Knowledge Engineering with Bayesian Networks for Fog and Low Cloud forecasting for Aviation in Australia

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2: Monash University

Fog

- Definition of fog
- Fog Formation
  - sky cover, wind, moisture
- Deceptively simple when it comes to fog prediction
- Involved Uncertainty
  - Incomplete knowledge
  - Missing data or poor quality data
  - uncertainty in observation
  - uncertainty in prediction tools
- It is a local process
  - Small scale
  - Sensitive to local processes

Fog Forecasting for Airlines

- Terminal Aerodrome Forecast (TAF) is issued every 6 hours and is valid for 30h

2pm ----------→| ~ 9am (Perth) /11am (Melbourne)

8pm ----------→| ~ 9am

2am ----------→| ~ 9am

  - when the fog probability ≥ 30% -> included in the TAF
  - If fog forecasted, aircrafts must carry enough fuel to
    - reach an alternative airport
    - maintain a holding pattern above the airport

- Code Grey < 30% chance of fog

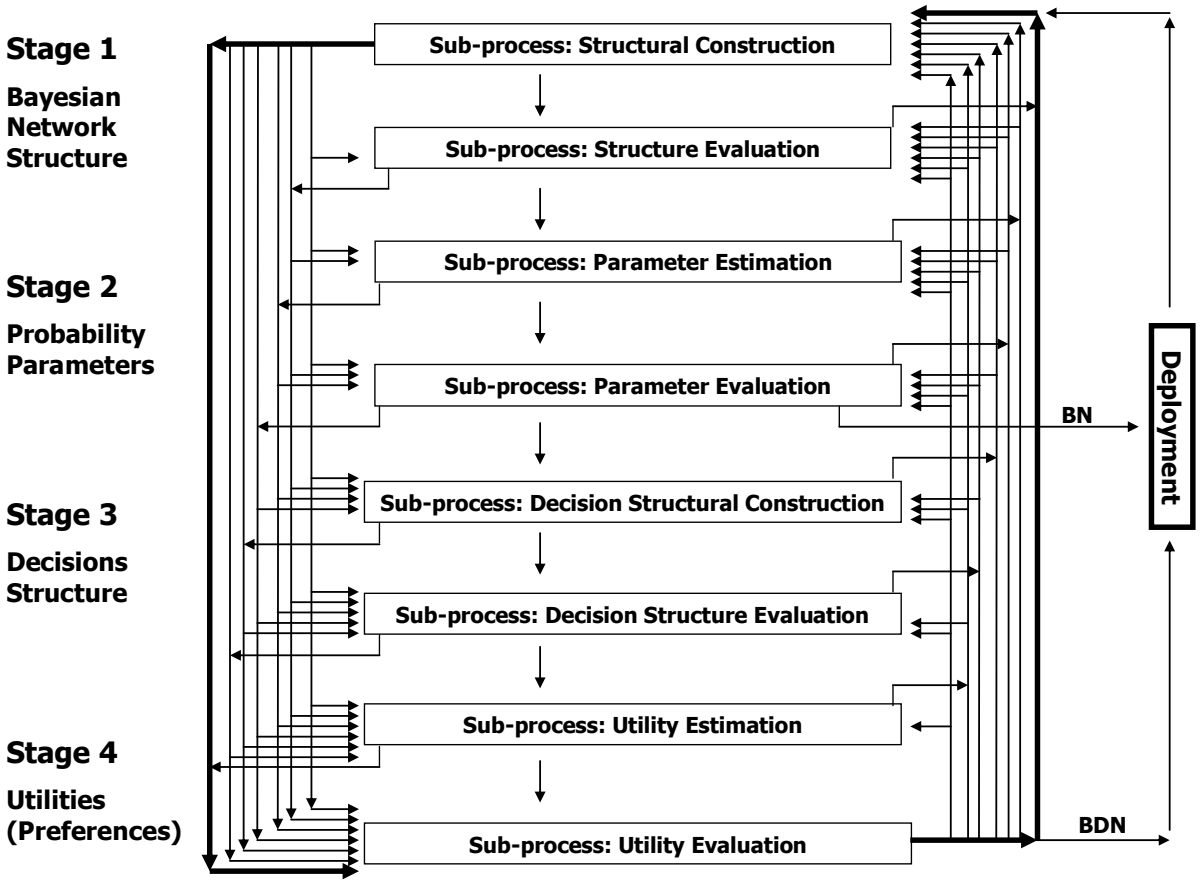
Existing Tools

- NWP (Numerical Weather Prediction models)
  - based on fluid dynamic and thermodynamic equations
- Subjective Judgment
  - local forecasters need to consider the uncertainties involved in the forecasting process and clients' requirements
- Local Guidance Tools
  - forecasters at regional offices developed their own regional specific tools and rules of thumb
- General AI solutions
  - Attempts to generalise guidance tools for different locations and times have not always been successful

Priority airports

- Four priority airports were chosen for fog forecast improvement:
- Melbourne
  - **~ 12-13 fogs and 33 low cloud per year**
- Sydney
  - **~ of 4 to 5 fogs per year**
  - **with the largest traffic volumes**
- Canberra
  - **~ 42 fogs and 79 low cloud per year**
- Perth
  - **~ 12 fogs per year**
  - **large distances to the nearest alternate airports**

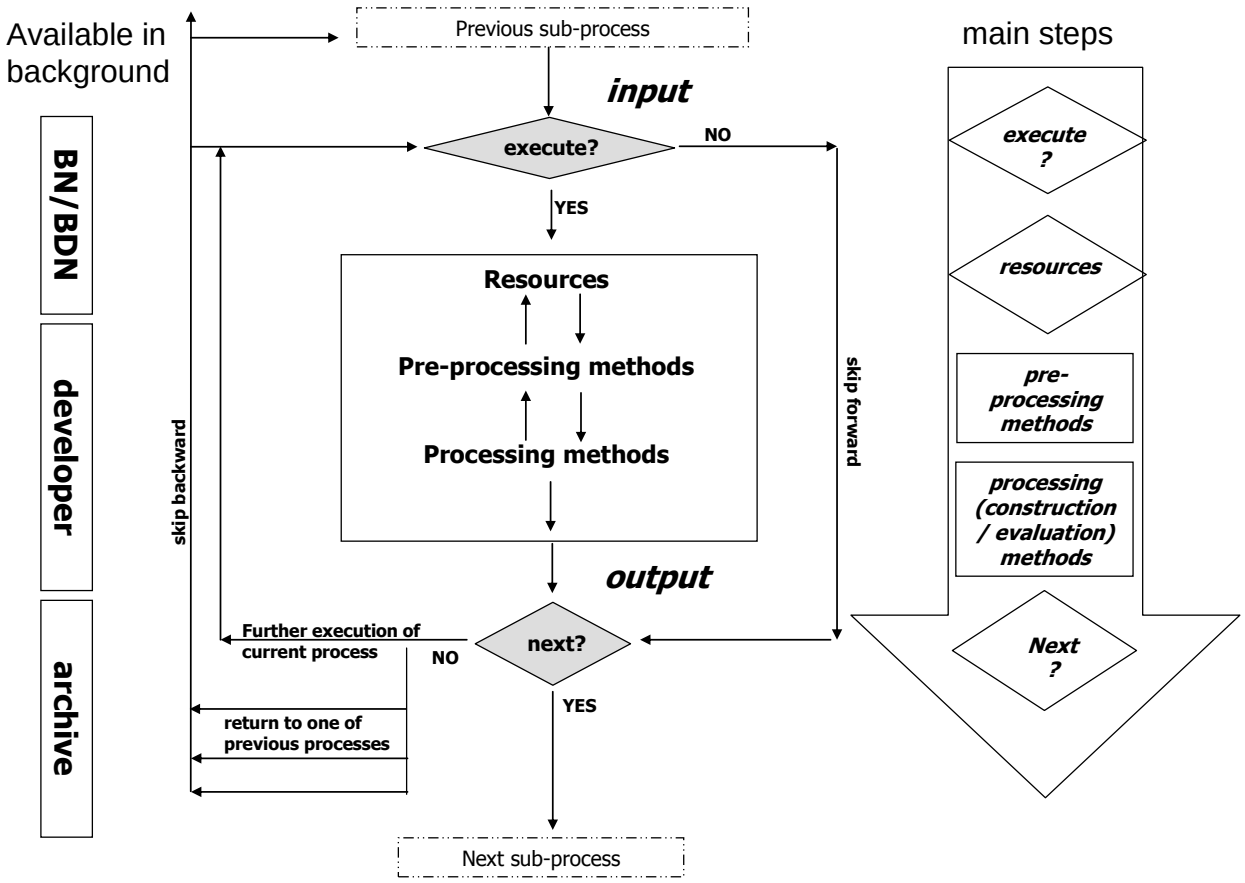
Knowledge Engineering: High Level methodology



- Comprehensive
- Descriptive
- Iterative
- Incremental

Boneh T, PhD Thesis, Monash University, 2010

Knowledge Engineering: for Each Sub-Process



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Requirements for BN Development

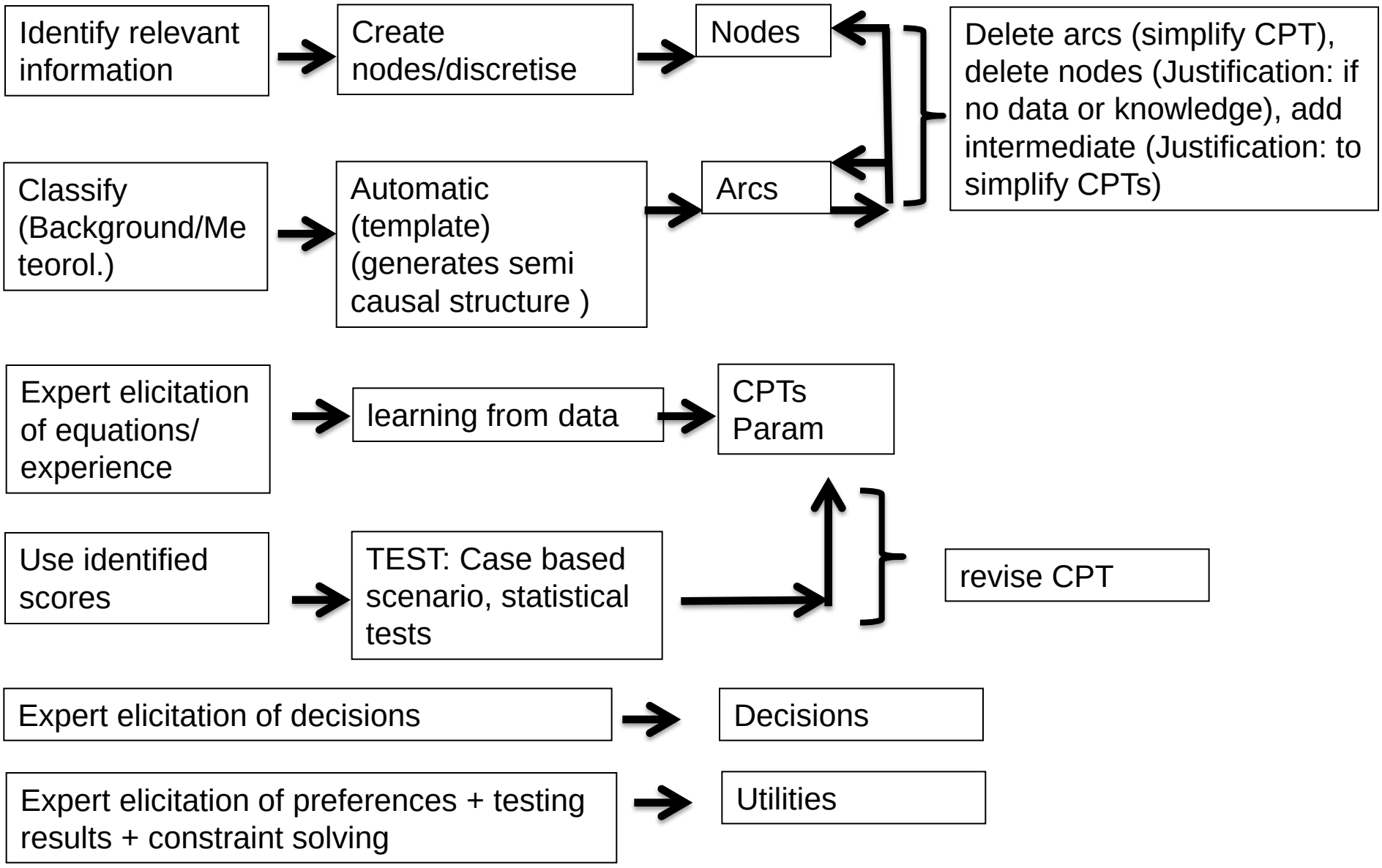
- Past experience indicated that small, problem-specific solutions were needed

  → Individual BDNs that are specific for space and time

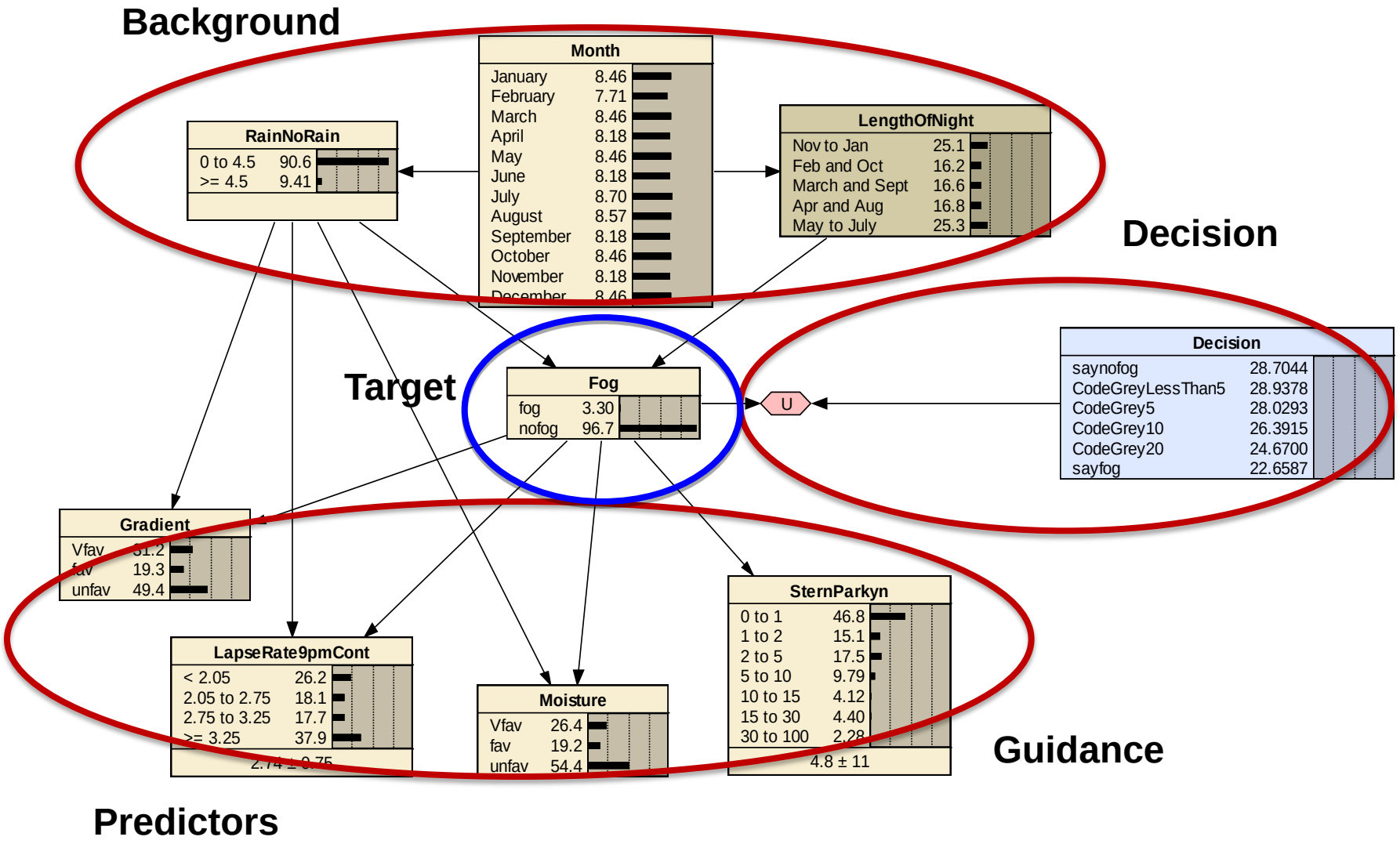
  → Required rapid development of BDNs

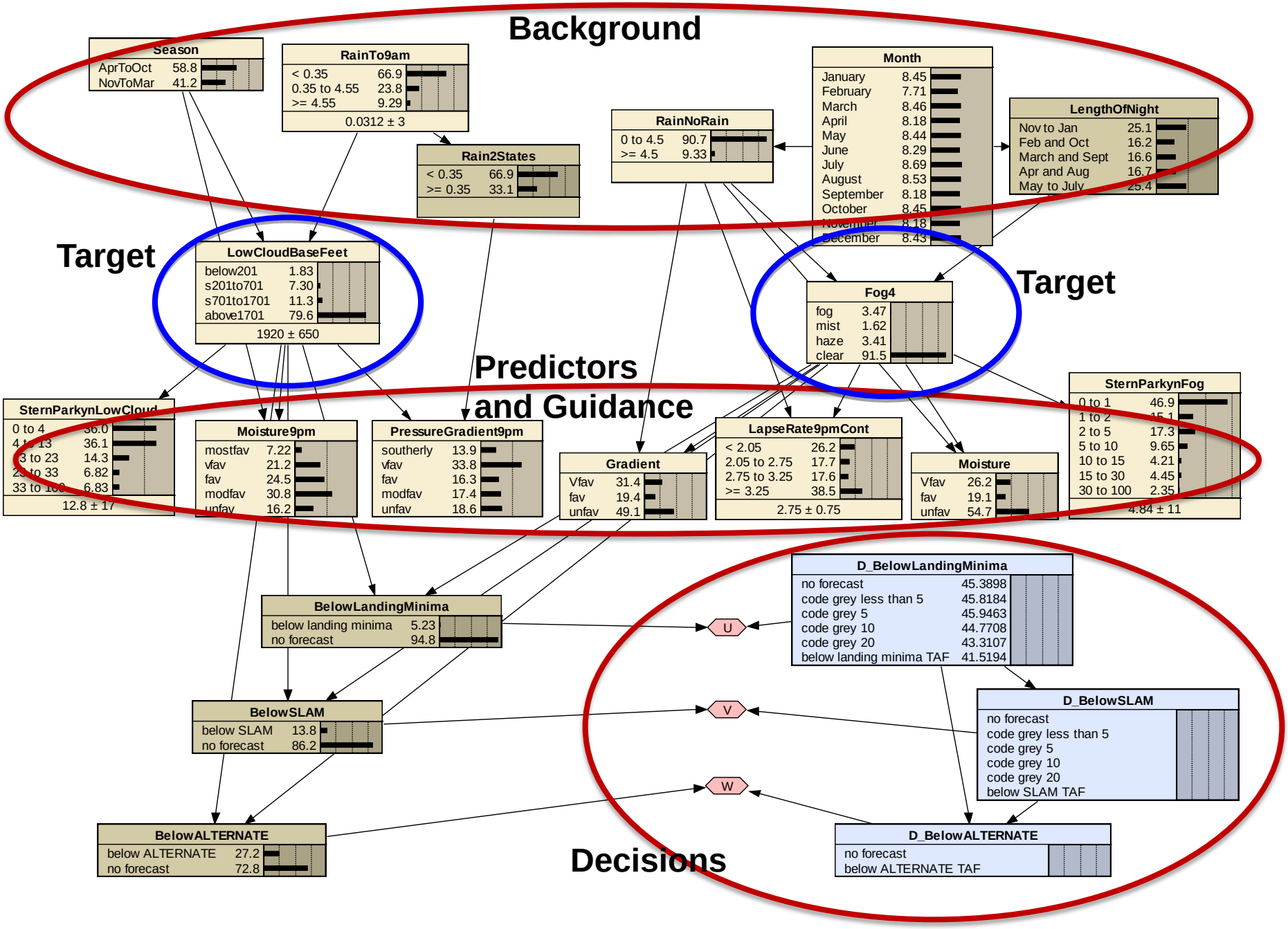
  → A design strategy that was more prescriptive and restrictive

Design Strategy



Example of semi-causal BDN created by the design strategy




Background
Season
AprToOct 58.8
NovToMar 41.2
RainTo9am
< 0.35 66.9
0.35 to 4.55 23.8
>= 4.55 9.29
0.0312 ± 3
Rain2States
< 0.35 66.9
>= 0.35 33.1
RainNoRain
0 to 4.5 90.7
>= 4.5 9.33
Month
January 8.45
February 7.71
March 8.46
April 8.18
May 8.44
June 8.29
July 8.69
August 8.53
September 8.18
October 8.45
November 8.18
December 8.43
LengthOfNight
Nov to Jan 25.1
Feb and Oct 16.2
March and Sept 16.6
Apr and Aug 16.7
May to July 25.4
Target
LowCloudBaseFeet
below201 1.83
s201to701 7.30
s701to1701 11.3
above1701 79.6
1920 ± 650
Target
Fog4
fog 3.47
mist 1.62
haze 3.41
clear 91.5
Predictors and Guidance
SternParkynLowCloud
0 to 4 36.0
4 to 13 36.1
13 to 23 14.3
23 to 33 6.82
33 to 100 6.83
12.8 ± 17
Moisture9pm
mostfav 7.22
vfav 21.2
fav 24.5
modfav 30.8
unfav 16.2
PressureGradient9pm
southerly 13.9
vfav 33.8
fav 16.3
modfav 17.4
unfav 18.6
Gradient
Vfav 31.4
fav 19.4
unfav 49.1
LapseRate9pmCont
< 2.05 26.2
2.05 to 2.75 17.7
2.75 to 3.25 17.6
>= 3.25 38.5
2.75 ± 0.75
Moisture
Vfav 26.2
fav 19.1
unfav 54.7
SternParkynFog
0 to 1 46.9
1 to 2 15.1
2 to 5 17.3
5 to 10 9.65
10 to 15 4.21
15 to 30 4.45
30 to 100 2.35
4.84 ± 11
Decisions
BelowLandingMinima
below landing minima 5.23
no forecast 94.8
U
D_BelowLandingMinima
no forecast 45.3898
code grey less than 5 45.8184
code grey 5 45.9463
code grey 10 44.7708
code grey 20 43.3107
below landing minima TAF 41.5194
BelowSLAM
below SLAM 13.8
no forecast 86.2
V
D_BelowSLAM
no forecast
code grey less than 5
code grey 5
code grey 10
code grey 20
below SLAM TAF
W
BelowALTERNATE
below ALTERNATE 27.2
no forecast 72.8
D_BelowALTERNATE
no forecast
below ALTERNATE TAF

A Large Number of Networks

4 Airports

			Forecast Times					
Airport	Variant	F/LC/name of net	3 pm	6 pm	9 pm	12 am	2 am	3 am
Melbourne	1	Fog 2state 3pm	√	winter	summer			
	2	Fog 2state 12am				√		
	3	Fog 4state 9pm						
	4	Fog 4state 12am						
	5	Low Cloud 9pm			√			
	6	Low Cloud 12am				√		
	3+5	Fog + Low Cloud 9pm			√			
	4+6	Fog + Low Cloud 12am				√		
Sydney	1	Fog 2state 12am				√		
	2	Fog 2state 2am					√	
	3	Fog 2state 3am						√
Canberra	1	Fog 4state 6pm		√				
	2	Fog 4state 12am				√		
	3	Fog 4state 3am						√
	4	Low Cloud 6pm		√				
	5	Low Cloud 12am				√		
	6	Low Cloud 3am						√
	3+6	Fog + Low Cloud 3am						√
Perth	1	Fog 2state 3pm	√	√	√	√	√	√

Fog Definitions at Different Airports

	# of nets	Fog (Y/N)	# of nets	visibility	# of nets	Low cloud Base	# of nets
Melbourne	8	Y if vis <=1000m	2	Fog<=1000, 1000<mist<=3000, 3000<haze<=7000, 7000<clear	2	below201ft, s201to701ft, s701to1701ft, above1701ft	2
Sydney	3	Y if vis <= 2000m	3				
Canberra	7			LessThan1001m, V1001To2000m, V2001To5000m, MoreThan5000m	3	LessThan251ft, B251To1400ft, B1400To2000ft, MoreThan2000ft	3
Perth	1	Y if vis <= 2000m	1				

Weather Information Used at Different Airports

	Melbourne	Sydney	Canberra	Perth
Weather situation	X	X	X	X
Moisture	X	X	X	X
Moisture Upstream	X	X		
Wind	X	X	X	X
Stability	X		X	
Visibility			X	
Visibility Upstream		X		
Sky Cover		X	X	X
Guidance	X			X

Evaluation

- What is required for acceptance of the BDNs?

1. Network should have explanatory power
   - No Black Box Solution!

2. Same or better results compared with existing approaches , using their existing measures

Evaluation Scores

		observed		
		fog	nofog	total
forecast	fog	a	b	a + b
	nofog	c	d	c + d
	total	a + c	b + d	a + b + c + d

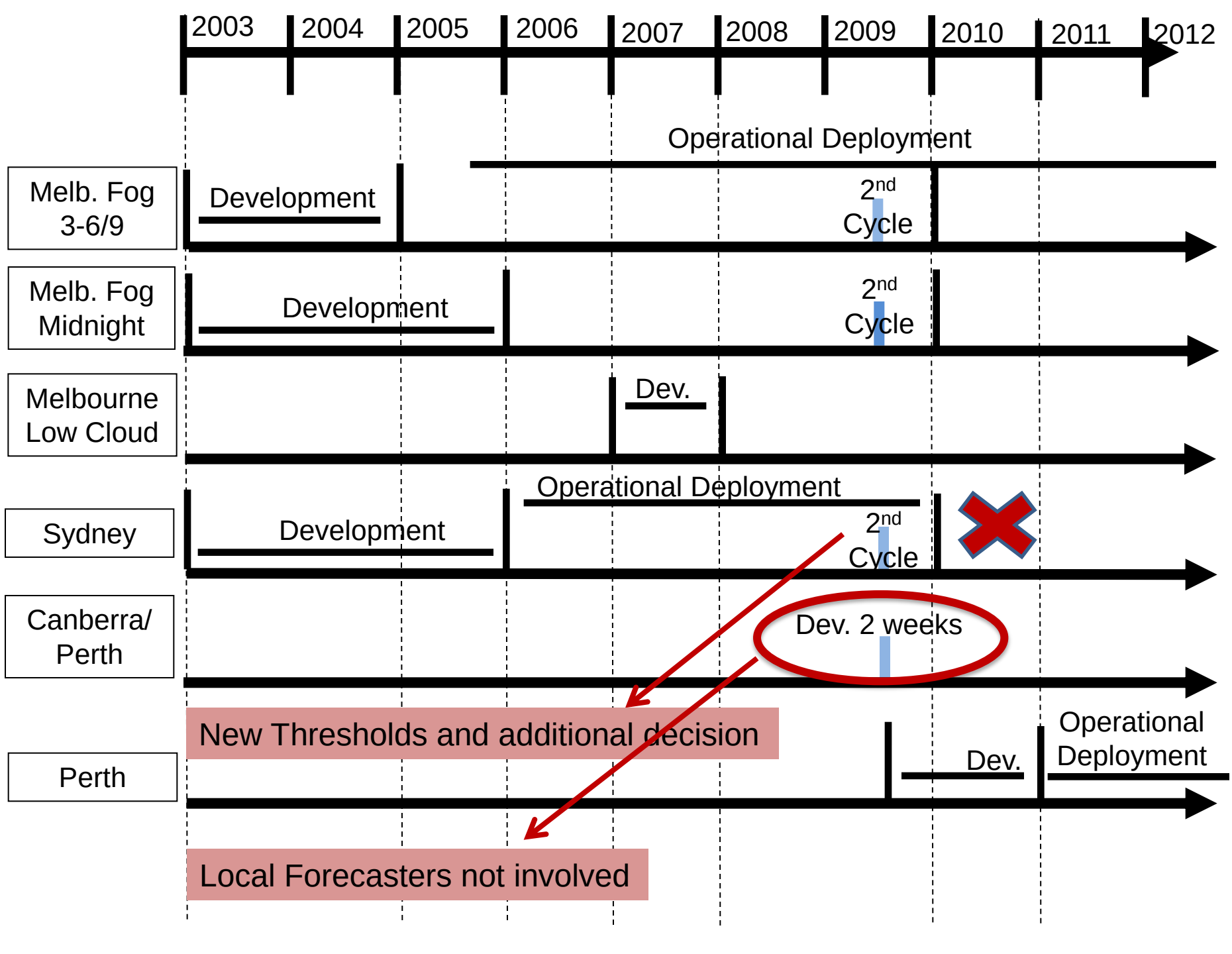
a	hits/true positives	events forecast to occur, and did occur
b	false alarms/false positives	events forecast to occur, but did not occur
c	misses/false negatives	events forecast not to occur, but did occur
d	correct negatives/true negatives	events forecast not to occur, and did not occur

Score		
POD	Probability Of Detection, or hit rate	(a)/(a+c).
FAR	False Alarm Ratio	(b)/(a+b)
FAR*	False Alarm Rate	(b)/(b+d)

Example – Evaluation

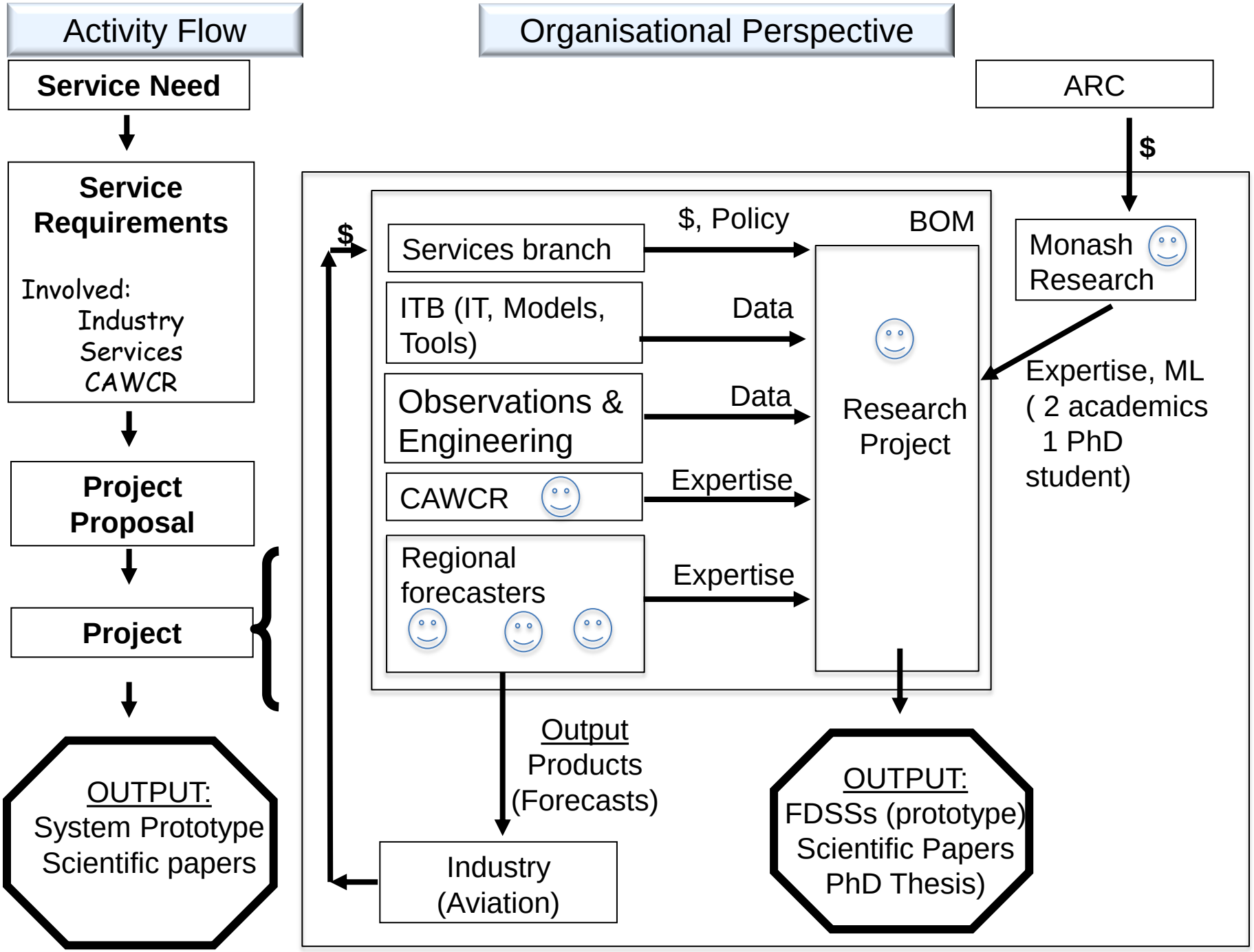
Forecast	Operational		Network Cross Validation 1994	
	POD (%)	FAR (%)	POD (%)	FAR (%)
3pm TAF	64	77	67	77
3pm TAF and Code Grey	87	90	95	89
9pm TAF	67	73	70	76
9pm TAF and Code Grey	87	90	95	88
Midnight TAF	74	72	75	76
Midnight TAF and Code Grey	90	90	96	86

TAF POD	TAF FAR	BN POD	BN FAR
94%	52%	97%	52%


2003
2004
2005
2006
2007
2008
2009
2010
2011
2012
Operational Deployment
Melb. Fog 3-6/9
Development
2nd Cycle
Melb. Fog Midnight
Development
2nd Cycle
Melbourne Low Cloud
Dev.
Operational Deployment
Sydney
Development
2nd Cycle
Canberra/ Perth
Dev. 2 weeks
New Thresholds and additional decision
Perth
Dev.
Operational Deployment
Local Forecasters not involved

Future Work
(ARC Linkage 2012 – 2014)

- Refine process
  - Discretisation
  - Calibration
  - Parameterisation
- Refine Networks
  - Additional information
  - Accommodate for different seasons
  - Onset and Clearance
- Dynamic Bayesian networks


Activity Flow
Service Need
Service Requirements
Involved:
Industry
Services
CAWCR
Project Proposal
Project
OUTPUT:
System Prototype
Scientific papers
Organisational Perspective
ARC
$
$
Services branch
$, Policy
BOM
ITB (IT, Models, Tools)
Data
Observations & Engineering
Data
CAWCR
Expertise
Regional forecasters
Expertise
Research Project
Monash Research
Expertise, ML
(2 academics
1 PhD
student)
Output
Products
(Forecasts)
Industry
(Aviation)
OUTPUT:
FDSSs (prototype)
Scientific Papers
PhD Thesis)

Thank You

Perth Fog Onset

```
getStartTime:
        if (month < 4 OR month > 10) {
                return startTime = 18;
        } else {
                start = 10 + ABS( 6 - month ) + Math.round( air_temp(10Z) – dewpoint(10Z) );
                if rain:
                        start = start - 1;
                if ( start > 20 )
                        start = 20;
                if ( start < 12 )
                        start = 12;
                prGradDiff = PrGradGP(at 10Z) + PrGradPA(at 10Z);
                if ( prGradDiff >= 5.0 && start < 15 )
                        start = 15;
                if ( prGradDiff >= 8.0 && start < 18 )
                        start = 18;
                return startTime = start;
        }
```

- Pressure gradient Geraldton-Perth, Perth-Albany

Perth Fog Clearance

```
getFinishTime:
        if (month < 4 OR month > 10) {
                return finishTime = 23;
        } else {
                finish = 24;
                prGradDiff = PrGradGP(at 22Z) + PrGradPA(at 22Z);
                if ( prGradDiff > 4.0 OR prGradDiff < 1.0 )
                        finish = 24;
                else
                        finish = 01;
        return finishTime = finish;
        }
```

- Pressure gradient Geraldton-Perth, Perth-Albany