N	N	geen

Tocht — Oestrus

Dier	24-apr	25-apr	26-apr	27-apr	28-apr	29-apr	30-apr	Status	Ltst tcht	Opmerkingen
		0		1		0	0			
537			1					GEDEKT	op	28-4-12
612	1							DRACHTIG		UWKALF: 21-8-12
646			1					VERS		KALFDAT: 31-1-12
726	1							GEDEKT	op	26-4-12
802	1							DRACHTIG		UWKALF: 26-6-12
842			1	1				GEDEKT	op	28-4-12
867			1					GEDEKT	op	28-4-12
933	1		1					GEDEKT	op	17-4-12
935			1	1				GEDEKT	op	28-4-12
984	1							VERS		KALFDAT: 13-3-12

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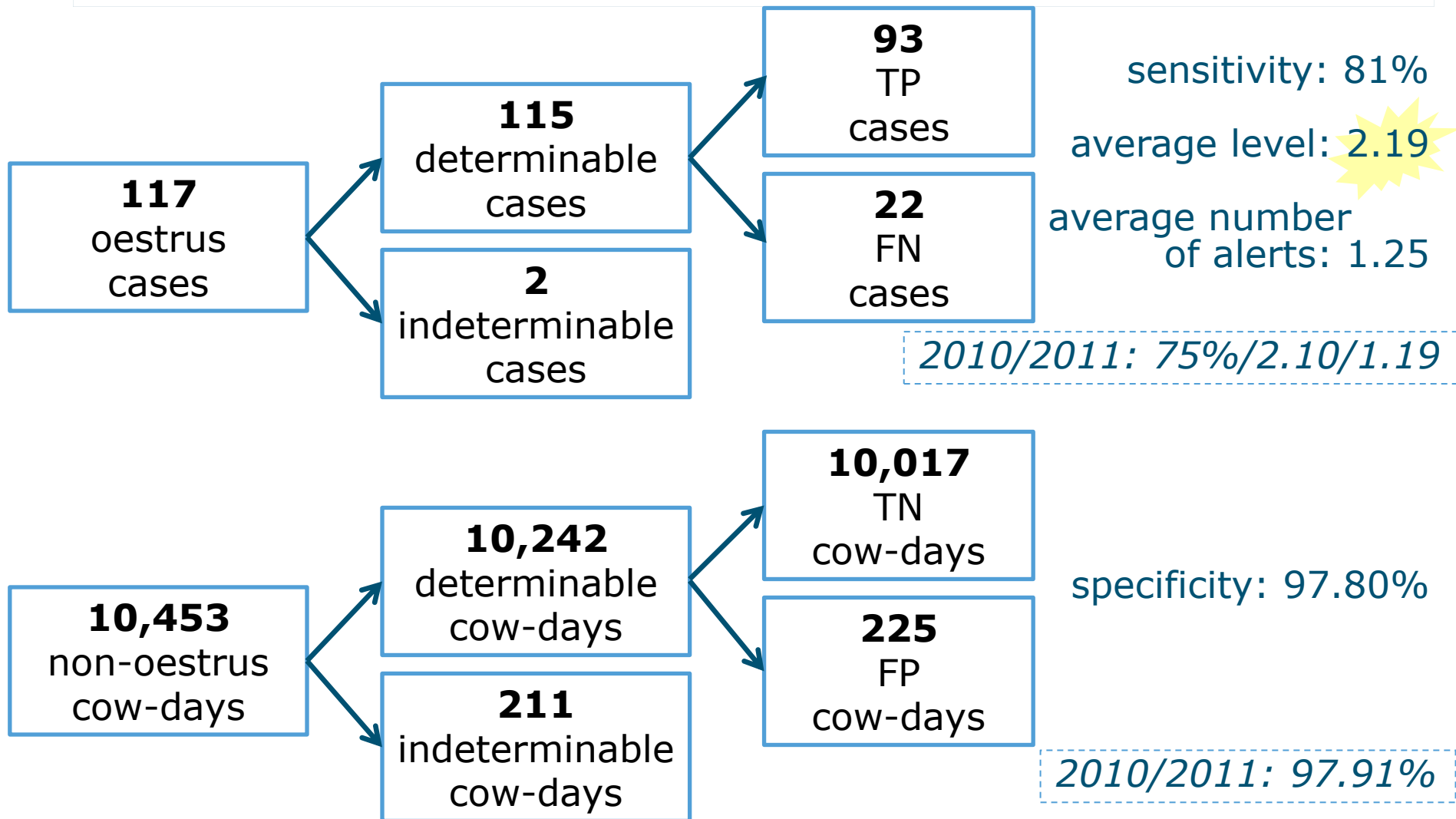WAGENINGEN UR

Results Live test: practical problems

- storage of parameter values of DLM models in database for next-week run

- model calculations for short intervals

- missing data on last available day

- run-time errors in case of incomplete data

- udder with three teats

- different data not available for same period

- errors in cow-tag bookkeeping

- …

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Results: Live test 2012 Lameness detection

15 lameness cases → **15** determinable cases → **12** TP cases

15 determinable cases → **3** FN cases

15 lameness cases → **0** indeterminable cases

sensitivity: 80%

average level: 3.50

average number of alerts: 5.67

2010/2011: 87%/3.54/7.07

8,162 non-lameness cow-days → **7,986** determinable cow-days → **7,173** TN cow-days

7,986 determinable cow-days → **813** FP cow-days

8,162 non-lameness cow-days → **176** indeterminable cow-days

specificity: 89.82%

2010/2011: 88.55%

Results: Live test 2012 Oestrus detection

117 oestrus cases → **115** determinable cases → **93** TP cases

115 determinable cases → **22** FN cases

117 oestrus cases → **2** indeterminable cases

sensitivity: 81%

average level: 2.19

average number of alerts: 1.25

2010/2011: 75%/2.10/1.19

10,453 non-oestrus cow-days → **10,242** determinable cow-days → **10,017** TN cow-days

10,242 determinable cow-days → **225** FP cow-days

10,453 non-oestrus cow-days → **211** indeterminable cow-days

specificity: 97.80%

2010/2011: 97.91%

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Results: Live test 2012 Mastitis detection

13 mastitis cases → **13** determinable cases → **13** TP cases / **0** FN cases

0 indeterminable cases

sensitivity: 100%

average level: 2.15

average number of alerts: 1.92

2010/2011: 89%/2.73/2.38

10,547 non-mastitis cow-days → **10,447** determinable cow-days → **10,217** TN cow-days / **230** FP cow-days

100 indeterminable cow-days

specificity: 97.80%

2010/2011: 97.16%

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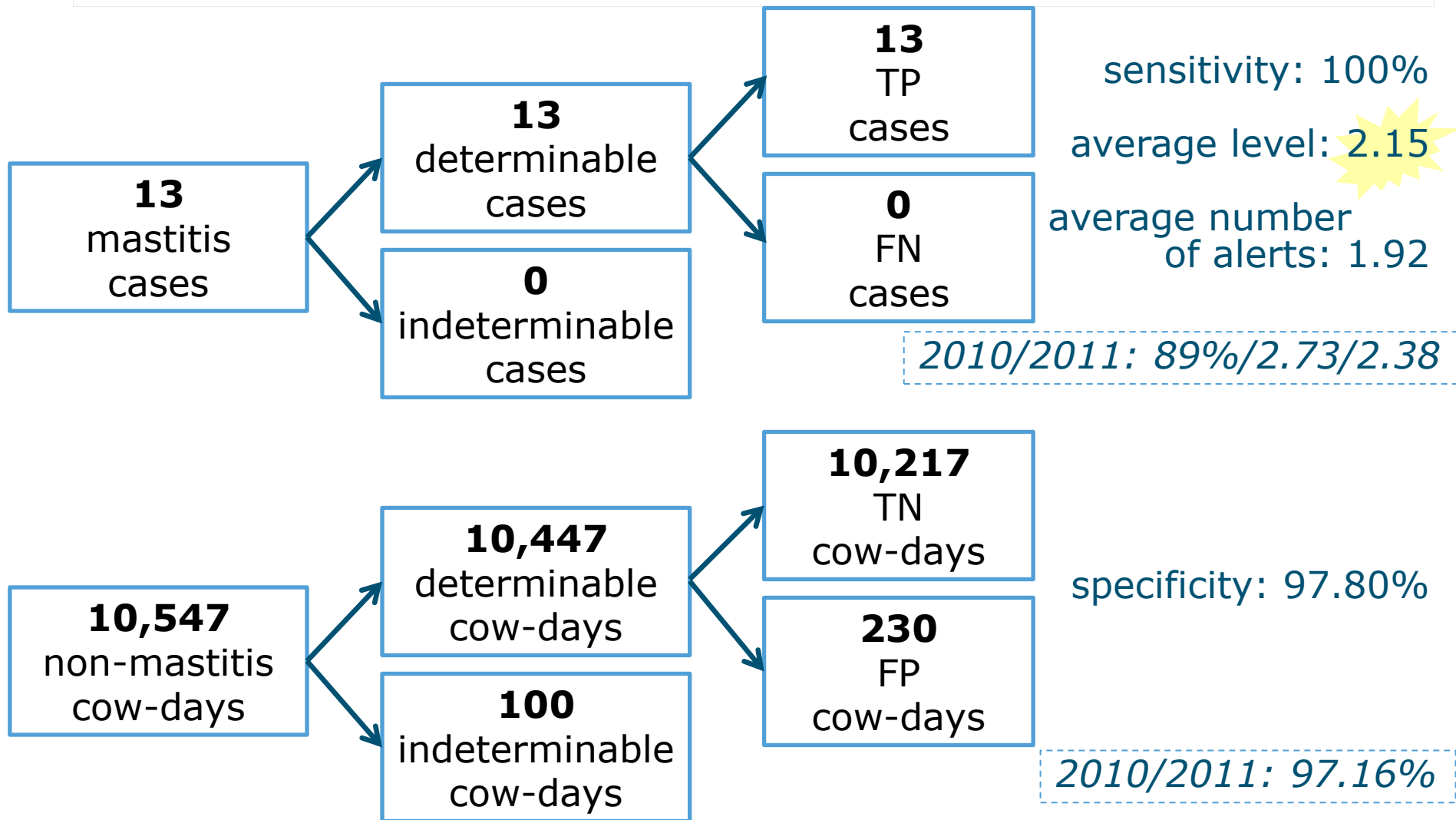
Discussion

- Golden standard?
  - lameness: locomotion score or claw treatment
  - oestrus: sometimes incomplete, unrealistic
  - mastitis: treatment with udder balm = mastitis?

- Availability and performance of sensors?!

- Effects of missing data on performance?

- Setting of thresholds in DLM model?

- Presentation of alerts: 0/1 or alert level?

- Timeliness of alerts

- …

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Conclusions

- Performance in Live test similar to performance in 2010/2011

- Activity data can be used to detect changes in behaviour, therefore useful for lameness detection

- Activity data can be used to detect peaks in number of steps and other variables,
therefore useful for oestrus detection

- Activity data can be used to detect additional changes in case of lameness,
therefore useful for mastitis detection

- But only if sensor performance is okay

Questions?