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An engineered approach to bushfire management

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AN ENGINEERED APPROACH TO BUSHFIRE MANAGEMENT

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ABSTRACT: In the summer of 2010 to 2011, enhanced levels of vegetation occurred across Queensland due to a number of major rainfall events. New mining operations, as well as significant coal seam gas gathering developments, were considered to be under threat from bushfire hazards during the impending dry season due to abnormal natural fuel loads. This paper outlines a risk based fire management strategy using high level multi-discipline systematic risk analysis tools, including fault tree analysis, to develop controls that were viable in terms of implementation and cost. A quantitative approach to the designation of fire risk zones was applied through the calculation of thermal radiation caused by potential fire in vegetation surrounding exposed areas. The methods used to perform these calculations were derived from the Australian Standard AS 3959:2009 - construction of buildings in bushfire prone areas. Bushfires are a significant risk in Australian conditions. Putting in place measures to protect local worker communities, process assets, cultural heritage values and the environment, was seen as essential under current and impending climatic and ecological conditions. The use of a risk based approach offered an effective, quantifiable and reproducible system to meet this challenge.

INTRODUCTION

The initial development of the engineered approach to bushfire management was developed out of a requirement to reduce the life safety risks and risks associated with asset loss in relation to a major Coal Seam Gas (CSG) operator's upstream surface facilities in Queensland. The predominant hazard was seen as an uncontrolled fire event due to high residual fuel loads resulting from recent above average rainfall and dry hot summer weather forecasts. To address the identified credible threat, a high level Fire Management Strategy (FMS) was developed with a particular focus on the CSG operator's gas gathering network surface equipment, but with the flexibility to address existing infrastructure, as well as future development. A risk based approach was taken to develop the FMS and through this process, a thorough and detailed analysis of the issues surrounding the potential associated threats to personnel, property, cultural heritage and environmental assets caused by fire, whether planned or wild, was conducted. This methodology has since been effectively applied to further scenarios involving a Bowen Basin coal mine and a Victorian alpine zinc mine. The approach is therefore seen as being particularly relevant to existing and future mining.

In order to identify the conditions resulting from the occurrence of an unwanted event, extensive Fault Tree Analysis (FTA) workshops were facilitated. In these workshops professionals from a range of engineering and science disciplines worked together to understand the problem and to identify areas that needed to be managed to reduce the level of risk. The FTA workshop project team was split into three areas consistent with the three contributing key events leading to the top level event; fuel sources, ignition sources, and exposures. Each of the key events were then further analysed in risk workshops, where the team evaluated the available risk treatments, and risk acceptance criteria. The range of risk treatments consisted of operational, procedural and engineering risk management controls. Several hundred fault tree inputs were identified and assessed.

As part of the development of the FMS, a review of the 'Final Report Recommendations' of the 2009 Victorian Bushfires Royal Commission was carried out. Fifteen (15) key recommendations were identified as relevant, and appropriate actions were included as part of the overall FMS. The purpose of the overarching FMS was to provide a guideline for the development of subordinate site specific Fire Management Plans (FMPs) that can be developed, reviewed, modified and deployed, as needs change, by the mining operators' staff and contractors.

It is important to note that a level of 'on the job' training and experience is required to develop the competence to complete the assessments, as fire management specific terms, measurements and calculations are required to determine essential outcomes based on the application of Australian Standard AS3959: 2009 'Construction of Buildings in Bushfire Prone Areas' (Standards Australia, 2009).

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In some situations, such as where life safety exposures exist, or where asset exposures exist under certain conditions relating to sloping ground or where limited available separating distance from fire sources exists, a higher level assessment is required. This assessment involves fire modelling, engineering calculations and experienced judgement.

Fire fighting training and equipment options were addressed in this project. The options ranged from a do nothing reliance on fixed fire suppression and passive systems in infrastructure facilities to a fully operational industrial fire brigade. The FMS was intended to be a living document, which reflects current research in bushfire management and the changing needs of the mining operator and the fire risks facing its operations.

FIRE MANAGEMENT STRATEGY

In relation to uncontrolled fire events, the FMS delivers a framework that provides a uniform, structured and planned tool for managing the asset by minimising fire life safety risk, fire exposure risk to environmental and cultural heritage artefacts, losses associated with property and subsequent reputational risk.

The solution to address the original CSG operators' challenge involved the development of a FMS or guideline that could be applied by users as guidance in developing site specific FMPs. The preservation and improvement of the associated agricultural portfolio and the natural environment was also a key factor addressed by this risk management framework. The FMS achieved its purpose by allowing the development of site-specific FMPs across the variety of sites that make up the gas field or mine site. These site-specific FMPs are developed to assist in making decisions in land and asset management on an ongoing basis providing for the protection of life, the environment, items of cultural heritage and assets, from the threat of bushfires.

The FMS development project addressed the following:

1. Conduct a thorough and detailed risk analysis of the issues surrounding the potential associated risks to personnel, property, cultural heritage and environmental assets caused by fire, whether planned or wild;
2. Develop suitable preparedness and response strategies for gas plants, wells, rig sites, agricultural land, environmentally and culturally sensitive areas and general plant and equipment;
3. Set out the requirements for managing fire on non operator owned properties with a particular focus on preventing fire spread from the gas gathering network surface equipment;
4. Establish a Bushfire Management Plan template for sites, which cover building requirements, asset protection zones, fuel management, access and emergency response measures consistent with legislative and business requirements;
5. Review and include any relevant findings from the Victorian Fire Board 'Black Saturday Report';
6. Establish equipment needs and requirements; and
7. Establish training and competency requirements.

Fire risk analysis

A focussed FTA workshop was facilitated and documented, determining a wide range of 'trigger events' leading to the 'top level event' - which was recorded as an 'Unwanted Planned or Unplanned Fire Event'. The fault trees were developed at this workshop by project teams, comprising of both the CSG operator and the fire and risk engineering team. Likewise, subsequent mine projects in Queensland and Victoria were carried out in a similar way, but with the benefit of experience of the original CSG project.

In risk analysis, the graphical construct FTA is considered useful for modelling the system conditions using binary variables (0's and 1's) that may result in the occurrence of an unwanted event. The significance of the output event (otherwise known as the 'top level event') is nominally recognised as the 'consequence factor' associated with risk, therefore values of probability (random variables) are not normally applied.

Boolean logic 'AND' gates and 'OR' gates are used in FTA. For example, both logic inputs of a two (2) input 'AND' gate need to be concurrently a logic level '1' or 'TRUE' for the output of the 'AND' gate to be '1' or 'TRUE'. Any other combination would result in a logic '0' or 'FALSE' output. For an 'OR' gate, either logic input or both logic inputs can be a '1' or a 'TRUE' level for the output to be 'ONE' or 'TRUE'.

The combination of events in an 'AND' gate configuration or even a single event, as in the case of an 'OR' configuration, is required to trigger the output of the fault tree (to achieve a value '1'), so input event probability (or risk likelihood factor) is not associated with fault trees.

The consequence levels associated with the fault tree top level event can be graded either qualitatively, or quantitatively. For the purpose of a qualitative assessment, it was considered that any event that was acceptable would signify a consequence value of '0', while any event that was unacceptable would have a consequence value of '1'. Acceptability was based on the operators risk appetite.

An overall reduction of risk may be achieved by preventing fault tree outputs from 'triggering'. This is realised through implementing risk mitigation controls that reduce the likelihood or probability of achieving a '1' input condition into a logic gate.

Three (3) risk workshops were facilitated as part of the fire risk analysis component of the FMS project, where risk registers were developed based on the information coming from the initial FTA.

A diverse disciplinary range of team members attended the sessions, which were focussed on determining and documenting the level of risk and risk management treatments acceptable to the CSG operator in relation to the contributors of the identified 'Unwanted - Planned or Unplanned Fire'.

As stated earlier, the contributors to this risk consist of: 'Fuel Sources', 'Ignition Sources' and 'Exposures', with each requiring specific risk management.

- Workshop one addressed 'Fuel Sources', which included a significant representation by ecological and environmental professionals.
- Workshop two addressed 'Ignition Sources' and 'Exposures', and was attended primarily by health and safety professionals and fire and risk engineers.
- Workshop three addressed, 'Ignition Sources' and 'Exposures' and was attended by a wide range of engineers and scientists.

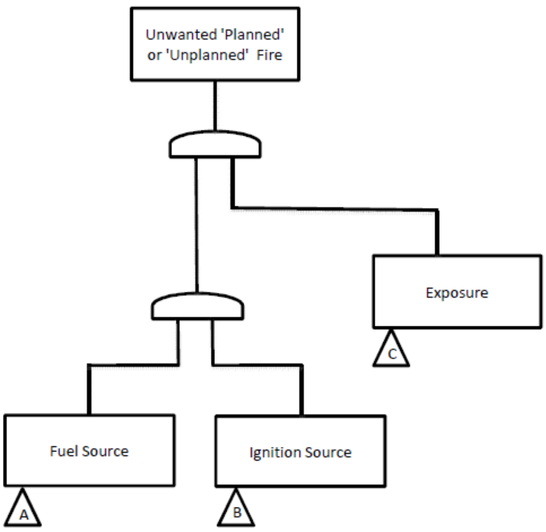

Figure 1 - Fault tree analysis

Fire risk was assessed in two ways:

1. The risk of fire spread from the operators property or assets
2. The risk of fire spread to the operators property or assets

The developed risk treatments were considered achievable and relevant to the operations with the range of risk treatments consisting of operational, procedural and engineering risk management controls. A key benefit of the combined FTA and traditional risk matrix approach is that it takes both a 'bottom up' and 'top down' approach. The 'bottom up' approach addresses measures required to reduce the likelihood of fuel sources becoming 'readily combustible' and ignition sources becoming 'adequately strong'. The 'top down' approach addresses the protection of exposures, such as life safety, the environment, cultural heritage values and assets, given the occurrence of an 'Unwanted Planned or Unplanned Fire'.

In this way, the risks are managed such that at least two 'layers of protection' exist: one layer to reduce the fire risk and another layer to reduce the fire exposure. Both methods reduce the risk of 'losses'. This risk-based approach has since been successfully deployed at a Victorian and a Queensland mine.

Bushfire preparedness and response strategies for mines

The stay or go policy in relation to mine sites and remote drill pads and the like, will require the decision to be a core responsibility of the management team that by the nature of their role will have all the relevant site information: Fire Danger Index (FDI) and weather information for the site, as well as FMPs. Any site that has been identified as being 'at risk' to the extent that the stay or go policy has to be considered should be assessed in accordance with Method 2 of AS3959 (Standards Australia, 2009) to establish if further controls can be made to mitigate the risk prior to any manned operations to the site.

While both management and individuals will make choices about what to do and how best to prepare in advance of a fire occurring, the emphasis should be on taking protective action rather than choice or options. Drilling or other activities on sites at risk from bushfire need to be scheduled outside of the bushfire season, however if essential work is deemed to be vital to business continuity then on days where the FDI raises the bushfire risk above moderate (High; Extreme; or Catastrophic) all access to these activities should be prohibited.

The stay or go policy must be considered in the light of available information. For example in a worst-case scenario, a bushfire might travel at 1.5 km/h in a forest or woodland and faster in grassland. To ensure safe escape routes are available evacuation must take place before the fire is within approximately 3 km of the site. Access and choices of travel determine whether or not escape routes to defendable locations are practical and are not vulnerable (tops of ridges). When the fire is within approximately 2 km, ember attack may cause spot fires that may impact on escape routes, therefore alternative routes need to be identified and documented in the site FMP. These considerations are site specific and as such, need to be documented for each FMP.

In the event of a bushfire approaching a manned site, a decision to leave site should be made early. Any decision to stay on site and defend assets should only be made if appropriately trained staff with suitable fire fighting equipment is in place and the site has been proven to be able through a bushfire engineering study to provide a safe place of refuge.

In the instance of the Victorian (underground) gold mine, the mineshaft with refuge chamber was considered the safest refuge location. To ensure safe egress is possible, the design and maintenance of access roads is imperative in ensuring staff are able to securely leave the site.

To ensure this, site planners and machinery operators should be suitably trained in the design and construction of access roads, so regular inspection and reporting of damage to these roads are important in maintaining safe egress integrity.

Engineered approach

The Australian Standard AS3959: 2009 'Construction of Buildings in Bushfire Prone Areas' (Standards Australia, 2009) is the basis of determining the impact of fire on various targets, including those typically located at mines and similar industrial facilities in close proximity to vegetation. Its' application requires the assessor to carry out either a basic assessment of the minimum separation distance, known as an Asset Protection Zone (APZ), between a potential vegetation fire and infrastructure under the 'Method 1' approach, or a more rigorous assessment involving engineering analysis and judgement, under AS3959's 'Method 2' approach.

It is recommended that only persons competent in each assessment area be engaged to carry out this work. Both approaches estimate radiant heat flux at the target based on the distance from the subject vegetation fire by vegetation type or category.

The AS3959 (Standards Australia, 2009) Method 1 approach is quite appropriate in most circumstances to estimate an APZ, however the 'granularity' of the Method 1 table in AS3959 (Standards Australia, 2009) is quite coarse. As a result, tabulated separation distances between the target and the source take wide steps and often overstate the required vegetation clearance distance.

The slope of the ground also restricts Method 1's applicability and maximum Fire Danger Index (FDI) levels listed in the table. The Method 1 assessment procedure represents a useful, streamlined approach to risk mitigation for buildings or infrastructure located on the vegetation interface, however, often it will result in an inaccurate risk model for structures exposed to unique vegetation topography or shape.

In cases where life safety is the dominant risk, or where high value assets, such as overland conveyors are at threat, the analytical AS3959 (Standards Australia, 2009) Method 2, in conjunction with performance based fire engineered construction solutions, is recommended.

The Method 2 assessment procedure provides the calculation methodology and accepted inputs that the Method 1 assessment matrix was derived from. The Method 1 assessment procedure focuses purely on radiant heat and is non-granular in assessment. Primary limitations with the Method 1 assessment procedure include:

1. There is no consideration of flame contact.
2. Upslope vegetation is considered as being level
3. Vegetation slopes are divided into 5-degree increments with the highest slope in the range determining the vegetation slope.
4. The site slope, being the slope between the vegetation and the building is not differentiated from the slope within the vegetation.
5. The structure receiver is measured opposite the midpoint of the flame, which is often inaccurate.
6. Vegetation width may be less than the predefined 100 m.
7. Radiant heat shielding from the surrounding landscape is not considered.

The Method 2 detailed procedure for determining the radiant heat flux measure, referred to as Bushfire Attack Level (BAL) was originally published as a model proposed by Tan (Tan, *et al.*, 2005). This model builds upon the Drysdale (Drysdale, 1985) radiant heat model to create a three-dimensional landscape to model the bushfire within.

The model contains two sets of equations: one, that models bushfire behaviour, while the other models radiation. Key to the fire behaviour model is the determination of the configuration or view factor as shown in Figure 2.

This factor is assessed via an algorithm that tilts the flame as a flat panel emitting radiant heat to determine the worst possible case scenario. The main variables that determine the view factor include:

1. Fire Danger Index (FDI);
2. Vegetation type;
3. Site slope (slope between the vegetation and the structure);
4. Vegetation slope (slope within the vegetation);
5. Vegetation width; and
6. Elevation of receiver (the most vulnerable height of the structure).

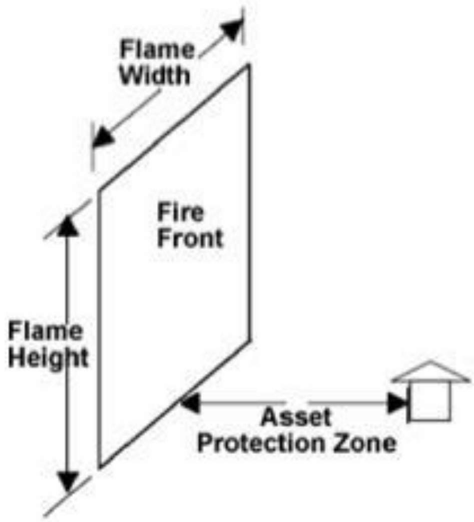

Figure 2 - Theoretical radiating surface of bushfire

By specifying an accurate peak elevation of receiver, the flame trigonometry provides a more accurate view factor for determining radiant heat. This is due to the path between the midpoint of the tilted flame and the receiver being increased or decreased.

The vegetation interface often leads to topography where the site slope does not match the vegetation slope. By specifying a more accurate elevation of receiver, a design fire that more closely represents the real world scenario can be used to assess bushfire risk.

An assumption of the view factor calculation is that the radiant heat panel is a blackbody of evenly distributed heat. Therefore the panel can be divided into multiple pieces to effectively add or subtract from the model to equate to the view factor of the receiver. Using this methodology the width of the flame and subsequent radiant heat flux that will impact on the site can be predicted. Furthermore, using this methodology, any shielding effect can be quantified by the subtractive methodology of the view factor model. The rate of spread determines the flame length, fire intensity and the radiant heat flux.

A fire in vegetation will eventually reach equilibrium rate of spread. Grass and woodland take 5-10 min to reach equilibrium and forest in 12-45 min in winds above 4 m/s. AS3959 (Standards Australia, 2009) design fires are based on a bushfire in equilibrium or a quasi-steady state.

The main acceptance criteria are based on life safety and the requirement to provide a safe refuge for any persons located at the facility whilst the fire front passes. Where a safe refuge is not available, the radiant heat flux will need to be below 2.1 kW/m² to provide an acceptable level of protection, as shown in Table 1 (Assael and Kakosimos, 2010). In this situation the APZs will need to provide sufficient setbacks to ensure that a radiant heat flux of 2.1 kW/m² is not exceeded where there is no shielding or safe refuge.

Table 1 - Effects on humans of radiant heat (Assael and Kakosimos, 2010)

Radiant Heat (kW/m^2)	Impact
37.5	100% lethality in 1 min 1% lethality in 10 s
25.0	100% lethality in 1 min Significant injury in 10 s
12.5	1% lethality in 1 min 1st degree burns in 10 s
4.0	No lethality 2nd degree burns probable Pain after exposure of 20 s
1.6	Acceptable limit for prolonged exposure

A second consideration is the structures and assets within the facility, which may consist of combustibles, which will begin to distort and char at a radiant heat flux of between 10 kW/m² and 12 kW/m².

Therefore any radiant heat flux from a bushfire impacting on the facility assets will need to be below 10 kW/m^2.

AREA SPECIFIC FIRE MANAGEMENT PLANNING

Preparedness and response strategies were embedded into risk controls and risk registers. Risk registers were developed for 'ignition sources,' 'fuel sources,' and 'exposures.' These risk registers were aimed at identifying a level risk that is acceptable to the CSG operator and subsequently for miners.

As a part of the risk assessment carried out, the risk registers developed considered requirements for managing fire on non-operator owned properties, in particular where gas gathering network surface equipment was located.

The findings of the Black Saturday Report (Victorian Govt, 2009) indicated that a requirement to manage ignition sources (overhead power lines in the case of the Black Saturday fires) should be incorporated in the operators FMS. The gas gathering network in this situation and subsequent mine scenarios, was considered in a similar way to overhead power lines. A FMP template was developed in conjunction with the FMS strategy, including FMP development procedures and a sample FMP.

The Victorian Fire Board's Black Saturday report (Victorian Govt., 2009) was considered as part of the development of the FMS. Where appropriate, findings from the report were incorporated into the FMS. Options for fire fighting and fire protection needs of the operator were developed to assist in informed decision making in relation to fire fighting training and fire equipment needs.

A range of competency and subsequent training requirements exist for the development of FMPs and for potential fire fighting activities. Some of these training requirements are legislated, depending on the level of activities undertaken with respect to each.

FMP development using AS3959 Method 1 (Standards Australia, 2009) by mine operational staff was enabled as part of this project through the development of field manuals, which included 'step by step' instructions via flow charts and a comprehensive set of reference data in appendices.

Figure 3 shows an example of a flow chart developed to enable creation of specific area FMPs.

CONCLUSIONS

This paper demonstrates an example of how a risk based approach to the development of a FMS to address bushfires was conducted. It further demonstrates how a thorough and detailed analysis of the issues surrounding the risks to personnel, property, cultural heritage and environmental assets caused by fire, whether planned or wild, can be addressed using a multi-discipline approach to minimise the impact on the environment using engineered methods.

The purpose of the overarching FMS was to provide a guideline for the development of site specific FMPs that can be implemented by the operators' staff and contractors.

It is important to note that a level of 'on the job' training and experience is required to develop the competence to complete the assessments, as fire management specific terms, measurements and calculations are required to determine essential outcomes, based on the application of Australian Standard AS3959:2009 'Construction of Buildings in Bushfire Prone Areas' (Standards Australia, 2009).

A 'Fire Management Strategy - Field Management Plan Procedure' document was developed as part of this project, to facilitate the collection of field data required for the Method 1 assessment approach as detailed in AS3959, to allow the development of FMPs.

As part of the development of the FMS, a review of the 'Final Report Recommendations' of the 2009 Victorian Bushfires Royal Commission (Victorian Govt., 2009) was carried out. Fifteen (15) key recommendations were identified as relevant, and appropriate actions incorporated as part of the overall FMS.

The Fire management Strategy was intended to be a 'living document', which reflects current research in bushfire management and the changing needs of mining and the fire risks facing its operations.

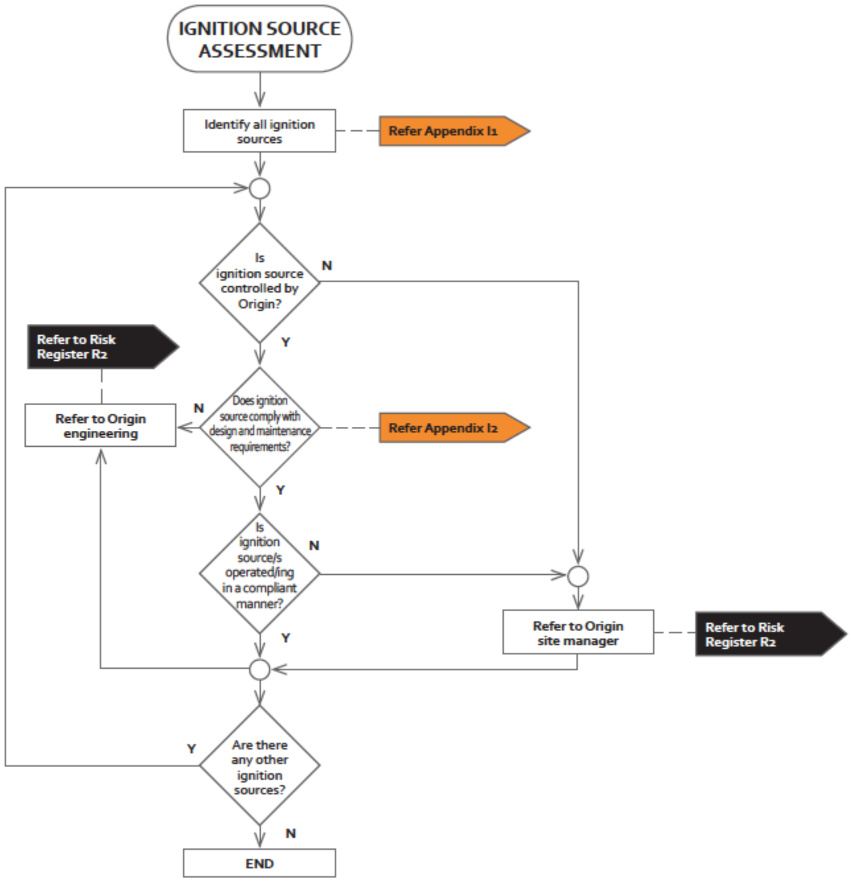

Figure 3 - Typical example of guidance provided in FMP development template

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