CUSUM charts

CUSUM stands for the **CU**mulative **SUM** of outcomes.

The SICSAG monthly ICU reports include a CUSUM track chart for a unit's 300 most recently discharged patients. The CUSUM chart provides an early warning system for changing mortality rates based on APACHE II predictions and documented hospital outcomes. A signal occurs when a sequence of outcomes is better or worse than might be expected from these patients' APACHE II mortality predictions.

An **increase indicator** and a **decrease indicator** are calculated for each patient. These values are based on the patient's APACHE II mortality prediction and whether the patient was alive or dead on discharge from hospital.
Cumulative totals of these indicators are kept. The increase indicator is added to the cumulative increase indicator, and the decrease indicator is subtracted from the cumulative decrease indicator. The cumulative increase indicator is restricted to be above zero, and the cumulative decrease indicator is restricted to be below zero.

The **cumulative increase indicator** measures whether a sequence of hospital outcomes is **worse** than might be expected from these patients' APACHE II mortality predictions.
The **cumulative decrease indicator** measures whether a sequence of hospital outcomes is **better** than might be expected from these patients' APACHE II mortality predictions.

If the patient is **alive** on discharge from hospital:

- the increase indicator is negative, and so the cumulative increase indicator goes down, towards the middle of the chart
- the decrease indicator is positive, and so the cumulative decrease indicator goes down, towards the bottom of the chart

If the patient is **dead** on discharge from hospital:

- the increase indicator is positive, and so the cumulative increase indicator goes up, towards the top of the chart
- the decrease indicator is negative, and so the cumulative decrease indicator goes up, towards the middle of the chart

The size of the increase and decrease indicators depends on the mortality prediction.

- If the patient has a **low** mortality prediction and is **alive** on discharge from hospital then
    - the increase indicator will be small and negative
    - the decrease indicator will be small and positive
- If the patient has a **low** mortality prediction and is **dead** on discharge from hospital then
    - the increase indicator will be large and positive
    - the decrease indicator will be large and negative
- If the patient has a **high** mortality prediction and is **alive** on discharge from hospital then
    - the increase indicator will be large and negative
    - the decrease indicator will be large and positive
- If the patient has a **high** mortality prediction and is **dead** on discharge from hospital then
    - the increase indicator will be small and positive
    - the decrease indicator will be small and negative

Catriona Haddow, Senior Information Analyst, ISD
September 2011

So, if the expected happens, that is, a patient expected to live lives, it has a small effect on both cumulative indicators pulling them slightly downwards. If a patient expected to die dies, this has a small effect on both indicators, pulling them slightly upwards.

However, if a patient expected to die lives, this has a much larger effect on both cumulative indicators, pulling them both downwards. A sequence of outcomes where more patients with high predicted mortality survive will cause the decrease indicator to signal– the sequence of outcomes is better than expected. In this situation, the cumulative increase indicator will usually reach zero, and because it is restricted to be above zero, it will remain there.

Similarly, if a patient expected to live dies, this has a big effect on both cumulative indicators, pulling them both upwards. A sequence of outcomes where more patients with low predicted mortality die will cause the increase indicator to signal– the sequence of outcomes is worse than expected. In this situation, the cumulative decrease indicator will usually reach zero, and because it is restricted to be below zero, it will remain there.

If either the cumulative increase or decrease indicators signal, they are reset to zero.

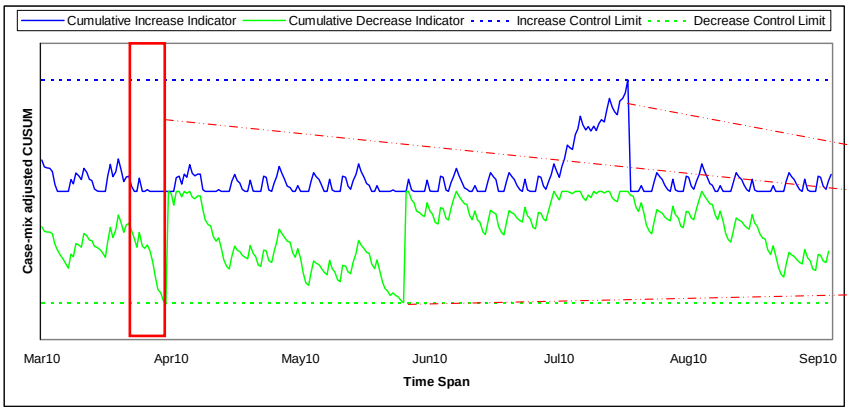
The cumulative increase indicator has been designed to signal when the odds of mortality are double that expected given the APACHE II mortality predictions.
The cumulative decrease indicator has been designed to signal when the odds of mortality are half that expected given the APACHE II mortality predictions.

Example report using dummy data

Example report containing dummy data

Any Hospital Intensive Care Unit	September 2010

1. Track Chart for Case-mix Adjusted Hospital Mortality



Increase indicator signal

The data for the period outlined in red is given below, and is displayed in the more detailed chart.

Decrease indicator signal

Summary table

	First date	Last date	Predicted mortality	Increase control limit	Decrease control limit
ANY ICU	01/03/2010	26/09/2010	34.73%	51.56%	21.01%

Table showing data for patients discharged during selected time period

Patient Number	Discharge Date	APACHE II mortality prediction	Hospital Outcome	Increase Indicator	Decrease Indicator	Cumulative Increase Indicator	Cumulative Decrease Indicator
1	23-Mar-10	49.80	Lived	-0.40	0.29	0.22	-1.58
2	26-Apr-10	56.4	Lived	-0.45	0.33	0.00	-1.91
3	27-Apr-10	60.2	Lived	-0.47	0.36	0.00	-2.27
4	29-Apr-10	-	Lived	-	-	-	-
5	29-Apr-10	15.5	Died	0.55	-0.61	0.55	-1.65
6	29-Apr-10	85.4	Lived	-0.62	0.56	0.00	-2.21
7	29-Apr-10	16.4	Lived	-0.15	0.09	0.00	-2.30
8	30-Apr-10	86.6	Died	0.07	-0.13	0.07	-2.17
9	01-May-10	40.5	Lived	-0.34	0.23	0.00	-2.40
10	01-May-10	73.6	Lived	-0.55	0.46	0.00	-2.86
11	01-May-10	88.8	Lived	-0.64	0.59	0.00	-3.44
12	02-May-10	30.1	-	-	-	-	-
13	03-May-10	81.2	Lived	-0.59	0.52	0.00	-3.96
14	04-May-10	26.00	Lived	-0.23	0.14	0.00	-4.10
15	05-May-10	53.20	Lived	-0.43	0.31	0.00	-4.41
16	05-May-10	27.60	Lived	-0.24	0.15	0.00	-4.56
17	07-May-10	25.60	Lived	-0.23	0.14	0.00	0.00

The cumulative increase indicator cannot go below 0

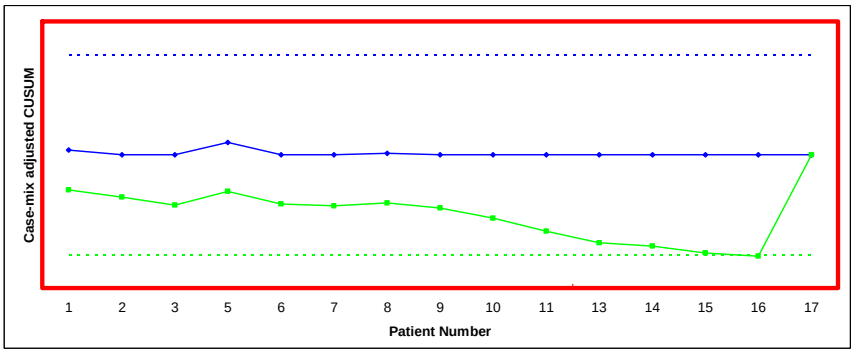
Excluded from CUSUM as Apache mortality prediction is not documented or not appropriate for this patient

Excluded from CUSUM as hospital outcome is not currently available for this patient

The decrease indicator signals here, indicating that the mortality rate is lower than expected given the Apache mortality predictions.

The cumulative decrease indicator has been reset to 0.

Detail of track chart for patients discharged during selected time period



Catriona Haddow, Senior Information Analyst, ISD
September 2011

CUSUM versus Standardised Mortality Ratio (SMR)

The CUSUM charts included in ICU monthly reports and the SMR funnel plots included in the SICSAG annual reports both measure outcomes taking consideration of APACHE II mortality prediction, however, the two methods are not the same. A unit with a signal on a CUSUM chart will not necessarily be an outlier in the annual SMR funnel chart. Conversely a unit that is an outlier in the annual SMR funnel chart may never have had a signal in its monthly CUSUM charts.
SMR funnel charts compare a unit's annual results against Scotland's. A short spell of increased mortality can make the CUSUM signal but not show in an annual SMR calculation. Higher mortality over a longer period would show in a top heavy CUSUM (where the increase indicator is generally nearer to the increase control limit than the decrease indicator is to the decrease control limit) and could result in a high SMR, even if there is no signal.

Also, SMRs are based on ultimate hospital outcome whereas CUSUM charts are based on hospital outcome. This is because CUSUM charts need to be timely and ultimate hospital outcomes take longer to be complete. As a result, units which transfer out a higher proportion of patients may be an outlier on SMR funnel plot when the CUSUM chart gave no reason for concern.

Appendix

ApMortProp = Mean of the APACHE II mortality predictions for the selected 300 patients

Increase indicator

If hospital outcome = dead:
Increase indicator = ln(2/ (1+ApMortProp)).

If hospital outcome = alive:
Increase indicator = ln(1/ (1+ApMortProp)).

Decrease indicator

If hospital outcome = dead:
Decrease indicator= ln(.5/ (1-.5*ApMortProp)).

If hospital outcome = dead:
Decrease indicator= ln(1/ (1-.5*ApMortProp)).

The increase control limit is set at 4.5 and the decrease control limit is set at -4.5. The increase indicator of the CUSUM chart tests the hypothesis that the odds of mortality have doubled against the null hypothesis that the odds of mortality have remained at the expected rate. The increase control limit is the point at which the cumulative evidence suggests that the null hypothesis should be rejected: the odds of mortality have changed.
Limits in CUSUM charts need to balance the risk of a series of outcomes signalling on the increase indicator through chance alone (a false alarm), and the risk that an unsatisfactory series of outcomes does not signal.
The ICU CUSUM charts have resulted in around 1 signal on the increase indicator each year.

Reference

David A Cook, MBBS; Stefan H. Steiner, PhD; Richard J. Cook, PhD; Vern T. Farewell, PhD; Anthony R. Morton, MD Monitoring the evolutionary process of quality: Risk adjusted charting to track outcomes in intensive care; Crit Care Med 2003 Vol 31 No 6

Catriona Haddow, Senior Information Analyst, ISD
September 2011