SAFETY CULTURE AND PERFORMANCE INDICATORS FOR A 'TOP TIER' COMAH SME

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In this paper we discuss the approach taken by Roxel (UK Rocket Motors) Ltd towards the development of Safety Performance Indicators (SPIs) for the high hazard process of manufacturing nitroglycerine (NG). The nitroglycerine plant was selected as the development study for the company as it contained some of the highest hazard operations; these include storage and use of concentrated sulphuric and nitric acid mixtures, explosive materials and waste materials from the NG manufacturing process.

The reason for developing and using safety performance indicators for Small and Medium Enterprises (SME) is very clearly stated by the Organisation for Economical Cooperation and Development (OECD);

"Management of SMEs should be particularly concerned about potential chemical accidents and what can be done to prevent them, since one accident could force the enterprise out of business (in addition to possibly harming employees, members of the public and/or and the environment).

Use of SPIs can be a very effective tool for SMEs. Smaller enterprises tend to have more limited expertise and fewer resources dedicated to chemical safety. Management is often directly involved in process activities and employees tend to be responsible for several functions. An SPI Programme can provide an efficient means to help focus attention on the critical aspects of the enterprise that create risk and aid in setting priorities for action." (OECD, 2008)

There are many sources of information on the development and use of safety performance indicators from the OECD, Centre for Chemical Process Safety (CCPS, 2011), American Petroleum Institute (API, 2010) and the Health and Safety Executive (HSE, 2006). Although the guidance gives a very clear plan on the process to develop a suite of SPIs, the selection of robust and meaningful indicators is the responsibility of the Company.

ROXEL HISTORY AND PRODUCTS

Summerfield Research Station was established in 1951 on the site of a WWII munitions factory, for research into the manufacture and development of Cast Double Base (CBD) solid fuel rocket motors. The site has operated continuously since its establishment and continues as a world leader in tactical battlefield rocket propulsion. Roxel (UK Rocket Motors) Ltd was formed in 2003 following the formation of a joint venture between Royal Ordnance Rocket Motors and CELERG in France.

CDB rocket motors and modern variants are based on a nitroglycerine/nitrocellulose (NC) matrix 'cured' to produce a glassy or rubbery solid. The physical and chemical (burning) properties are modified by the use of other ingredients such as metal salts and plasticisers. By careful adjustment of the constituents the rocket performance can be tuned.

Nitroglycerine manufacture began with the building of a 'Nilssen And Brunnberg' (N.A.B) plant by Imperial Chemicals Industry Nobel Division, to replace the transport of desensitised nitroglycerine by road from the Royal Navy Propellant Factory, Caerwent, Wales and the onsite extraction of nitroglycerine from dynamite. The nitroglycerine plant has been in continuous operation since the late 1960's through to the present day. With the closure of other facilities in the United Kingdom, Summerfield is now the only production scale manufacturer in the UK. The facility is largely unchanged since commissioning; the original combination of pneumatic and electromechanical controls maintains safe and reliable operation.

SAFETY IN EXPLOSIVES MANUFACTURE

The manufacture of explosives has long been recognised as presenting significant hazards. Transport and storage of gunpowder was controlled before the first act regulating gunpowder manufacture in the United Kingdom in 1772. The very basic rules in the earlier act on quantities and separation of buildings were amended and improved in The Explosives Act of 1875. The current regulations are laid out in the Manufacture and Storage of Explosives Regulations, 2005.

The accident rate for modern explosives manufacture is low and was estimated by Moreton (Moreton, 1998) at 1×10^{-2} per process-building-year. In comparison the continuous manufacture of nitroglycerine as discussed later has an accident rate of 5×10^{-3} per-process-building-year.

Generally for explosive manufacture several approaches to process safety are taken, and these are discussed below.

EVENT MITIGATION

To minimise the human cost of an incident the number of operators allowed in a building/area was traditionally very tightly controlled. The manning limits for every building or compartment had to be displayed clearly. Remote operation has further reduced the risk to operators; however such controls are still, sensibly, maintained.

The quantity of explosive is tightly controlled; each building is licensed to hold a maximum quantity of explosive material. This limit can be influenced by changes to the use of other buildings and even developments outside the site boundary.

Event transmission from building to building is prevented by the use of mounds or bunkers with a combination of very lightweight construction and/or very heavy construction. The inclusion of lightweight sections can be used to direct blast through a wall or roof to minimise projectiles. Mounds will 'catch' low angle projectiles but not prevent the transmission of a pressure wave which may still cause significant damage over an extended area, as was seen at Buncefield in 2005. To minimise the effect from a pressure wave, process buildings and magazines are sited at set minimum distances to prevent sympathetic detonation. For high explosives the risk from thermal flux and radiant heating must also be taken into account. In the same way 'Danger Buildings' must be sited away from public roads, paths, housing or offices (both off and on site). This develops the striking characteristic of an explosives facility; lots of green spaces.

PREVENTION OF INITIATION

Explosives can be initiated in several different ways, and as the material contains both fuel and oxygen once initiated the explosive may burn rapidly (deflagration) or detonate. Initiation can occur through heating, friction, spark or impact.

Initiation due to electrical discharge (including lightning) is controlled by comprehensive earthing, lightning conductors and intrinsically safe rated electrical equipment. Conductive floors and shoes are used in high hazard areas; personnel are also checked with a 'personnel resistance meter' to ensure that there is no build up of static on the person. Humidity is also controlled to prevent the accumulation of static on dry powder or dusty materials, during handling operations such as decanting, mixing or sieving.

Careful control of materials used for tools, furniture, floors, walls and equipment is maintained. Metal to metal contact is avoided or where unavoidable sparking is minimised by using 'soft' metals or alloys. Tools are made of non-sparking copper/beryllium alloy; nuts and bolts are arranged so material cannot accumulate in threads. Prior to maintenance fastenings and joints should be wetted thoroughly with a suitable solvent to remove any traces of material or 'desensitise' the explosive by dilution.

Wooden or antistatic surfaces on work benches and shelving are used. Friction from sliding or dragging objects across surfaces has caused several accidents. Whenever objects need to be moved lifting and carrying is the best practice. Lead floors are still present in many explosive buildings; lead is an ideal material: soft, waterproof and acid resistant. Before the use of stainless steel lead was also used for process equipment, as in the event of explosion it will burst or split without shattering.

Initiation may also occur through adiabatic heating as bubbles or voids are compressed in processing. This is a concern when mixing to blend components or pressing to extrude material. When mixing material can either be processed as slurry or mixed slowly with minimum shear. Pressing and extruding is carried out by ensuring the rate of travel for the piston and applied pressure are closely controlled, high speed movement at low pressure or rapidly rising pressure is to be avoided.

The design of valves and flow controls must also be considered, pinch points or sliding surfaces should be avoided. Valves and process piping must also be designed to eliminate dead-legs or trapped material, as the confined material may become unstable and decompose leading to detonation. The NG process is designed to largely self draining after shut-down; traditionally factories have been built on a 'hill' to allow free flow using gravity between process stages.

Prior to any repair or maintenance to or inside any danger building, the building should be cleared of all explosives (so far as reasonably practicable), and thoroughly washed out. When working on potentially contaminated equipment a 'Free from visible explosives' statement forms part of the Permitting system. Maintenance is associated with many accidents across industry (Kletz, 2009) and needs to be carefully planned and prepared. The initial torque required to loosen fastenings such as nuts or retaining rings should be applied remotely. A spanner operated through a hydraulic arm or pulley system is the preferred method.

Good housekeeping to ensure the removal of all traces of grit or rust is essential. Grit or rust if mixed into explosive materials increases the likelihood of initiation. Careful control to ensure no process material is left in a facility when not in use prevents cross contamination, any finished product must be stored in a designated magazine.

All ingredients are subject to strict material control; this has grown from the requirement that all ingredients be sifted and checked to remove foreign matter, to modern chemical analysis and compatibility testing to prove no potential adverse reactions with explosive materials.

Even in the 1875 Act clothing is proscribed; 'suitable working clothes without pockets, suitable shoes...' this is to prevent the introduction of matches, grit or any other material likely to cause explosion or fire. The absence of pockets also helps prevent explosive materials being carried out of controlled areas by mistake.

SAFETY CULTURE

The Explosives Act also had the provision of 'Special rules for the regulation of workmen....'; "With a view to secure the observance of this Act therein, and the safety and proper discipline of the said persons and the safety of the public", the maintenance of an effective safety culture is the best means to secure everyone's continuing health and wellbeing.

To assess the safety culture and adherence to good working practices regular workplace inspection tours are carried out both by the local line manager and by the SHE Committee. The SHE committee includes Trades Union representatives, operatives and managers, to ensure a breadth of representation and opinion. The SHE committee inspections bring independent observers into each production area and normalise each local managers own inspection. The key areas covered by each inspection are; emergency response, permitting, material control (storage and use), tools and work equipment, risk assessment and work practices (PPE, procedures), cleanliness and building condition. The overall inspection is scored out of 100%; individual items may require action even if the overall inspection is deemed acceptable.

Operators are expected to inspect machinery before starting work and to report any situation (e.g. noise, vibration, smell, heat) that is unusual or unexpected. If an unusual condition is observed during production the process is stopped and put in a safe condition before any investigation work is carried out.

A high level of training, awareness and discipline is essential for operators and management involved in explosives manufacture. A low accident rate must not be allowed to give rise to complacency by operators, managers and engineers. The difficulty in finding a SPI to suit culture is discussed later.

PROCESS SAFETY IN NITROGLYCERINE MANUFACTURE

The manufacture and handling of nitroglycerine has led to significant numbers of deaths and injuries since its discovery by Ascanio Sobero in 1847. Alfred Nobel who commercialised the manufacture of nitroglycerine, dynamite and gelignite lost his younger brother Emil when the Nobel factory in Sweden was destroyed by an explosion in 1864. The United Kingdom Nitroglycerine Act of 1869 was passed in response to the numerous fatalities associated with handling nitroglycerine, although repealed later as the improved safety of dynamite and gelignite were demonstrated. Nitroglycerine is very sensitive to initiation by friction and impact, this obviously contributed to the large number of accidents when handling pure nitroglycerine.

The process safety risks in nitroglycerine manufacture have been reduced by the change from batch production to continuous methods, resulting in a smaller quantity of nitroglycerine present during the most hazardous nitration stage from >1000 kg to <10 kg using the NAB (Nilssen And Brunnberg) process (Urbanski, 1965). Batch manufacture required long reaction times of 20~50 minutes and subsequent slow separation up to 30 minutes; decomposition of the NG and the nitrating acid (known as spent acid) during this time was a very serious risk. These times were reduced with the development of continuous processes by Schmid and Biazzi.

The NAB process was developed in 1950 by Nilssen and Brunnberg, at Nitroglycerin Aktiebolaget Gyttorp in Sweden. The process has many built in process safety features. Nitration and separation time is reduced to approximately 2 minutes, with the minimum quantity of free nitroglycerine at each stage. The nitroglycerine is maintained as a non-explosive emulsion except in the outlet of the centrifuges or other separators. The key features of the design are given below; numbers refer to Figure 1 Nitroglycerine manufacture process flow.

1. Nitrating acid – a continuous flow of acid is maintained through the system. The composition is controlled to maintain the correct ratio of water:H_2SO_4:HNO_3:NG
2. Glycerine/acid ratio – controlled by the nitration injector; a continuous flow of the nitrating acid through a venturi creates a controlled vacuum to draw in the glycerine. A large excess of acid drives the reaction to completion. The design of the venturi system ensures that a fall in acid flow results in a much larger fall in glycerine flow (though loss of the vacuum). This prevents incomplete reaction and subsequent decomposition.
3. Temperature – The nitrating acid is cooled to 0°C prior to the injector. The glycerine is heated to ~60°C to reduce viscosity and the reaction proceeds at 45~50°C, this maintains a high yield of more stable NG (complete reaction). The acid/nitroglycerine emulsion is then rapidly cooled to 16°C to stabilise the mixture and promote separation.
4. Centrifugal separation – rapid continuous separation of the nitroglycerine from the spent nitrating acid further minimises the potential for decomposition. The spent nitrating acid is split into two streams, one third is sent to stabilisation and disposal while two thirds are recovered after addition of a strong mixed acid (sulphuric/nitric acid mixture). The separated nitroglycerine is emulsified using a second injector with warm water and transported to a second centrifuge to separate the washed nitroglycerine from the water. In each centrifuge the quantity of nitroglycerine is minimised and the emulsions will not transmit detonation between the process stages.
5. Storage – after separation from the wash water the nitroglycerine is washed a second time with a dilute sodium carbonate solution using an injector and transported as an emulsion prior to mixing with other ingredients or storage under water. The emulsion is allowed to split and separate prior to mixing.
6. On-line mixing – the nitroglycerine is introduced with a minimum hold-up into a mixer to make casting liquid or nitroglycerine/nitrocellulose 'paste'. Both materials are much less sensitive than neat nitroglycerine and can be handled with relative safety.

The manufacture process is undertaken remotely with the operators and Nitration Officer located in a reinforced control room. Access to the facility is strictly controlled while nitration is in progress.

DEVELOPMENT WORK ON SETTING PROCESS SAFETY PERFORMANCE INDICATORS (PSPIS)

Following the six step process as set out in HSG254 a small team was established comprising the Head of Manufacturing, SHE Manager and Nitration Officer. Using the nitroglycerine plant as a development study for the site, the

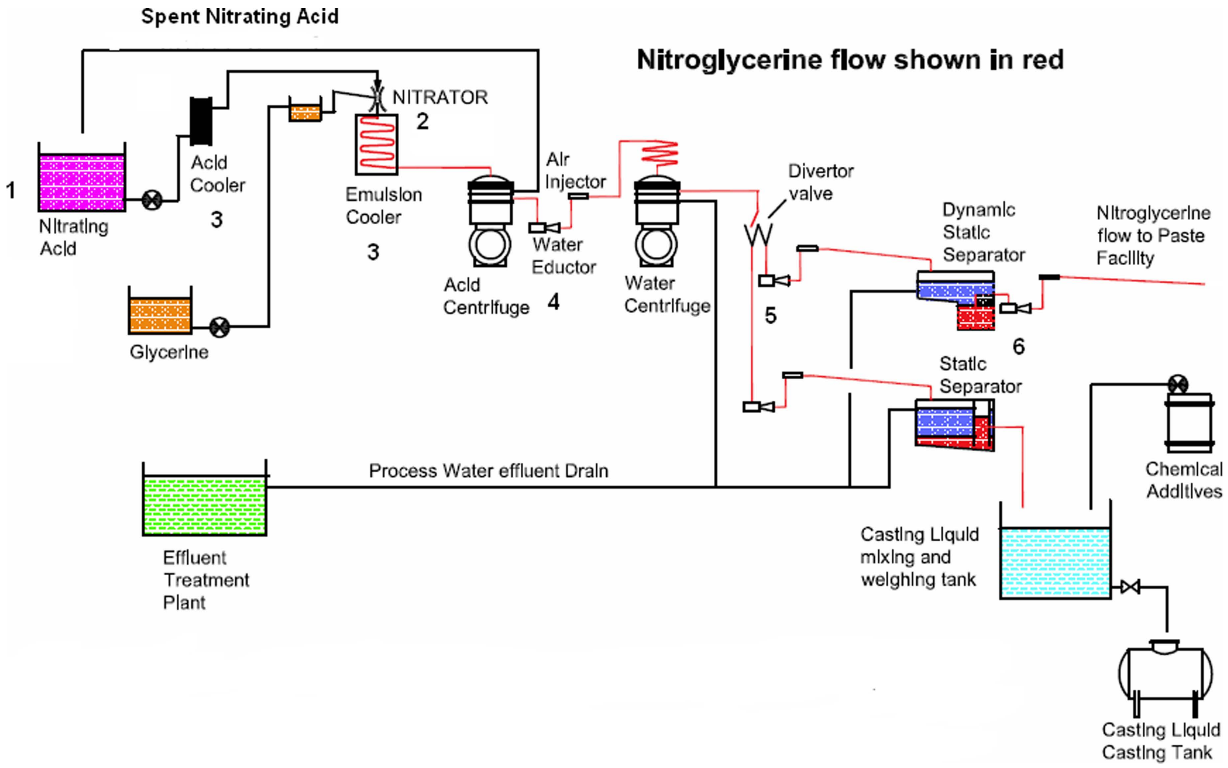

Figure 1. Nitroglycerine manufacture process flow

team began to develop a suite of safety indicators for operations, culture and assets (equipment, maintenance and buildings).

Using the COMAH safety report for the nitroglycerine plant as a basis for the development (Fearnley, 2009); Roxel started to explore the event tree leading up to the Major Accident Hazard scenarios. This was supplemented by a Past Accident Review using historical data from a variety of sources; both external (Biastutti, 1985, Moreton 1998, Explosives Incidents Database Advisory Service) and Internal information from HAZOP studies, FMEA work and incident reports. This allowed prioritisation of areas with known accident history. Over 70 initiating events were identified in the safety report, this was reduced to 38 candidate indicators by aggregating events sharing the same safety barrier, and further refined by the team to focus on measures that are currently monitored and can be closely identified with high hazard processes or generic site wide indicators. This produced a set of 22 indicators covering performance for People, Plant, Process, Procedure and Planned Preventative Maintenance (PPM). Of these the indicators covering people, plant, procedure and PPM are largely generic and transferable across the whole organisation.

The process indicators are more specific to the safe operation of the nitroglycerine facility; with four of the six process indicators being monitored when NG is manufactured. Using measures that already form part of the plant operational control makes maximum use of resources, and maintains visibility of PSPIs. Indicators include conversion efficiency and composition of the process acids. The spent acid after separation from the acid/nitroglycerine emulsion was identified as a key factor in several incidents, and may cause the greatest off-site disturbance to the local community. The overall conversion efficiency of nitroglycerine manufacture gives a very strong indicator for the general 'health' of the plant. Any shortfall in inventory is a very serious concern, it may be due to a loss of containment or poor separation both of which put highly hazardous material in the wrong place. The increased risk in spill clean-up is an order of magnitude greater than normal operation.

PPM and plant performance indicators have been selected to ensure that controls, equipment and instruments are available, calibrated and maintained. Monitoring of alarms, trips and unplanned outages provide very valuable measures of equipment and safety systems. Condition monitoring for key process equipment is measured and scored against the planned schedule.

Safety culture and management performance indicators covering people and procedure have proved much harder to implement. The selection and identification of performance indicators for 'safety culture' has been greatly assisted by sharing experience and best practice across the explosives industry. An industry led stakeholder group was established with the support of the HSE Explosives

Industry Forum in July 2011 to bring together companies across the military and civil explosives sector to compare approaches, results and lessons learnt. This stakeholder forum has generated valuable insight for Roxel UK and brought the benefit of over 20 safety professionals' knowledge and experience together.

Safety leadership performance may be measured by senior management visibility and actions to resolve safety concerns. In an SME the management is often closer to the workforce, however this may not guarantee that the right questions are being asked or the right answers being given. For the Safety leadership of the senior management to enhance performance the indicators must measure a tangible outcome with value, such as close out on actions or safety concerns resolved. The raising of safety concerns and the timely reporting of 'dangerous occurrences' or 'near misses' is a key indication of safety culture, and requires positive safety leadership. However setting specific number targets for reporting safety issues can lead to reporting of trivial matters which may obscure more serious concerns. If behaviours change in response to SPIs, have the right outcomes been achieved or have the SPIs become the goal rather than the real activity?

The reporting of the performance indicators is also key to the impact and clarity of the measures. Safety KPIs form the primary means of management feedback for the control of process safety risk and form part of the business assurance model for safe operation (Brown, 2009).

An effective reporting template to bring the key information from the SPIs to senior management attention and allow the prioritisation of management intervention was developed. This template is designed to allow the detail of SPIs to be seen at an appropriate level. The 'process' and 'plant' indicators are linked back to operating data collected at the facility. This data is plotted to show the long term trends. The next level is to reduce the number of indicators displayed by combining the SPIs scores from a matrix to a 'traffic light' display. *See* Fig 2. Any red or amber light is carried forward as the display is simplified; there is no weighting of the scores to average out the indicators. A green indicator will always be overwritten by red or amber. An all green display is the desired outcome, but should trigger a review of the indicators if it is maintained over several reporting cycles.

As SPIs are extended to cover all the facilities on the site these scores will be combined further to produce a simplified display for senior management with the ability to mine the data when required. The display of a trend for changes in the SPIs score is considered to be important. Initially we displayed the previous score as a faded colour next to the current value. The display has been extended to cover the six previous results.

Each type of SPI may need to be measured at a different frequency or by selective sampling techniques. Manufacturing and operational indicators may need to be considered on a production run or shift basis. Confirmation that plant is operating within the process control envelope, is better than relying on a measure of 'safety alarms that failed to operate as designed'. Longer intervals such as weekly or monthly measures for plant maintenance and material storage are reasonable without losing detail. Monthly to quarterly intervals for audit based measures of risk assessments, procedures and permitting for example, allow best use of a limited audit resource in an SME.

Table 1. SPI selection for nitroglycerine manufacture

Safety Barrier	SPI	Lead/Lag
People	Competence audit	Lead
	Training record	Lead
	Operational team skills	Lag
	Workplace inspection	Lag
	Accident frequency rate	Lag
Plant	Centrifuge vibration	Lead
	NDT testing	Lead
	Pre-run checks	Lag
	Time to repair	Lag
Process	Free NG in acid	Lead
	Product analysis	Lead
	Process conversion %	Lead
	Spent acid composition	Lag
	Nitrating acid composition	Lag
	Production schedule adherence	Lag
Procedure	Change control	Lead
	Documentation correct	Lead
	Permit audit	Lag
	SHE action close out	Lag
PPM	Calibration adherence	Lead
	Maintenance schedule	Lead
	Unplanned outage rate	Lag

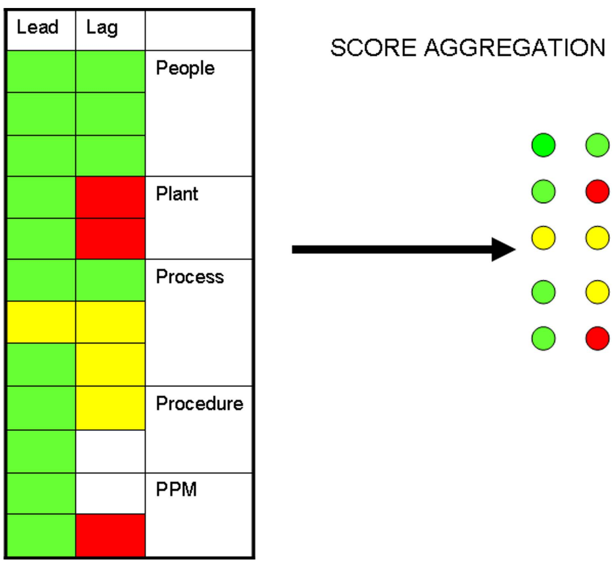

Figure 2. Aggregation of facility level SPI matrix to traffic light

CONCLUSIONS

As an SME involved in a high hazard manufacturing process Roxel UK faced a difficult task in developing SPIs to aid management focus on safety. Using the approach set out in HSG254 by the HSE and the OECD guidance consumes considerable time and resource. By starting with the NG plant Roxel has been able to develop the skills in house to select, implement and review SPIs on a 'small' scale prior to rolling out the scheme across the site.

Concentration on the highest hazards and processes, delivers the maximum benefit from a limited resource. Review of past accidents gave data to support the selection of SPIs, which could indentify the pre-cursors to a major incident. The sharing of experience and knowledge through a peer-to-peer forum has proved invaluable for measures around safety culture and leadership.

The selection of SPIs is not set in stone and some measures may not be capturing the best information. Periodic review of SPIs allows the indicators to evolve as experience is gained. The use of dual purpose indicators that can be shared for quality or process improvements is recommended.

ACKNOWLEDGEMENTS

The author wishes to thank Roxel (UK Rocket Motors) Ltd for permission to publish this paper. The views expressed in this publication are those of the author and do not necessarily reflect the opinion of Roxel. The Author also wishes to express his thanks to the members of the HSE Industry Stakeholder Group on Safety Performance Indicators for the Explosives Sector for allowing presentation of their discussions in this paper.

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