# Application of Variable Life Adjusted Displays (VLAD) on Victorian Admitted Episodes Dataset (VAED)

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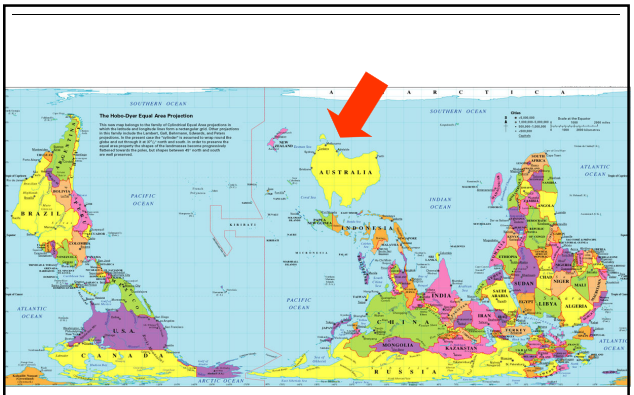


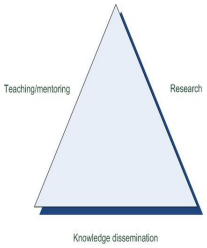



## Objectives of the CRE-PS

- To establish a national Centre of Research Excellence that will promote and develop resources to improve patient safety that will lead to:
  - Better identification of factors that affect patient safety
  - More effective use of data to monitor quality of care
  - Better understanding of human factors, organisational factors and system deficiencies leading to error
  - Use of clinical simulation to provide a safe environment for research, training and education
  - Development of mechanisms for ensuring uptake of research findings
  - Training of new patient safety researchers



- **Research** to strengthen the evidence base for developing and implementing system improvements to reduce adverse events and improve safety and quality
- **Teaching/ mentoring** to improve patient safety at clinical level and develop new researchers
- **Knowledge dissemination** to enhance patient care






## Introduction

- Control charts for quality control
- In-control vs out-of-control states for systems
- Many types e.g.
  - VLAD
  - Shewhart
  - Cumulative Sum (CUSUM)
  - Exponentially Weighted Moving Average (EWMA)
  - (Resetting) Sequential Probability Ratio Tests (SPRT and RSPRT)



## Background

- Centre for Research Excellence in Patient Safety (CRE-PS) evaluated the VLAD methodology for Department of Human Services (DHS) Victoria
- In-hospital mortality for acute myocardial infarction (AMI), heart failure (HF) and stroke used for proof of concept
- Logistic regression risk model for each condition based on Queensland Hospital Admitted Patient Data Collection (QHAPDC) models

## Background

Data management and initial analysis

↓

Logistic regression

↓

VLAD

↓

VLAD limits

↓

Implementation plan



## VAED

- Victorian hospital admissions
- Over 3.9 million between 1st July 2004 – 30th June 2007
- De-identified hospital code
- Gender, age-group, admission date, separation date
- Primary admission diagnosis and up to 39 other co-morbidities captured as International Classification of Diseases (ICD 10) codes e.g.
  - AMI – I21 or I22, HF – I50, stroke I61-I64
- Separation mode e.g.
  - "D" = death, "T" = transfer



## Separations - AMI

| Criterion | N(%) |
|---|---|
| **Total separations 2004-7** | **32550(100)** |
| LOS <4 days and mortality = no | 14814(45.5) |
| LOS >30 days | 418(1.28) |
| Not admitted through hospital emergency department | 8830(27.1) |
| Transfers out | 10616(32.6) |
| Age <30 years | 67(0.21) |
| Age ≥85 years | 4661(14.3) |
| **Eligible separations** | **8924(27.4)** |



## Separations - HF

| Criterion | N(%) |
|---|---|
| **Total separations 2004-7** | **27389(100)** |
| No overnight stay | 3786(13.8) |
| LOS >30 days | 649(2.4) |
| Not admitted through hospital emergency department | 6293(23.0) |
| Transfers out | 4510(16.5) |
| Age <30 years | 141(0.5) |
| Age ≥85 years | 7876(28.8) |
| **Eligible separations** | **11124(40.6)** |



## Separations - Stroke

| Criterion | N(%) |
|---|---|
| **Total separations 2004-7** | **22706(100)** |
| LOS <4 days and mortality = no | 6239(27.5) |
| LOS >30 days | 1432(6.3) |
| Not admitted through hospital emergency department | 4641(20.4) |
| Transfers out | 8071(35.6) |
| Age <30 years | 311(1.4) |
| Age ≥85 years | 4768(18.4) |
| Carotid endarterectomy | 102(0.5) |
| **Eligible separations** | **5857(25.8)** |



## Mortality - AMI

| Year | N | % | Deaths | % | Mortality risk | Risk ratio |
|---|---|---|---|---|---|---|
| 2004-5 | 2999 | 33.6 | 338 | 31.9 | 11.3% | 1.00 |
| 2005-6 | 2977 | 33.4 | 371 | 35.0 | 12.5% | 1.11 |
| 2006-7 | 2948 | 33.0 | 350 | 33.1 | 11.9% | 1.05 |
| 2004-7 | 8924 | 100 | 1059 | 100 | 11.9% | - |

## Mortality - HF

| Year | N | % | Deaths | % | Mortality risk | Risk ratio |
|---|---|---|---|---|---|---|
| 2004-5 | 3598 | 32.3 | 213 | 34.6 | 5.9% | 1.00 |
| 2005-6 | 3683 | 33.1 | 194 | 31.5 | 5.3% | 0.89 |
| 2006-7 | 3843 | 34.6 | 209 | 33.9 | 5.4% | 0.92 |
| 2004-7 | 11124 | 100 | 616 | 100 | 5.5% | - |

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## Mortality - Stroke

| Year | N | % | Deaths | % | Mortality risk | Risk ratio |
|---|---|---|---|---|---|---|
| 2004-5 | 1922 | 32.8 | 540 | 30.9 | 28.1% | 1.00 |
| 2005-6 | 1966 | 33.6 | 609 | 34.8 | 31.0% | 1.10 |
| 2006-7 | 1969 | 33.6 | 599 | 34.3 | 30.4% | 1.08 |
| 2004-7 | 5857 | 100 | 1748 | 100 | 29.8% | - |

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## Comorbidities - AMI

| Comorbidity | N | % | Deaths | % | Mortality risk | Risk ratio |
|---|---|---|---|---|---|---|
| Hypotension/ shock | 1393 | 15.6 | 437 | 41.3 | 31% | 3.80 |
| Dysrrhythmias | 2241 | 25.1 | 553 | 52.2 | 25% | 3.26 |
| CVD | 179 | 2.0 | 64 | 6.0 | 36% | 3.14 |
| HF | 1993 | 22.3 | 403 | 38.1 | 20% | 2.14 |
| Renal failure | 1715 | 19.2 | 357 | 33.7 | 21% | 2.14 |
| Dementia | 189 | 2.1 | 46 | 4.1 | 24% | 2.10 |
| Malignancy | 196 | 2.2 | 43 | 4.1 | 22% | 1.88 |
| Diabetes | 2876 | 32.2 | 323 | 30.5 | 11% | 0.92 |
| Hypertension | 4693 | 53.6 | 449 | 42.4 | 10% | 0.66 |
| **All separations** | **8924** | **100** | **1059** | **100** | **12%** | - |

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## Comorbidities - HF

| Comorbidity | N | % | Deaths | % | Mortality risk | Risk ratio |
|---|---|---|---|---|---|---|
| Septicaemia | 96 | 0.9 | 41 | 6.7 | 43% | 8.19 |
| Hypotension/ shock | 1031 | 9.3 | 195 | 31.7 | 19% | 4.53 |
| CVD | 129 | 1.2 | 27 | 4.4 | 21% | 3.91 |
| Renal failure | 3599 | 32.4 | 387 | 62.8 | 11% | 3.53 |
| Dementia | 267 | 2.4 | 42 | 6.8 | 16% | 2.98 |
| Lower limb or decubitis ulcer | 502 | 4.5 | 71 | 11.5 | 14% | 2.76 |
| Malignancy | 307 | 2.8 | 43 | 7.0 | 14% | 2.64 |
| LRTI/ Influenza | 1587 | 14.3 | 177 | 28.7 | 11% | 2.42 |
| IHD | 2256 | 20.3 | 207 | 33.6 | 9% | 1.99 |
| Dysrrhythmias | 2720 | 24.5 | 223 | 36.2 | 8% | 1.75 |
| Hypertension | 4605 | 41.4 | 218 | 35.4 | 5% | 0.78 |
| **All separations** | **11124** | **100** | **616** | **100** | **6%** | - |

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## Comorbidities - Stroke

| Comorbidity | N | % | Deaths | % | Mortality risk | Risk ratio |
|---|---|---|---|---|---|---|
| Septicaemia | 72 | 1.2 | 49 | 2.8 | 68% | 2.32 |
| HF | 229 | 3.9 | 145 | 8.3 | 63% | 2.22 |
| LRTI/ Influenza | 250 | 4.3 | 130 | 7.4 | 52% | 1.80 |
| Malignancy | 182 | 3.1 | 94 | 5.4 | 52% | 1.77 |
| Renal failure | 543 | 9.3 | 216 | 9.3 | 40% | 1.38 |
| **All separations** | **5857** | **100** | **1748** | **100** | **30%** | |

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## Multiple logistic regression - AMI

| **2004-7 (N=8924)** | OR | 95% CI | P |
|---|---|---|---|
| **Sex** | | | |
| Male (reference) | 1.00 | | |
| Female | 1.21 | 1.04 – 1.40 | 0.013 |
| **Age - years** | | | |
| 30 – 54 | 0.55 | 0.37 – 0.81 | 0.002 |
| 55 – 59 | 0.54 | 0.34 – 0.85 | 0.008 |
| 60 – 64 (reference) | 1.00 | - | - |
| 65 – 69 | 1.17 | 0.83 – 1.66 | 0.378 |
| 70 – 74 | 1.52 | 1.10 – 2.10 | 0.011 |
| 75 – 79 | 2.21 | 1.63 – 2.98 | <0.0001 |
| 80 - 84 | 2.95 | 2.19 – 3.97 | <0.0001 |

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## Multiple logistic regression – AMI (cont.)

| 2004-7 (N=8924) | OR | 95% CI | P |
|---|---|---|---|
| **Comorbidities** | | | |
| Hypotension/shock | 3.99 | 3.42 – 4.65 | <0.001 |
| Dysrrhythmias | 3.03 | 2.62 – 3.50 | <0.001 |
| Cerebrovascular disease | 3.91 | 2.74 – 5.58 | <0.001 |
| HF | 1.30 | 1.11 – 1.52 | 0.001 |
| Renal Failure | 1.62 | 1.37 – 1.91 | <0.001 |
| Dementia | 1.52 | 1.04 – 2.23 | 0.031 |
| Malignancy | 2.16 | 1.48 – 3.16 | <0.001 |
| Diabetes | 0.98 | 0.83 – 1.16 | 0.833 |
| Hypertension | 0.49 | 0.42 – 0.57 | <0.001 |



## Multiple logistic regression – AMI (cont.)

| 2004-7 (N=8924) | OR | 95% CI | P |
|---|---|---|---|
| **Year of separation** | | | |
| 2004-5 (reference) | 1.00 | - | - |
| 2005-6 | 1.09 | 0.91 – 1.29 | 0.347 |
| 2006-7 | 1.09 | 0.92 – 1.30 | 0.311 |



## VLAD

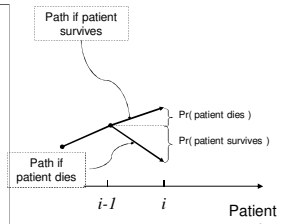
- Plots cumulative expected (E) – observed (O) events
- E calculated from 2004-5 logistic models
- From 2005 onwards
- Calculated by de-identified hospital (N=11)

$$V_n = \sum_{i=1}^{n} E_i - \sum_{i=1}^{n} O_i$$



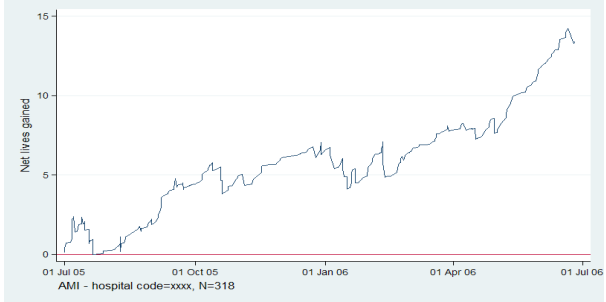
## VLAD

- Type of quality control chart
- Counts excess of expected to observed events
- Expected events calculated using:
  - Case mix adjusted logistic regression model
  - Data from 2005-07 only
- 'Up' line – performance improving
- 'Down' line – performance declining
- 'Flags' identify marked changes in performance






## VLAD






## VLAD - Limits

- Upper and lower risk adjusted CUSUM limits
- *rho* – odds ratio between risk of mortality under the alternative and null hypotheses
- *h* – control limit signifying when the CUSUM signals
- Resetting of limit with signal
- Methodology as per Sherlaw-Johnson[1]

[1]Sherlaw-Johnson C. (2005) A Method for Detecting Runs of Good and Bad Clinical Outcomes on Variable Life-Adjusted Display (VLAD) Charts. Health Care Management Science, 8: 61-65.

## VLAD - Limits

- For the lower limit the CUSUM of the *n*th observation ($C_n$) with the corresponding weight is given by:
  - $C_0 = 0$ and $C_n = \max\{C_{n-1} + W_n, 0\}$
- For the upper limit the CUSUM of the *n*th observation ($C_n$) with the corresponding weight is given by:
  - $C_0 = 0$ and $C_n = \min\{C_{n-1} - W_n, 0\}$
- where
  - $W_n = O_n \log rho - \log(1+(rho-1)E_n)$

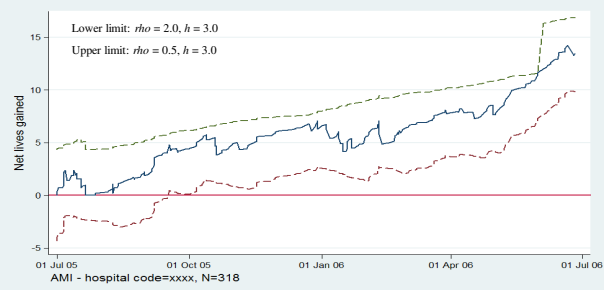


## VLAD - Limits

- The lower VLAD limit ($L_n$) can then be calculated by the expression
  - $L_n = V_n + (C_n - h)/\log rho$
- The upper VLAD limit ($L_n$) can then be calculated by the expression
  - $L_n = V_n - (C_n + h)/\log rho$
- Should $V_n$ intersect with $L_n$, the limit is reset to $Z_n$ by
  - $Z_n = L_n + h/\log rho$



## VLAD - Limits






## VLAD - Limits

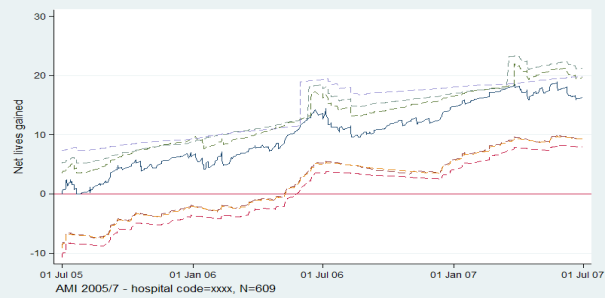
- ARL = Average run length to false alarms
- Coory et. al.[2]

| | improved performance | | | worse performance | | |
|---|---|---|---|---|---|---|
| *rho* | 0.70 | 0.50 | 0.25 | 1.30 | 1.50 | 1.75 |
| *h* | 2.6 | 3.6 | 4.9 | 2.8 | 3.7 | 5.0 |
| ARL | 229 | 682 | 2447 | 264 | 834 | 3118 |

[2]Coory M, Duckett S, Sketcher-Baker K. (2008) Using control charts to monitor quality of care with administrative data. International Journal for Quality in Health Care, 20: 31-39

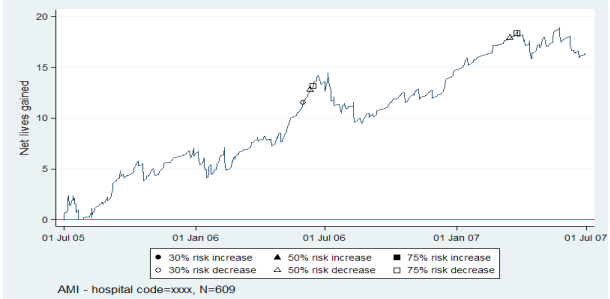


## VLAD – Multiple limits






## VLAD – Multiple limits



## VLAD - Signals

| | Risk Decrease | | | Risk Increase | | |
|---|---|---|---|---|---|---|
| **2005-7** | 30% | 50% | 75% | 30% | 50% | 75% |
| **AMI** | | | | | | |
| Total number of signals | 4 | 5 | 3 | 1 | 1 | 1 |
| Hospitals signaling at least once | 27% | 27% | 18% | 9% | 9% | 9% |
| **HF** | | | | | | |
| Total number of signals | 3 | 5 | 5 | 1 | 1 | 1 |
| Hospitals signaling at least once | 18% | 36% | 36% | 9% | 9% | 9% |
| **Stroke** | | | | | | |
| Total number of signals | 5 | 5 | 4 | 11 | 11 | 11 |
| Hospitals signaling at least once | 36% | 36% | 36% | 45% | 45% | 45% |



## Implementation

- Upwards of 30 outcomes from VAED data
- Development of models by bootstrapping techniques
- Possibility of rolling logistic model
- Monthly availability of data with 3 month lag
- Fine tuning of *rho* and *h*
- Validation of signals
- Response to signals and will this lead to change
- Initial trial with one or two well known outcomes in Victorian hospitals e.g. AMI



## Summary

- VLAD may be a clinically appealing measure of quality control
- Monitoring will give an indication of potential signals to investigate
- False positives will occur
- Further work needed on methodology, implementation and validation for Victorian hospitals



## Acknowledgements

- Department of Human Services, Victoria
- Associate Professor Michael Coory
- CRE-PS
- Department of Epidemiology and Preventive Medicine, Monash University





## Multiple logistic regression - AMI

| Year | N | Area under ROC curve | Hosmer-Lemeshow chi2(8) | P |
|---|---|---|---|---|
| 2004-5 | 2999 | 0.8344 | 13.77 | 0.0880 |
| 2005-6 | 2977 | 0.8200 | 11.13 | 0.1943 |
| 2006-7 | 2948 | 0.8147 | 39.37 | <0.0001 |
| 2004-7 | 8924 | 0.8207 | 43.94 | <0.0001 |

## Multiple logistic regression - HF

| Year | N | Area under ROC curve | Hosmer-Lemeshow chi2(8) | P |
|---|---|---|---|---|
| 2004-5 | 3598 | 0.8260 | 8.90 | 0.3506 |
| 2005-6 | 3683 | 0.8259 | 3.93 | 0.8631 |
| 2006-7 | 3843 | 0.7919 | 8.48 | 0.3881 |
| 2004-7 | 11124 | 0.8109 | 8.86 | 0.3540 |

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## Multiple logistic regression - Stroke

| Year | N | Area under ROC curve | Hosmer-Lemeshow chi2(8) | P |
|---|---|---|---|---|
| 2004-5 | 1922 | 0.6768 | 6.16 | 0.5208 |
| 2005-6 | 1966 | 0.6529 | 3.18 | 0.7862 |
| 2006-7 | 1969 | 0.6727 | 2.76 | 0.7370 |
| 2004-7 | 5857 | 0.6651 | 20.32 | 0.0092 |

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