

Using modern high performance drones for monitoring and risk review of an asbestos tailings dump.

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1. Abstract

BluBastet Fly uses a high performance professional drone equipped with a choice of specialized (optical, near infra-red, etc.) sensors and software to perform terrain data acquisition and analyses.

This paper shows the specific applications this technology provides to the environmental rehabilitation project of a large asbestos tailings dump at the former Balangero Mine in N-W Italy. Linking BluBastet Fly to a responsive Risk Evaluation platform like ORE (©Riskope **NB: a paper is presented to this same conference on ORE**) brings significant advantages to mining end-users, whether they are mining managers, tailings stewards or other key stakeholders. Preliminary off-line studies performed with ORE, using extant data, deliver initial estimates of: probability of occurrence of various failure modes, consequences of those failure modes, risk analysis based on extant data, preliminary alert thresholds, show results that allow the setup of emergency procedures.

Thanks to BluBastet Fly's technology it is possible not only to confirm and gradually calibrate extant data, old reports, but also to rather inexpensively gather high resolution imagery and perform quantitative analyses and volumes calculation on the terrain. The last capability is of particular interest when in presence of mass movements and when in the need to verify their volumes, whether they are man-made (construction) or natural (slides, displacements, erosion). High performance drones' capabilities make it possible to compare measured values vs. preliminary estimate and operate meaningful calibrations, check of alert thresholds, emerging crises scanning, updates of data (variability) and, if necessary, update probabilities and all the other significant hazards and risk parameters to understand where projects stand in term of mitigations at discrete and up to almost real-time pace.

2. Introduction

The Balangero asbestos open pit mine, located 35 km NW of Torino (Italy), was the largest operation of this kind in Western Europe. In 1918, it was foreseen that the mine would extract 26,000 m³ rock per year, but in 1961 the mine extracted 1.3 Mm³ rock. In 1966 a new mill with a capacity of 25,000 t fibres per annum was installed. The dry tailings were lifted by a conveyor belt from the mill, then through a tunnel to the opposite side of a hill, and then dumped over a natural slope with an approximate angle of 25 degrees from the altitude of about 830 m a.s.l. to the bottom of the valley at 580 m a.s.l.. As the dumping proceeded, a total surface of about 250.000 m² was progressively covered with tailings thicknesses going from few meters to an estimated maximum of 60 – 80 m.

Risk Based Decision Making (RBDM) was used through the feasibility, design and construction follow-up of the environmental restoration of the 60Mm³ dry asbestos Balangero's tailings dump (Oboni et Al., 1997, 1998, Bruce & Oboni, 2000). Risk Based Decision Making (RBDM) was used by the winning project of an international competitive bid at each and every step of the design which started in the year 2000.



Fig. 1 The Balangero asbestos tailings dump before rehabilitation: 800 m wide, 200–250 m high, slopes between 35 and 45 degrees and an estimated volume of 50-60 Mm³.

The project had several interesting problems related to environmental management, such as dusting and active instabilities. RBDM showed that using innovative and unusual solutions like, for example, an aerial tramway instead of classic hauling would allow reducing dusting and project's carbon footprint meanwhile bringing an income (selling electricity produced while braking the downhill loads) and

reducing general human health risks. Overall, the integration of hydraulics, geotechnique, pedology and risk management led to a well balanced and sustainable winning project based on risk-based decision making from its inception.

3. The restoration project's alternatives selection

During the pre-feasibility phase of the bid winning restoration project a wide array of design alternatives were carefully analyzed and compared. Risks were used to discriminate alternatives and were carefully evaluated at each specific phase of the project life (Oboni, 2006, Oboni et Al. 2001, Oboni & Oboni, 2004). Designs based on shear compliance to codes or recommendations may quite significantly differ from Risk Based Decision Making (RBDM) ones. Differences may go as deep as choosing different material hauling systems, different drainage patterns, etc. Furthermore alternatives which are perfectly code-compliant and require the same investments and maintenance may expose the owner to totally different levels of risk all along their expected life.



Fig. 2 Various phases of the environmental rehabilitation work.

At Balangero, material hauling, i.e. 250.000 m³ of excavated material, had, for example, numerous possible alternatives including hauling trucks, cable car and even fluidized mud via a gravity pipe on the slope. The specific risk profile of each one of these alternatives was very different in terms of duration of works, air pollution, asbestos dusting, energy consumption (the cable car allowed to produce energy while doing the job) and finally carbon footprint.

The choice of the slope stabilisation method can also be conducted by optimising all the key aspects involved in the final decision: new geometry of the crest, number and gradient of the runoff collection berms, vertical distance between berms along the slope, size of the berms.

RBDM for Reclamation Projects requires robust and simple tools for choosing among alternatives at each and every step of a project life encompassing conceptual design, construction maintenance and then necessary performance monitoring and evaluations before reaching the end of its expected life.

The method allowing this type of comparison was specifically developed for this project and then formalised under the name CDA/ESM (F. Oboni, C. Oboni, 2007), today a subset of the Optimum Risk Estimates methodology summarized in a section further down in this paper (Oboni, Oboni, 2016). ORE and CDA/ESM have been used extensively, on projects all over the world, to compare alternatives considering risks and uncertainties from cradle to grave.

4. Example of BluBastet Fly capabilities applied to Balangero

A monitoring mission was organized in February 2016 with the purpose of checking the present conditions of the slopes and to update the quantitative risk assessment. Data was acquired with high resolution aerial images in a series of flights covering a total area of 0.7595 km² (0.2934 sq.mi.= 187.766 acres) with the following parameters:

- Images detected: 168
- Ground Sample Distance (GSD): 4,67 cm/1.84 in
- Ground Control Points (GCPs): 13
- Mean RMS Error: 0,03 m

The methods applied to the flight data/imagery are based on mathematical functions and empirical scientific formulas, published in related professional scientific literature, delivering information, statistical analysis and visualisation of topography, water/solids flows, drainage patterns and erosion, slope modelling (avalanche & debris flow paths), tension cracks, volumes differentials, sun exposure and related parameters, vegetation (cadastre, stem volume, etc).

NIR (near infra-red camera) is available as well as Multi-spectral camera & thermal camera are available for special cases.

Figure 3 below shows an oblique view of the topography of the rehabilitated slopes. This image was taken after the slopes and drainage network had endured a particularly severe series of meteorological severe events including a so called “Medicane” (a Mediterranean Hurricane, a type of severe storm becoming more and more frequent with climatic changes). In 2011 the site got indeed hit by two extreme rainy events, which caused billions of damage in Northern Italy and Southern France, Balangero being

right in the middle of the events: one was Storm Quinn, the other was “Medicane” Rolf. As Figure 3 shows Balangero slopes came out unscathed and no trees were lost to erosion. These two storms were not the first ones to hit the area, but with their 400mm to 650mm (locally) of rain they passed the severe summer storms the slopes had already endured prior to 2011.

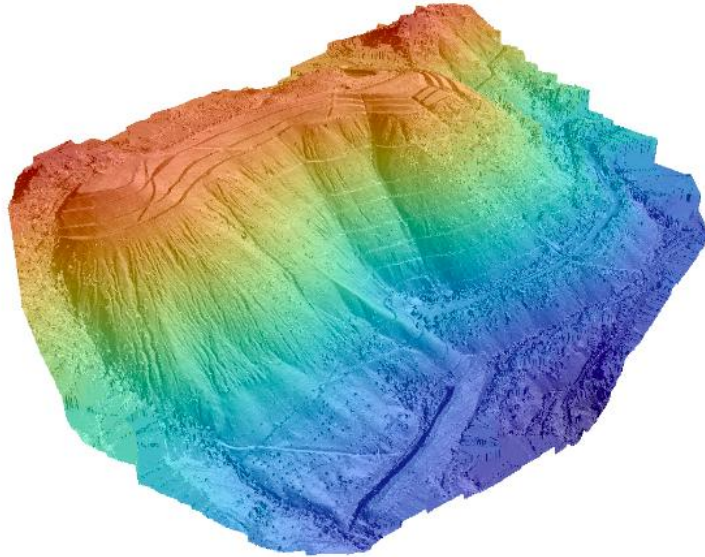


Fig. 3 Oblique view of the topography.

Figure 4 shows the results yielded by the analyses of erosion potential. Flow erosion is calculated via the stream power index (Moore et al., 1991) using the local slope and the specific catchment area. The highest values are observed in the drainage channels which were armoured using natural materials as shown in Figure 2. The algorithm does not use the construction details, just the topography, i.e. a mathematical function of slope and specific catchment area. The risk analyst has to consider this and check if there are displaced volumes before updating any probability of nefarious events along the courses or at the slope-toe.

Figure 5 shows the results for drainage patterns flow accumulation. The flow accumulation calculates accumulated flow as the accumulated weight of all cells flowing into each downslope cell in the output raster using the multiple flow direction method (Freeman, G.T., 1991). Cells with a high flow accumulation are areas of concentrated flow and may be used to identify stream channels. Again it is important to note that the simulation does not know of any drain pipes and the modelled result depends on the size of the cells. In the particular case of Figure 5 the numerous outflows from the benches are a model excess due to the computational cell size being too large.

As it can be seen in Figure 5, the analyst has to focus attention on the possible effects of the modeling assumptions, before jumping to conclusions and updating probabilities that do not require updating.



Fig. 4 Erosion potential analysis. The red areas are those where criticalities could exist. However, if there is no solid displacement, these areas are to be considered as potentially erodible and not actually eroded.

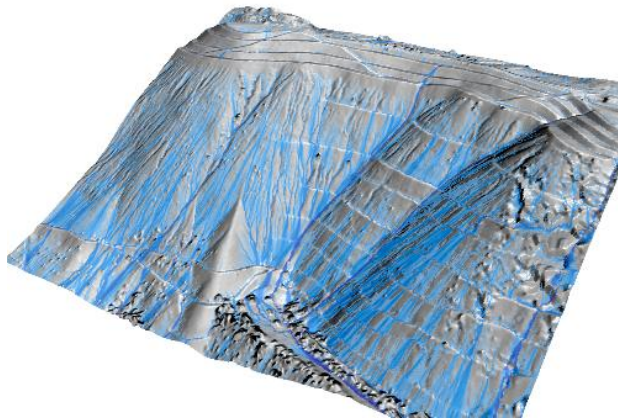


Fig. 5 drainage patterns flow accumulation. The size of the computational cells influences the results, thus caution has to be exerted by the analyst.

Multi-temporal data acquisition especially after heavy rainfalls is of high relevance regarding the accuracy assessment of the simulation results. Focus lies not only on the positions where erosion and material transportation occurs but also on the quantification of height changes and volume differences. These analyses can be done on flat terrain on a raster to raster basis. For high relief and vertical surfaces point cloud to TIN or point cloud to point cloud differences have to be calculated.

5. ORE methodology capabilities

In this section the Optimum Risk Estimates (ORE) methodology is summarized (Oboni, Oboni, 2016). A systematic approach to risk considerations in decision-making and project management support is

paramount especially when various layers of uncertainties surround alternatives, projects, operations, because decision-makers need to understand the:

- assumptions made, so that evaluations can be discussed, audited),
- uncertainties surrounding the decision,
- probabilistic future behaviour (evolution)
- benefits of updating risk information during the life cycle of the system,
- benefits of a scalable (from “high level” to detailed operational, no information wasted) risk analysis system.

The approach needs to cover:

- physical losses (human and assets)
- business interruption (BI)
- environmental damages
- reputational damages and crisis potential.

Riskope has developed a Step by Step Quantitative Risk Assessment Framework (QRAF) approach named ORE (Optimum Risk Estimates ©Oboni Riskope Associates Inc.) (Fig. 6) ORE delivers its results with a series of graphic representation (dashboards) and other communication means agreed upon with the client. ORE delivers the multi-hazard risk landscapes for the studied system.

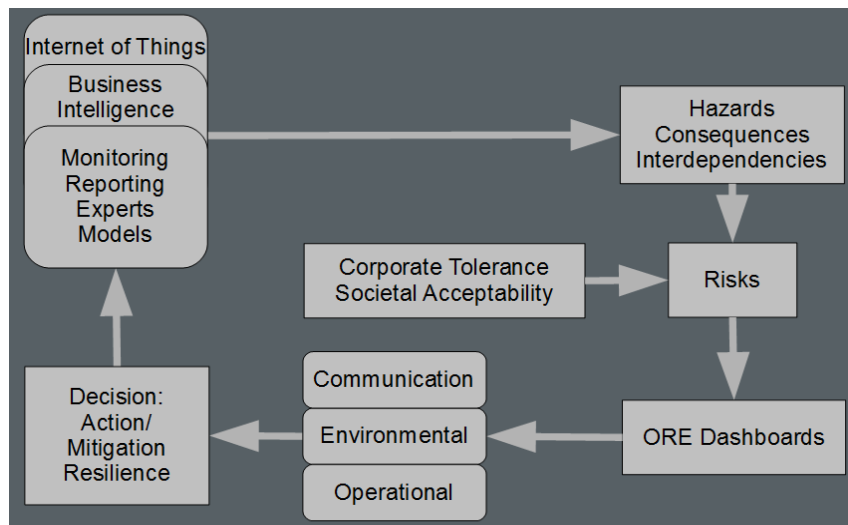


Fig. 6 Scheme of the ORE (Optimum Risk Estimates) continuous process. Scalable and drillable from cradle to grave for any project, alternative, operation. The top left box is where the link between Blubastefly quantitative data and ORE takes place.

Data from extant reports, monitoring devices, expert opinion and quantitative data generated by Blubastefly are merged, after taking the necessary precautions, to distil new probability-magnitude

estimates for the hazards and their consequences, thus allowing Bayesian updates of the risks. At each new flight, risks are displayed in ORE dashboards to give managers and decision makers the best possible understanding of the risk landscape evolution.

Through the process uncertainties are re-evaluated in the risk register. ORE foresees the formulation of a blended consequence metric to be agreed in advance of any specific Risk Assessment with the Client. “Total risk” is defined for each record. Deliverable is a General Risk Register, sorted by decreasing “total risk” or other selected filters. ORE foresees an optional treatment of the prior results based on proprietary methodologies as follows: definition of the Client’s Tolerability Threshold for its operations. A ranking based on the intolerable part of risks will be developed to highlight critical areas of the operation and to guide recommendations on possible mitigations. This ranking leads to more effective risk based decisions (Oboni, Oboni, 2014).

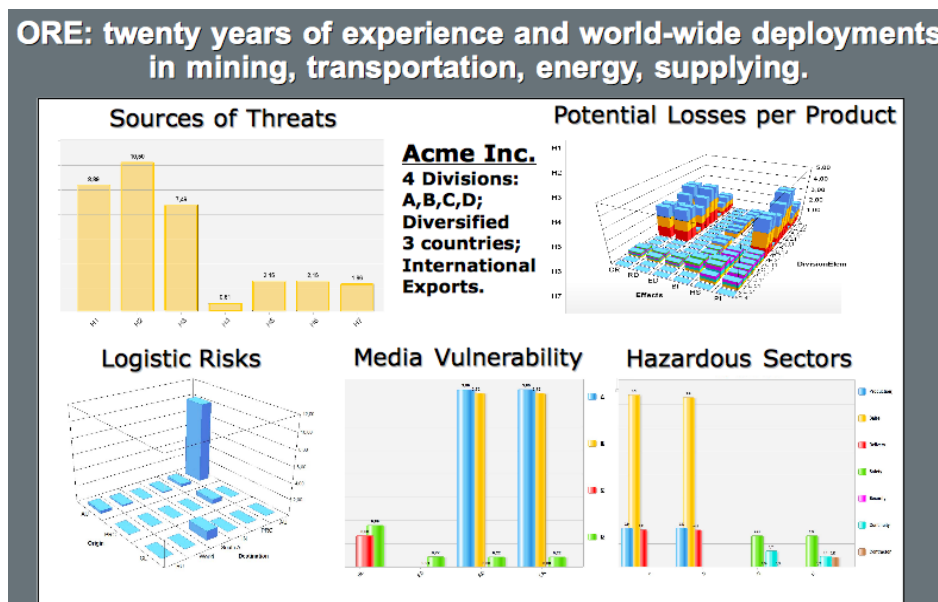


Fig. 7 ORE dashboards show the most critical sources of threats to the project or alternatives, and many other data constituting the risk landscape of any endeavor.

As an option ORE foresees the probabilistic alternatives' life-cycle evaluation “from cradle to grave” with CDA/ESM (Comparative Decision Analysis/Economic Safety Margin ©Oboni Riskope Associates Inc.). In this Step risk results from the prior steps will be integrated, meanwhile avoiding the pitfalls of other project evaluation methods such as NPV (Oboni, Oboni, 2010). ORE also comes complete with a set of communication documents which allow to properly inform all the stakeholders on the outcome of the Risk Assessment. Figure 7 displays a typical ORE dashboard for a project. It is possible to understand what are the most critical sources of threats to the project, which elements and hazardous sectors are loaded with the largest potential losses (split by type of loss: physical, BI,

environmental, etc.), where the highest logistic risks are and even how the media vulnerabilities are distributed within several elements (projects, alternatives, operations, etc.) of a same endeavor.

6. Joint capabilities

Obviously the link between Blubastet Fly and ORE is synergetic, insofar it allow delivering on a regular basis updated risk assessments with an economy of means. The Table below explains how various facility management activities benefit from the synergy, while expressing what is the inspection object and how it is used within a risk assessment.

Activity	Inspections	Risk Assessment	Benefit
Visual	Visual comparison of imagery at different times	Pre-existing damages, damage evolution	Focus enhancement, increased efficiency of site visits
Quantitative (geometry, topography)	Contour lines comparison (volumes, deformations), tension cracks, cross sections.	Detection of potentially unstable volumes, slow creeping volumes, deposit and erosion.	Enhanced Hazard Identification of existing or potential phenomena such as slides, debris flows, flashfloods, rockfalls etc.
Quantitative (surface hydrology)	Water/solid flows, drainage patterns, erosion patterns and deposit areas	Detection of potential debris flows, drainage malfunctions, overflows.	
Quantitative (slope cover management)	Slopes, orientation, vegetation cover	Detection of vegetation distress and its causes. Permafrost loss potential. Snow accumulations.	

7. How to use repeated quantitative updates within the ORE platform and Blubastet Fly

Frequencies

In this section we will focus the attention on the probabilistic updating of various types of data which may include, for example: deformation velocity (cm/year, for example), number of events of a certain magnitude (number of events exceeding a certain magnitude per year, for example), etc. The updating allows then to reframe probabilities present in the ORE risk register and to re-evaluate the risks. As a reminder, the annual observed rate of occurrence R (frequency) of an event of magnitude M (could be a rockfall, a mud slide, a water surge) can be expressed (Crovelli, 2000, Ang, Tang, 1975) as

$$R = n_{i(M)} / N$$

$n_{i(M)}$ number of observed events of magnitude $\geq M$ occurred historically.

N total number of observed events (of any magnitude) occurred historically.

For example: 15 rockfalls $\geq 1\text{m}^3$ have been observed over a total number of 100 rockfalls of any magnitude. $R=15/100=0.15$ The return period T_r of the event (average # of years between two events equally or exceeding magnitude M), provided the frequency is independent of time is:

$$T_r = 1/R$$

For example with $R=0.15$, $T_r = 1/0.15 = 6.67$ years.

Poisson process

Using the Poisson distribution it is possible to link the number of occurrences of an event over a selected time t to the mean occurrence rate (frequency). For example if 15 events over 10 years have been observed, that means a measured frequency of 1.5 events/year. Using Poisson it is easy to compute and graph the probability to see any number of events (1,2,...n) during a single year. In Fig. 8 the vertical axis shows the annual probability and the horizontal the number of events. It can be seen that with that frequency one event per year has $p=0.33$ to occur «next year», three events 0.12, etc.

The Table below shows some specific points of the relationship for at least one occurrence in the next time unit.

Frequency: occurrences/time unit (Rate)	Probability to see at least one occurrence in the next time unit
0.1	9.50%
1	63.20%
10	99.99%

For a rare event with a large return period, the probability of seeing one occurrence within the return period is always 0.632! The value is good also for smaller returns (say 10 years), with a small error (<5%)!

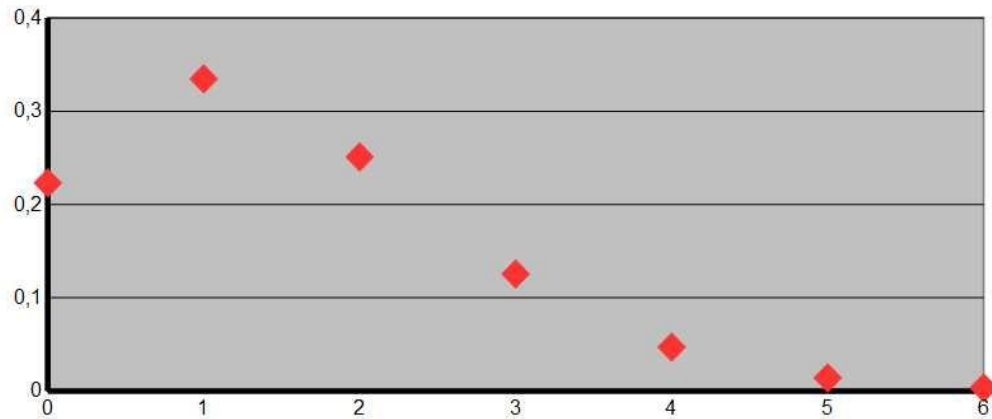


Fig. 8 With a measured frequency of 1.5 events/year the probability of occurrence (vertical axis) of 1,2,3..n events next year (horizontal axis) can be evaluated using Poisson's distribution.

As the monitoring delivers new occurrences of events, frequency and related probabilities can be updated, leading to updated risks yielded by ORE.

Exceedance Probabilities

The exceedance probability is the probability of an event being greater than or equal to a given value, i.e. to exceed, for example a given Magnitude M. It is important to forecast the future exceedance of previously observed extremes. We show below how it is done with an example.

Suppose records of prior flights show that annual presence of wet spots in a location on the slope have been as follows from the longest (Rank=1: 4 months) to the shortest (Rank=4: one month), with Rank 2,3 having intermediate duration, in the last four years (based on a monthly flight). The probability that annual presence of wet spots at the location will exceed 4 months is $1/(4+1)=0.2$. The probability that annual presence of wet spots at the location will be less than one month is $4/(4+1)=0.8$.

Based on repeated monitoring flights it is possible to re frame the probabilities of exceedance and thus to rationally update the risk register.

Bayesian analysis and updating

Bayesian analyses allow to update frequencies and probabilities as new data are generated (Ang, Tang, 1975, Straub, Grêt-Regamey, 2006). Consider for example the case where the available information is a set of observed n detached rocks from the slope, which are described by their volume and the time during which they occurred. Note that the Bayesian update will be valid only insofar the observations are free of error (i.e. all rocks are recorded), reason why regular monitoring is a necessity.

In order to allow later Bayesian update ORE has to include the a priori estimate of frequencies or probabilities. If no data are available beyond a Min-Max range defined by models or expert opinions, the simplest and oldest rule is to assume a uniform distribution (Fig .9).

However, if sufficient data were available, ORE could also be set-up with a more refined “PRIOR” distribution and then use Bayes to obtain the first “POSTERIOR” distribution....the the second posterior etc. The application of Bayes shows that one single event provokes a shift of the distribution as shown in

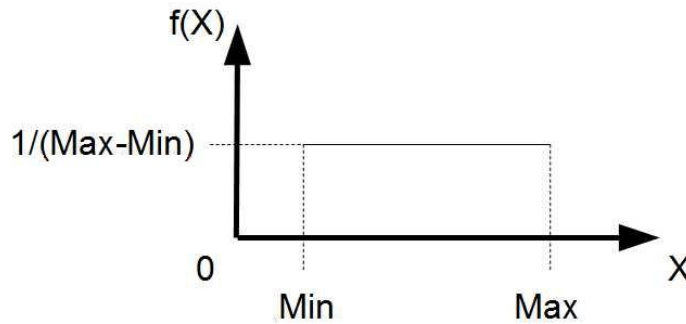


Fig. 10.

Fig. 9 Uniform distribution f parameter x between its estimated extreme values Min, Max.

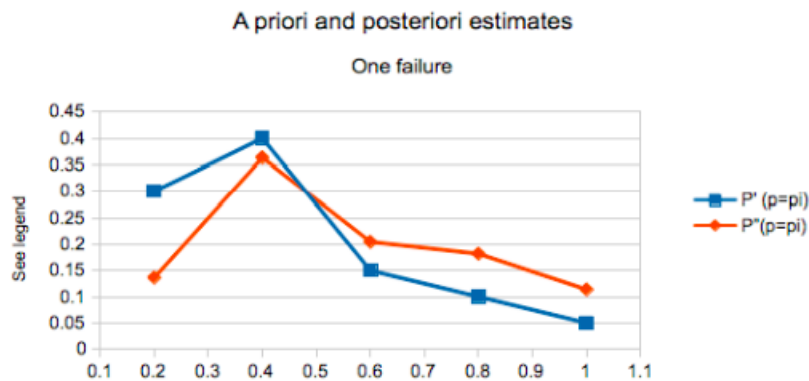


Fig. 10 A priori and a posteriori distribution of a parameter x between its estimated extreme values 0.2, 1.

8. Conclusions

The Balangero Asbestos dry tailings dump case history shows the benefits found in linking multi-temporal objective data acquisition with a dynamic convergent risk assessment platform in a mining environmental rehabilitation project long term monitoring. The link between the drone data acquisition and the risk assessment platform uses Bayesian updates of probabilities, frequencies and other selected parameters to distill the data used in the risk assessment. Connecting a dynamic quantitative risk analysis

platform with a high performance data gathering technique reduces costs, avoids blunders, constitutes a healthy management practice, especially for long-term projects requiring short or long term monitoring.

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