Seismic Activity Rate Tracker

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Abstract

Strong changes in the rate of seismic activity in mines are mainly due to a step loading caused by production blasting or by larger seismic events. However, seismic activity may also build-up gradually. Regardless, as the rate of seismic activity increases so does the likelihood that one of these events may be larger and damaging. This note presents a methodology to test the significance of the activity rate change. It can be applied to test the level of seismic activity after production blasts or after larger seismic events, or it can run continuously to map areas of elevated hazard.

The step loading caused by production blasting or by larger seismic events generates aftershocks clustered in space and in time. As the rate of seismic activity increases so does the likelihood that one of these events may be larger and damaging. The short term hazard associated with aftershock activity can be estimated by applying the rate function, e.g. the Omori or the stretched exponential, and the size distribution of seismicity for the given area to clusters of events, see *Mendecki* (2016) section 5.3. While the size distribution is relatively constant in the intermediate term, i.e. weeks to months, the rate function varies dramatically over the minutes and hours after the step loading and, for practical reasons, its parameters need to be estimated in real time. However, the inversion procedure to estimate these parameters is sensitive to temporal fluctuations in seismic activity and is not always suitable to be run in an automatic mode. One way to check if, after the production blasts, the elevated seismic activity has returned to an acceptable level is to test the null hypothesis of no change. The reference, or the acceptable level of seismic activity, can be defined a priori, or it can be taken as an average activity rate before step loading.

To detect changes in seismic activity rates in two different time intervals, Δt_1 and Δt_2, within the same volume of rock one can count the respective number of recorded events above a certain potency. If the time intervals are equal and relatively long and the observed number of events are significantly different, then a statement can be made about the relative change. However, the associated uncertainty increases as the time intervals get shorter and as the difference in the event counts becomes smaller. The situation is even more difficult if the time intervals are not equal.

Under normal conditions the event counts can be considered as outcomes of a Poisson process, therefore, their occurrence can be very irregular. The probability that the seismicity rate in two different time intervals, increased by more than k times is

$$\Pr\left(\frac{\lambda_2}{\lambda_1} > k\right) = \frac{1}{N_2! N_1!} \int_0^\infty x^{N_1} \exp\left(-x\right) \Gamma\left(N_2 + 1, kx\frac{\Delta t_2}{\Delta t_1}\right) dx, \tag{1}$$

where $\lambda_1 = N\left(\geq \log P\right)/\Delta t_1$ and $\lambda_2 = N\left(\geq \log P\right)/\Delta t_2$ are the activity rates during Δt_1 and Δt_2 respectively, and $\Gamma\left(N_2+1, kx\Delta t_2/\Delta t_1\right) = \int_{kx\Delta t_1/\Delta t_2}^{\infty} \exp\left(-t\right) t^{N_2+1} dt$ is the upper incomplete Gamma function (*Mendecki*, 2016 section 4.2).

Equation (1) can be used to track changes of seismic activity rate assuming that the reference activity rate, λ_1, for the volume of interest is defined. The reference activity rate can be estimated by taking an average over periods of time that satisfy the following criteria: (a) they are outside the influence of blasting, (b) there were no larger events and (c) there was normal production activity and people working in the area. It is expected that the coefficient of variation of the data selected to estimate the reference activity will not be far from 1.0, so the reference activity can be considered to be close to Poissonian.

Having established a reference activity rate one can start calculating probabilities of activity rate change (equation 1) in real-time and display traffic lights based on calibrated probability thresholds, e.g:

Traffic Light State =

if $\Pr\left(\lambda_2/\lambda_1 > 1\right) \leq 0.5$

if $0.5 < \Pr\left(\lambda_2/\lambda_1 > 1\right) < 0.75$

if $\Pr\left(\lambda_2/\lambda_1 > 1\right) \geq 0.75$

Figure 1: An illustration of probabilities given by equation (1) via the traffic light system.

Calculations can be based on the following data provided by the seismic monitoring system.

1. Seismic event activity, i.e. the number of recorded associated seismic events $\geq \log P_{min}$.
2. Trigger activity by an individual or group of seismic stations, i.e. the number of times the selected seismic site(s) triggered with ground motion $\geq \log PGV_{min}$.
3. Activity from Ground Motion Parameters (GMP) extracted from a stream of continuous data provided in real time by the selected seismic sites. Here events are declared every time a given GMP exceeds a threshold. The preferred GMP are the Peak Ground Velocity, PGV, and the Cumulative Absolute Displacement, CAD. CAD is defined as the integral of the absolute value of a velocity time series, $CAD = \int_0^{t_d} |\mathrm{v}(t)| dt$, which has units of displacement. It is the area under the absolute velocity time history and is more sensitive to lower frequency ground motion, i.e. to larger displacements.

Note that data on the activity of associated seismic events requires quality controlled seismological processing, i.e. location and source parameters, and therefore are delayed. Moreover, to provide a reasonable location the seismic system accepts events that associated with at least 5 stations, and this removes a great number of small events from the analysis. Data on the activity of associated events also under-reports on immediate aftershocks, some of them buried in the coda of the main shock. Data on triggers and GMP do not require processing, are reliable, numerous and available in real time and therefore provide an important supplement to the analysis.

Figure 2 shows 4 snapshots of seismic activity, 2, 4, 5 and 5.5 hours after the development blast. The dotted blue lines show the cumulative number of seismic events with $\log P \geq -3.0$ recorded within the polygon around the tunnel. The cumulative seismic potency after the blast is shown by the grey dotted lines scaled so that at any stage they match the cumulative number of events. The cyan dots mark the distance of each event from the location of the blast. The dotted black line show the cumulative number of triggers and dotted red the cumulative CAD. The gray histogram at the bottom of the triggers and CAD plot shows the activity rate of triggers per minute.

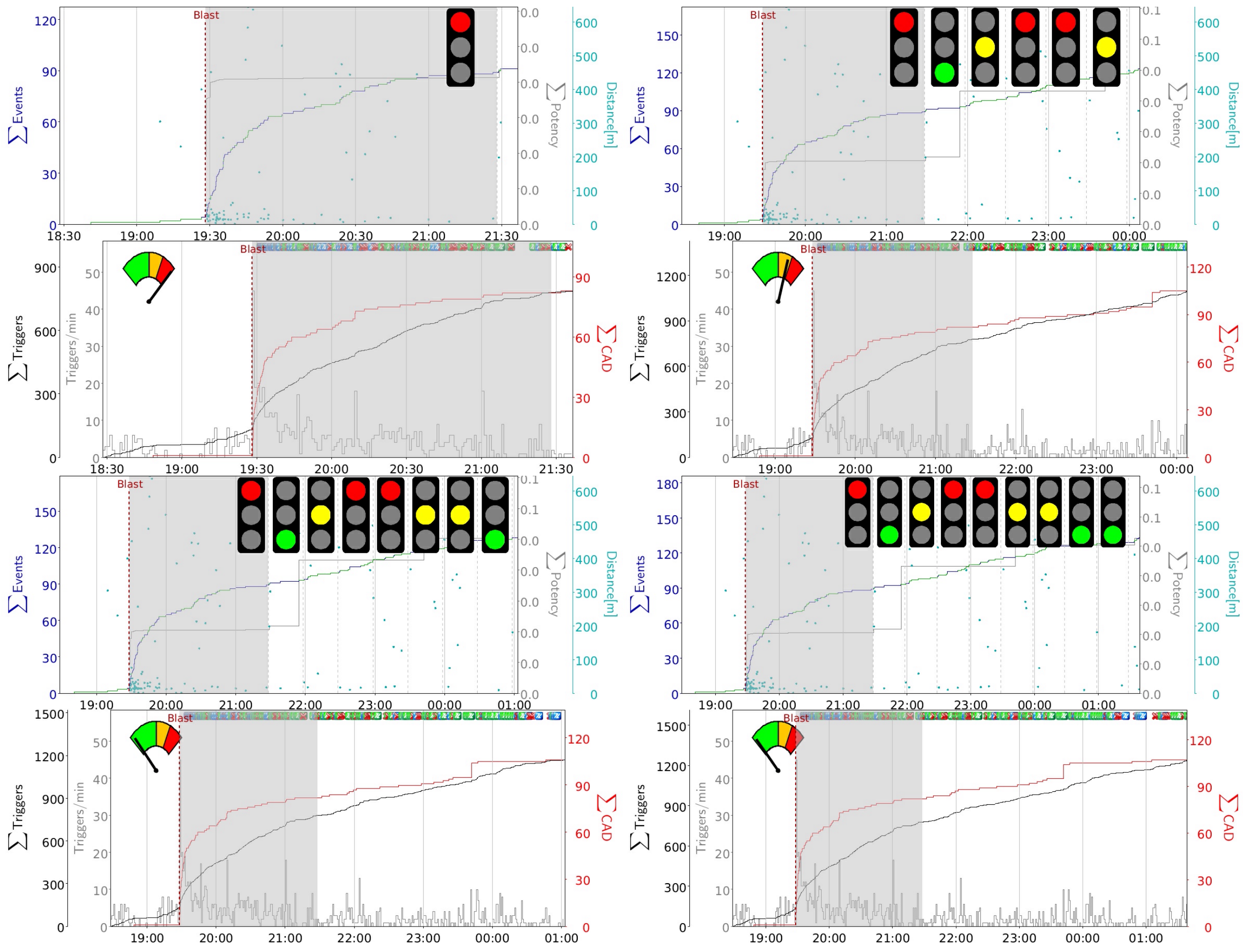

Figure 2: Snapshots of the seismic response to blasting.

References

Mendecki, A. J. (2016), *Mine Seismology Reference Book: Seismic Hazard*, 1 ed., Institute of Mine Seismology, ISBN 978-0-9942943-0-2, www.imseismology.org/msrb/. 1