Institute of Mine Seismology

Short Term Activity Tracker (STAT) Guide

1 Overview

STAT is a tool that is integrated into IMS Ticker3D and is used by mines as part of the reentry protocol. STAT monitors the seismic activity rate in user defined areas of the mine and gives the information in a user friendly way (in terms of green, yellow, or red traffic lights) to indicate current activity rate levels compared to a calibrated historical level. It is not necessarily a good idea to base the entire protocol on STAT as this only contains information about seismicity. Other factors, such as ventilation after blasting, safety etc should also be taken into account before people are sent back into mining areas.

STAT is based on the principle that during times not influenced by blasting and large events, seismicity is expected to occur as a sequence of independent occurrences of seismic events at a fixed rate. The Poisson Distribution is a good representation of such a process, which models these occurrences per fixed time interval as

$$\Pr(k \text{ events in interval}) = \exp(-\lambda)\lambda^k/k!$$

where the Poisson Distribution then has both a mean and variance of λ, the expected rate of events per time interval. More information about this distribution can be found on Wikipedia (Poisson). There are two examples on this wiki page that is important for our purposes and they are highlighted here:

1. *On a particular river, overflow floods occur once every 100 years on average. Calculate the probability of k = 0, 1, 2, 3, 4, 5 or 6 overflow floods in a 100-year interval, assuming the Poisson model is appropriate*.
   In mining terms we can express the above example as follows: If a certain area of the mine experiences one seismic event per hour on average, then calculate the probability that the same area will experience 0, 1, 2, 3 .... event(s) in the next hour. Note that in this example we assume that 1 event per hour occurs at random.

2. *The number of magnitude 5 earthquakes per year in a country may not follow a Poisson distribution if one large earthquake increases the probability of aftershocks of similar magnitude.*
   In this example the number of events following the main shock does not follow a Poissonian distribution as they are mainly driven by the main shock. Therefore we cannot use the Poisson distribution to calculate the probabilities that X number of aftershocks will occur within the next hour. Similarly, events following blasts may also not occur at random as they can mainly be driven by the blast.

In the two examples above we highlight the fact that for STAT we need the occurrences of events to be independent and their probability of occurrence to be proportional to the duration of the time interval under consideration. Also, these examples are phrased such that it attempts to calculate current occurrence rates based on historical reference rates. However in mining cases we already know the current rate. Therefore we rephrase the two examples above:

1. We are currently experiencing 2 events per hour in a particular area of the mine. Given that we usually experience 1 event per hour in the same area, what is the probability that what we are now experiencing is higher than the background?

2. We have experienced 10 events following the large event (or blast) that occurred an hour ago. Given that we usually experience 1 event per hour in the same area, what is the probability that what we are experiencing now is higher than the background?

The two rephrased examples act as a good basis for understanding the logic behind STAT. More theoretical details about STAT can be found in *Mine Seismology Reference Book, Mendecki 2016*. This manual assumes that the user has prior knowledge in using Ticker3D and will only cover the basics in using STAT. The details in creating, calibrating and using STAT in the software are described here and references to YouTube videos are given for simple tasks.

2 Licenses

The STAT tool in IMS Ticker3D is licensed and therefore it is not available to all users. Users have two options when choosing STAT licenses:

1. A single user network license. This implies that only one user at a time can use STAT by booking a network license similar to other IMS software.

2. An unlimited user site license. This means that any number of IMS Ticker3D users on the same seismic network ID can use STAT and no network license booking is required.

In most cases the second site license option is preferred as this tool is intended for multiple user levels. For example, geotechnical engineers will use the more advanced STAT features whereas personnel in mine control rooms will use the more simple features by just looking at STAT ratings for different areas of the mine.

3 Defining a STAT Area

3.1 Creating a new area for STAT

A STAT area is a volumetric box that is used as a spatial filter for seismic events. All seismic events locating outside the area are not used for calculating STAT ratings. A user may also choose to have multiple STAT areas defined in Ticker3D and therefore are not limited to only being one. However, having multiple areas implies that the volumes may become smaller and in a lot of cases this is not advisable. Details will be described in the next section. Follow this link (Create a STAT area) to see how a STAT area is created. In this example the area covers the whole mine, but smaller areas can also be used.

3.2 Testing if an area is viable for STAT

It can be a challenging task to decide which areas to monitor with STAT. Ideally we advise users to create one area that covers the whole mine since we consider the whole mine as one seismogenic region. However, this may not always be practical as in most cases reentry into an area that covers the whole mine is not cost effective and therefore smaller areas needs to be defined. From a miner's perspective we can understand that he would like areas to be as small as possible because this is the most cost effective scenario. This is also not ideal as multiple factors must be taken into account such as:

- seismic system coverage of the area,
- if a large event occurs in the area, the source size should not be bigger than the dimensions of the area,
- the area must be seismically independent from another area. For example, if a large event/blast occurs somewhere else on the mine, is there a seismic response in the area,
- if two areas overlap, how to treat a rating if one area has a high rating and the other has a low rating.

To quantify if an area is a viable candidate for STAT this link (Testing Area) shows a tool that was developed to cover a few of the points listed above. The numbers below agrees with tabs highlighted in the video.

1. **Blast response (Inside Area)**: This shows the individual- (lower plot) and stacked (upper plot) versions of the seismic response following blasts that occurred inside the area. This is used to get an idea of how seismically active this area is in response to blasting. Large events are indicated by yellow or red dots on this plot. This can also be used to measure the seismic response to large events that occurred inside the area.

2. **Blast Response (Outside Area)**: This plot shows the seismic response to blasts that occurred outside the area. Therefore if there is a strong seismic response following blasts that occurred outside the area, it may be an indicator that this area is not seismically independent from other areas. Ideally we do not want any seismic response in this area if blasted outside.

3. **Size Distribution**: This plot is simply used to determine the number of seismic events that occurred in the area for a certain period. Ideally we want enough events to occur in the area to calculate a reasonable reference event rate. However, this is not a requirement as areas that has a low seismic activity rate can also be used for STAT.

4. **System Sensitivity**: These two plots shows the system sensitivity and location accuracy inside the area. This part is important to quantify the system coverage since poor system coverage will significantly impact the STAT ratings. One can imagine that areas with no coverage cannot be used in STAT as seismic events cannot be reliably recorded in the area.

Once the user is satisfied with the performance of the area the next step is to calibrate the area to find a reference activity rate.

3.3 Calibrating a STAT area

Section 1 of this manual describes the importance of a dataset to be Poissonian for the STAT tool to work properly. However, in most cases the seismic activity rate in certain areas of the mine does not follow this distribution, making it very difficult to derive a meaningful reference seismic activity rate for the area. The calibration tool in Ticker3D uses advanced methods to separate seismic response to blasting/large events from seismic events that occur at random by asking the user a few questions. The calibration can be done manually or automatically. In the latter case a few assumptions are made to determine the reference activity rate. The sections below describes how to do both cases.

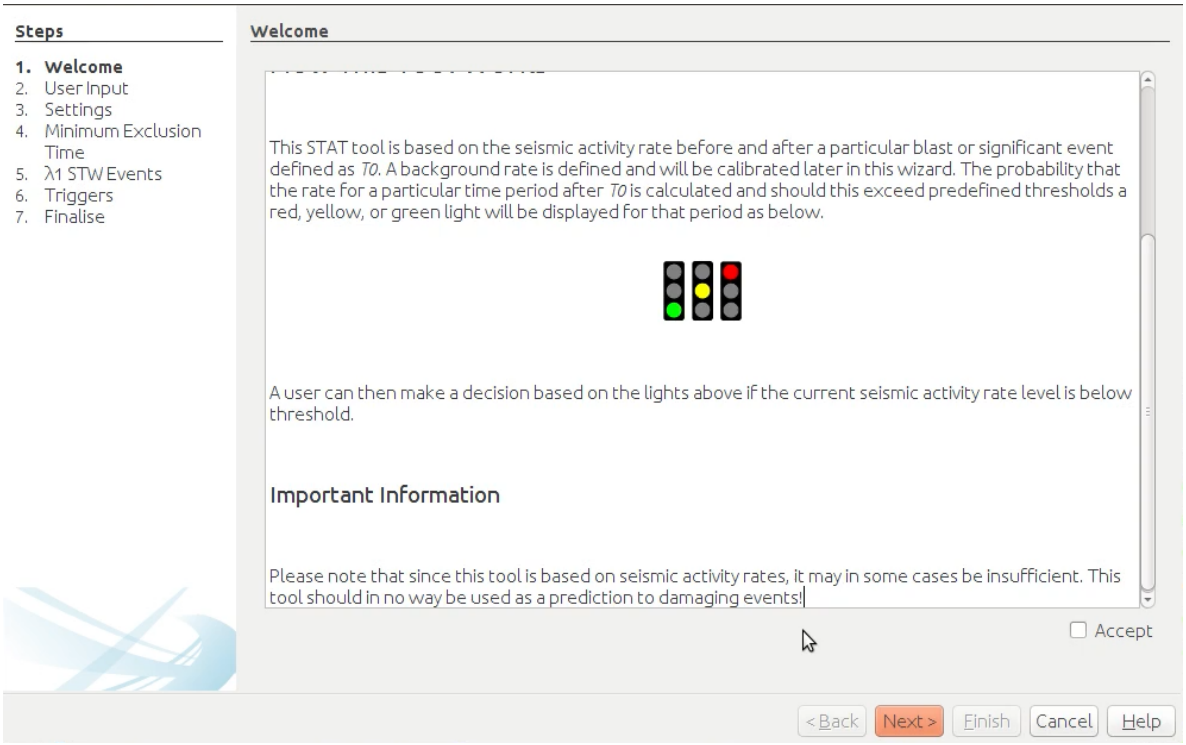
Note that a calibration is usually done once by advanced users. Most end users will never perform a STAT calibration. We do recommend that a calibration be done one every few months as conditions in areas may change and the reference activity rate values may change over time.

The STAT calibration tools that are included in Ticker3D provides a simple tool to help eliminate the effect of blasts and large events from the data on which the reference/background activity rate will be based. For a more advanced calibration (not covered by Ticker3D's tools) that involves other sources of information, IMS can assist with the process.

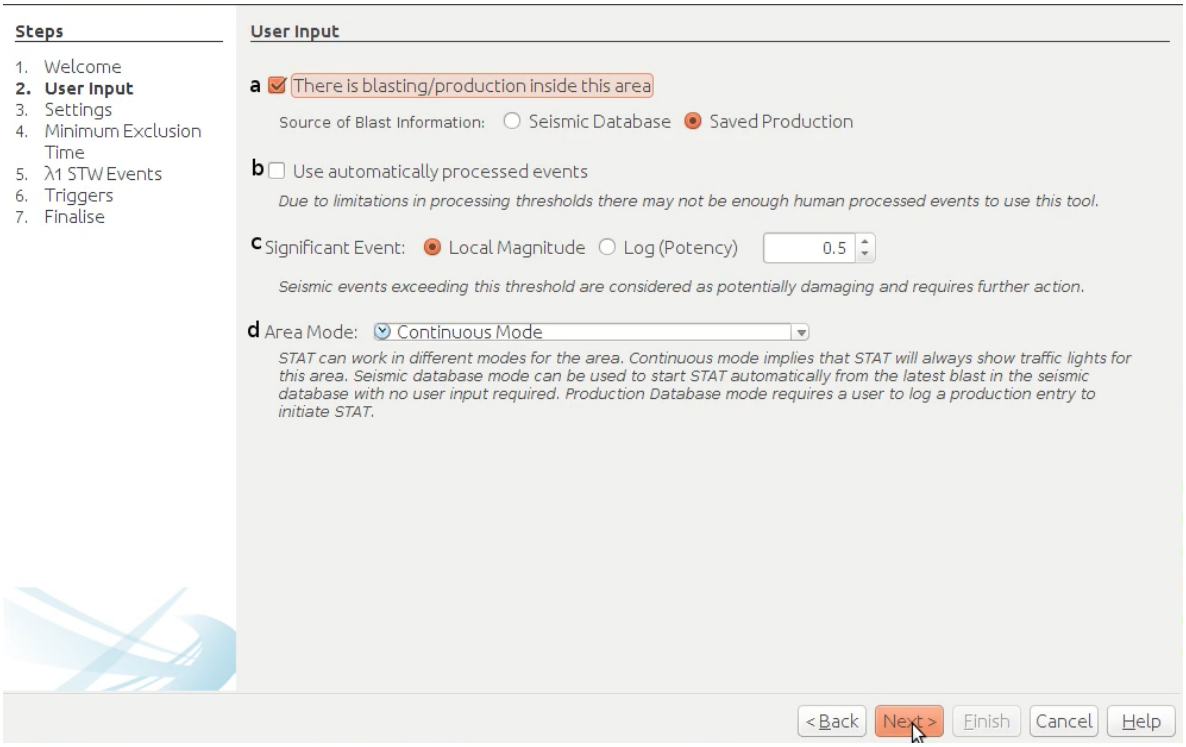
3.3.1 Manual calibration of a STAT area

Follow the steps as shown in this link (Manual Calibration) for a manual calibration.

1. Welcome: Some basic information about STAT is given.



2. User Input:



(a) The user must indicate if there are blasting in the area. If there is blasting, identify the source of production information should the algorithm use. If the users keeps an up to date production log this can be used. Alternatively blasts from the seismic database will be used for the calibration.

(b) For mines that do not process all events manually and with low seismic activity rates, automatically processed events can be used. However, this is not recommended as source parameters of these events are less trustworthy.

(c) The significant event size that the mine considers as potentially damaging in terms of local magnitude or log (Potency).

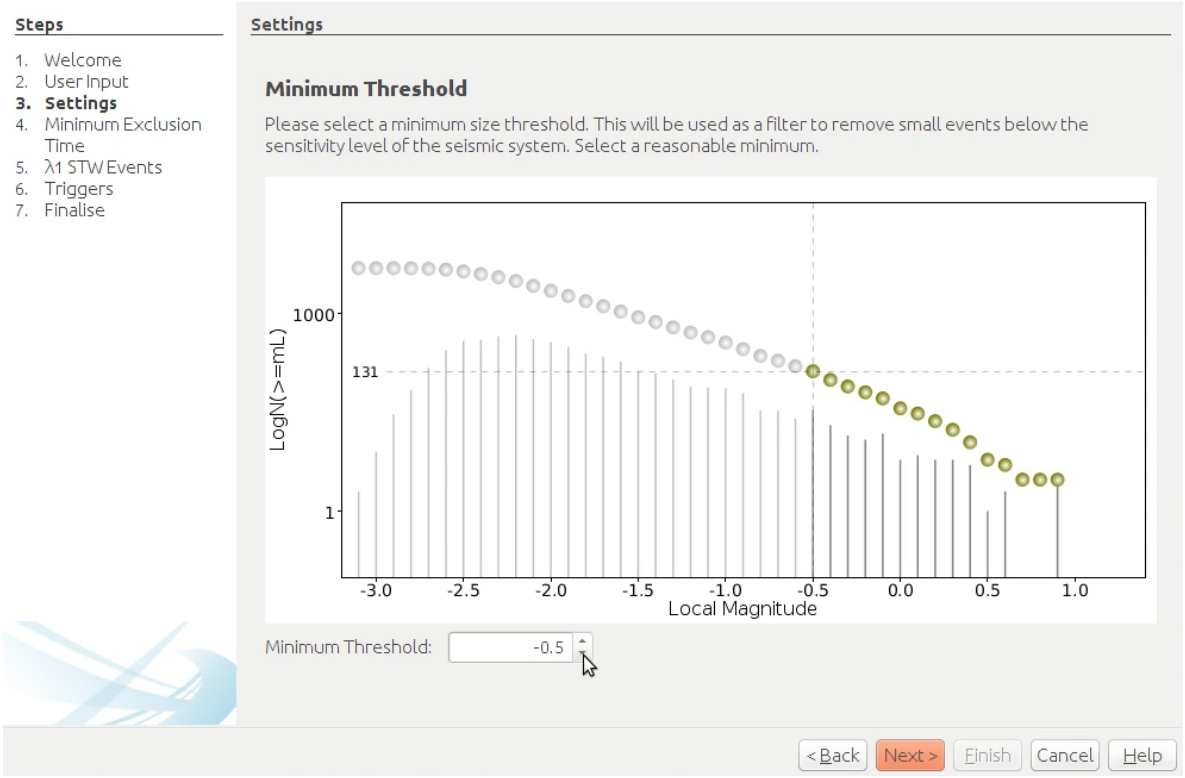
(d) Three modes are supported:

i. **Continuous mode**: Traffic lights will always be shown and is aligned to the nearest 30 minutes. Typically areas that does not have blasting will use this.

ii. **Blast mode**: the latest blast will automatically be detected in the seismic database and used as reference for STAT. Time will be aligned with this event.

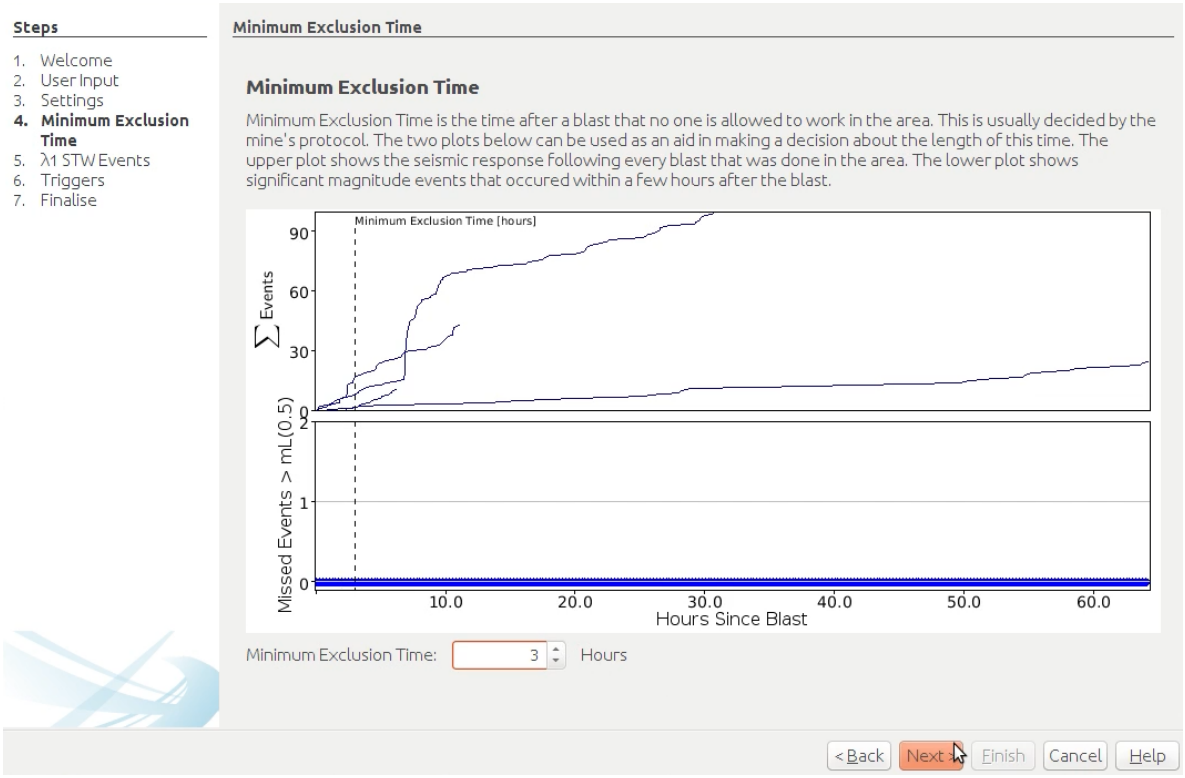
iii. **Production mode**: If a user keeps an up to date production log, then by entering a new production entry, STAT will be triggered. Time will be aligned with this log entry.

3. Minimum threshold:



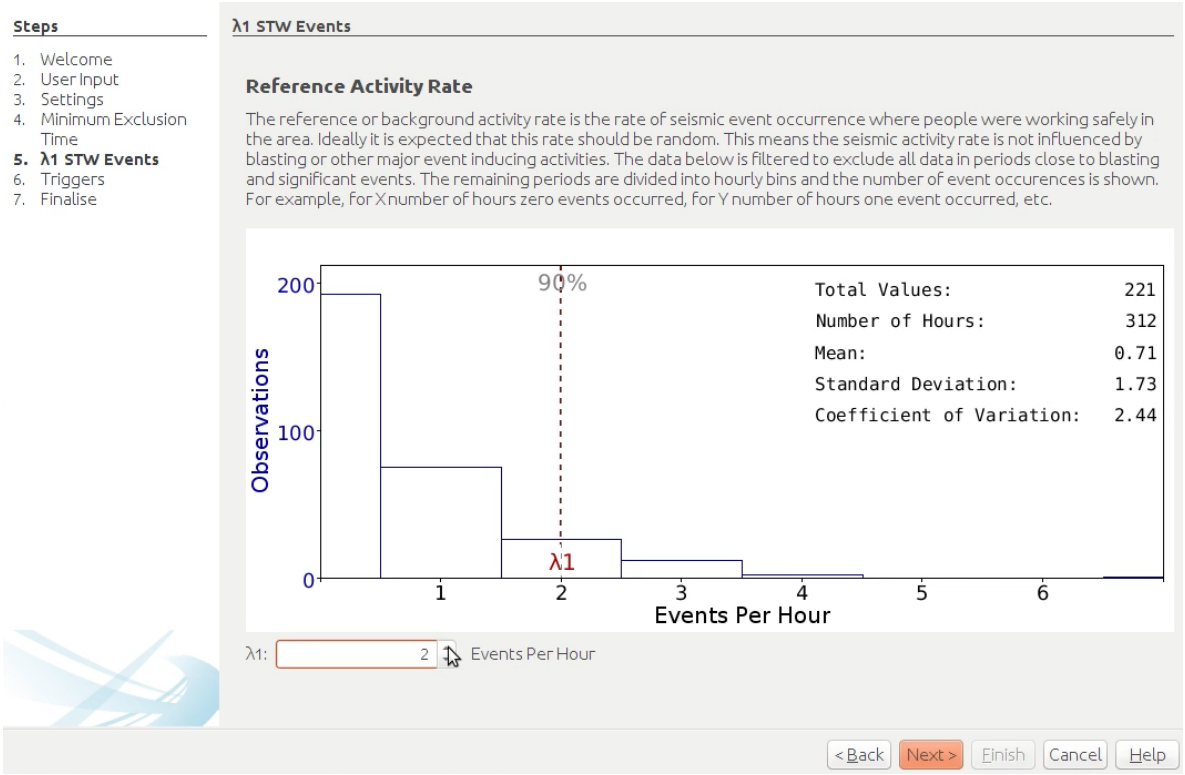
(a) The minimum event size threshold that will be used to filter events in the area. Users should choose values close to the system sensitivity in the area. Normally this is near or to the right of the plateau of the distribution.

4. Minimum exclusion time:



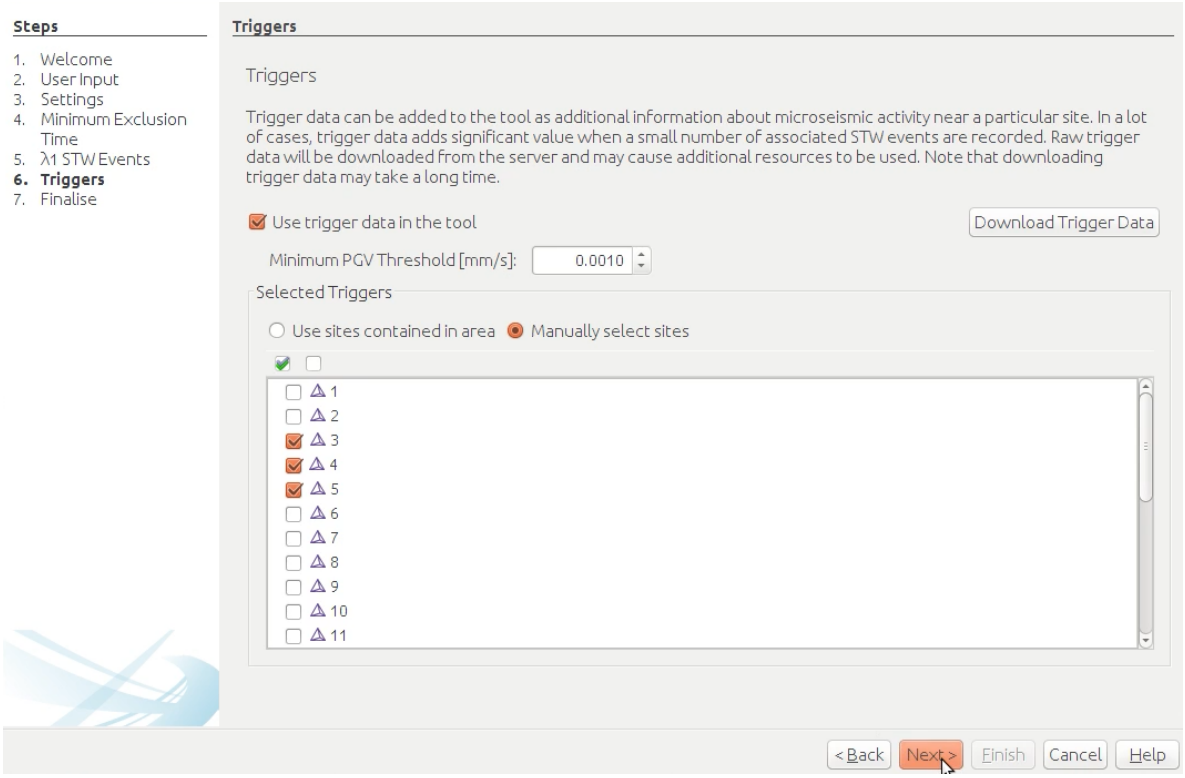
(a) This is the time after blasting where no person is allowed to work in the area. The calibration tool will also use this time to remove time periods where seismic activity may not be random, ie. it may be triggered by blasting.

5. Reference activity rate:



(a) Choosing the reference activity rate is probably the most important part of the calibration. The reference or background activity rate is the rate of seismic event occurrence of times when people were working safely in the area. Ideally it is expected that this rate should be Poissonian. This means the seismic activity rate is not influenced by blasting or other major event inducing activities such that it adheres to the Poisson distribution. The data is filtered to exclude all data in periods close to blasting and significant events. The remaining periods are divided into hourly bins and the number of event occurrences is shown. For example, for X number of hours zero events occurred, for Y number of hours one event occurred, etc. Usually we recommend that a reference rate close to the 90% mark indicated on the plot is chosen.

6. Triggers:

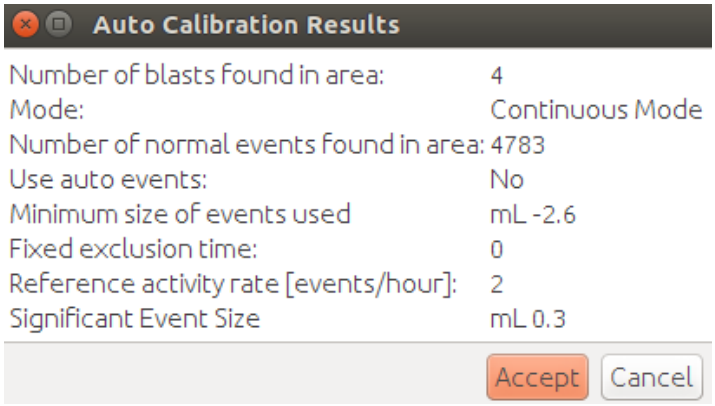


(a) Individual site trigger information can also be added in this tool. However, it does not influence the STAT rating. It acts as additional information (independent of association) that the user may use for a particular STAT rating.

3.3.2 Automatic calibration

Follow this link (Auto Calibration) to see how automatic calibrations are done. A few assumptions are made using the automatic calibration tool. For example:

- Automatic events are not used.
- Areas are always set to Continuous Mode.
- A fixed exclusion time of 0 is used.



The results of the calibration will be shown and a user may choose to accept the output. In most cases the automatic calibration tool performs as well as themanual calibration tool.

4 Using STAT

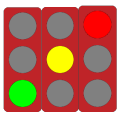
The previous section explains how a calibration is done for a STAT area. Usually a calibration is done once off by advanced users. The calibrated areas must be uploaded to the server for it to be available to all users. End users may choose to have 2 views of STAT for a particular area. Both will be discussed in the next sections. This link (Live STAT) shows a video of STAT for a running live for a particular mine where time is accelerated.

As mentioned in the Overview section, STAT gives a rating based on the probability that the current seismic activity rate is exceptionally high, given a (assumed to be Poissonian) reference activity rate that was calibrated for before. These probabilities are represented to the user in terms of traffic lights:

$$\text{Traffic Light State} = \begin{cases} \text{if} & \Pr\left(\lambda_2/\lambda_1 > 1\right) \leq 0.5 \\ \text{if} & 0.5 < \Pr\left(\lambda_2/\lambda_1 > 1\right) < 0.75 \\ \text{if} & \Pr\left(\lambda_2/\lambda_1 > 1\right) \geq 0.75 \end{cases}$$

where λ_1 is the calibrated reference activity rate and λ_2 is the current activity rate. Note that activity rate are only based on event numbers, while event size is not taken into account. For example: a local magnitude -2.0 event carries the same weight in

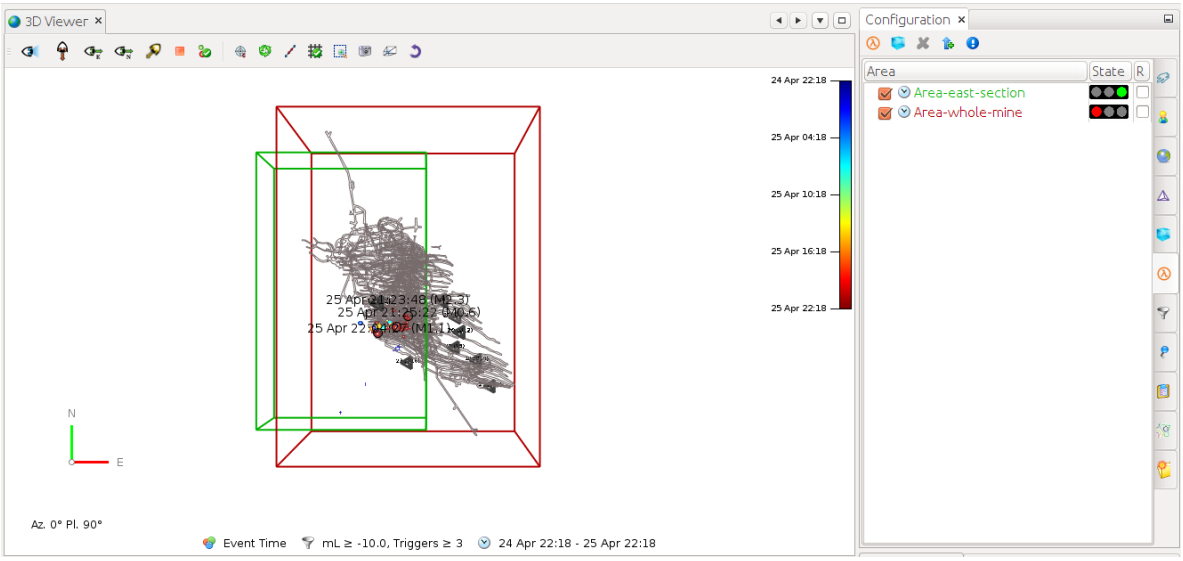
STAT as a local magnitude +2.0 event. For this reason another traffic light state was introduced:



In this example the borders of the traffic lights are highlighted in red to indicate to the user that a large seismic event occurred in the preceeding hours. The green, yellow and red lights are still valid to show the state of the activity rate.

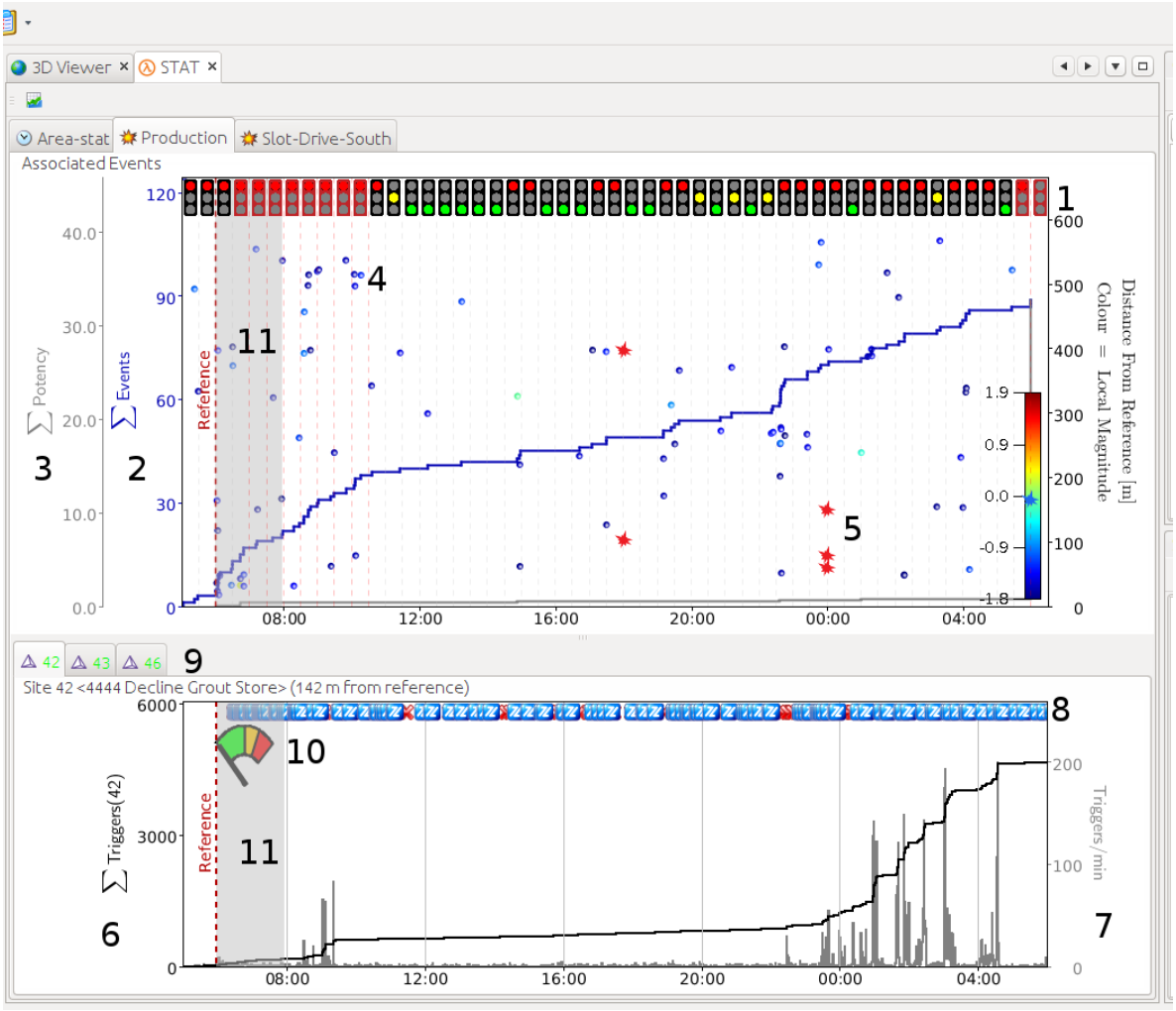
STAT will show a traffic light once every 30 minutes. The traffic light state will indicate the rating for a period of one hour. In special cases these time ranges can be customised, but for that please contact IMS at support@imseismology.org.

4.1 Simple view of STAT



The simple view of STAT shows each calibrated STAT area in the Configuration window together with its current rating. It also shows the area coloured by the same rating in the 3D viewer. Typically this view will be used by most users, for example in a mine control room.

4.2 Advanced View of STAT



The advanced view shows a plot of the seismic event history for each area that was calibrated. In the example above a large seismic event was recorded at 21:25 and triggered a series of aftershocks. Features of the plot are described:

1. Traffic lights are an indicator of the probability that the activity rate for that period is higher than background. Note that some traffic lights has a red border indicating a large seismic event was recorded in that period.

2. $\sum$ Events: A cumulative trend of the number of events that were recorded.

3. $\sum$Potency: A cumulative trend of the seismic potency of each event that was recorded.
4. Spheres: these are events that are coloured according to a user specified parameter and indicated the distance from the center of the area. Alternatively, if the area is in blast mode it will indicate the distance from the recorded blast. The color legend corresponds to the colour of the spheres.
5. Red and blue blast signs: indicates production entries.
6. $\sum$Triggers: A cumulative trend of the number of triggers for one particular site.
7. Triggers/min: shows the number of triggers in one minute interval for a particular site.
8. Event icons: indicated all seismic events into which the particular site was associated.
9. Sites that area associated to this area
10. A visual indicator that shows the probability that a particular site is experiencing a trigger rate as in previous page.
11. A gray band indicating the fixed exclusion time after a reference that people are not allowed back into the area. This value is specified by the user.

5 Mine Control Table

The Mine Control Table (also known as the Trigger And Response Plan - TARP) is intended for users running Ticker3D in mine control rooms. Mines can often have a complicated set of rules that must be applied by people working in control rooms. Below are a few examples:

- Event exceeding mL 0.0 is recorded - contact Shift Supervisor
- Event exceeding mL 1.0 is recorded - contact Shift Supervisor and Geotechnical Engineer
- Seismic System health is less than 75% - Contact technician and IMS engineer
- Shaking is reported in a certain work area - evacuate the area and establish barricades

The examples above are just a few of a long list of rules that must be strictly followed by control room personnel. TARP was implemented in Ticker3D to simply the thinking process and display the steps that must be followed by control room personnel when a particular rule is passed.

TARP consists of two phases namely:

1. Defining rules that define the test that should be applied (for example an event exceeding mL1.0 is recorded) and the steps that should be followed if the rule is passed. Usually these rules are defined and maintained by Geotechnical Engineers.
2. The TARP table that is monitored by control room personnel. As soon as the Ticker3D software detects that a rule's conditions are not passed, then an entry is automatically added in the TARP table and the steps that should be followed by control room users are outlined.

Currently there exists a few rules that can be defined in the software. These rules are seismic event related, STAT related or seismic system related. There also exists a custom rule that is non-seismic related. Should any mine require additional rules they can contact IMS to implement the new rule.

5.1 Defining a TARP Rule

Follow this link (Define TARP Rules) to see how automatic calibrations are done. This example shows how two rules are created namely:

1. an event passing a filter is recorded (in this case the filter was set up to include events above mL1.0) and
2. a STAT area experiencing a red traffic light.

All rules have a default configuration namely:

- a rule name
- the rule hazard level
- a priority (the entries in the TARP table is sorted according to priority)
- primary response
- secondary response

Additionally each rule has custom configuration (for example, the filter used to define event rules). Once the rules are defined, it is uploaded to the server and all users will have this. Some customizations to the table headers can be made via the Con Editor in IMS Software.

5.2 TARP Table For Control Room Users

This link (Using TARP) shows an example where a large event was recorded and subsequently a STAT area went into a red state. Note that the role of the control room user is to monitor this table and confirm entries after completing the assigned responses for each entry. The responses are logged in a special database on the seismic server which can later be viewed to check if an entry was acted upon.