Driving quality and consistency in barrier management through the application of best practice quality rules and corporate standard bow ties in developing asset specific bow ties

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The paper's objective is to share learning from applying best practice rules and the use of corporate standard bow ties to improve barrier management and the management of major accident risk for assets across an organisation.

Over the last 30 years we have seen a five to ten-fold improvement in safety performance in the process industries. Much of the improvement has been for occupational safety. Based on data available, any improvement in major accident / process safety is less evident. Such accidents, although infrequent for individual organisations, have the potential to harm multiple people and the environment, and can have a material impact on an organisation's operations and its (and the industry's) reputation. Many organisations are, therefore, looking to use "barrier management" to improve their management of major accident risk.

One tool which communicates the barriers which manage the risk of major accidents is the bow tie. Historically, although people have developed bow ties for similar major accidents and similar purposes, a diversity in bow ties has been evident across and within organisations. Differences are not necessarily wrong; however, variations in descriptions across assets may make an organisations Barrier Management System unnecessarily complex.

CCPS and the Energy Institute published "Bow Ties in Risk Management, A Concept Book for Process Safety" in 2018. Drawing on experience from different organisations in different industries and countries, this book defines best practice rules and describes a standard approach for developing bow ties. It also describes a wide range of uses of bow ties within an organisation's barrier and risk management activities. Some organisations have now been applying these rules and approaches for over a year. It is therefore appropriate to collect together and share the learning gained.

This paper pulls together and shares this learning in applying the best practice quality rules and the use of corporate standard bow ties to:

- Drive quality and consistency in asset level bow ties.
- Set a consistent basis / expectation for the management of similar potential major accident events.

It shares this learning with examples drawn from SBM Offshore experience. It explains challenges experienced and how these were overcome, shows the benefits gained, and provides guidance on how to develop and use bow ties effectively as part of your barrier management activities.

To a large extent the work described has focused on improving bow tie quality and barrier management effectiveness within areas where bow ties were already being used. It has, however, been undertaken with an eye on how barrier management can be improved and enabled in a more "digitised" future world. The paper will conclude by presenting ideas and a vision for developments over coming years to support and enable more proactive and effective barrier management, explaining the importance of the best practice rules and use of a corporate standard bow tie structure to this. More advanced barrier management has the potential to support better major accident risk management, leading to further safety performance improvement.

Keywords: Barrier management, process safety, bow ties, risk communication

Introduction

Objective

The objective of this paper is to share learning from applying best practice rules and the use of corporate standard bow ties, as defined in the Center for Chemical Process Safety (CCPS) and Energy Institute (EI) 2018 book; "Bow Ties in Risk Management, A Concept Book for Process Safety", to improve barrier management and the management of major accident risk for assets across an organisation.

Background

A bow tie diagram provides a powerful graphical representation of how the risk of a potential (adverse) event is managed, which is readily understood by all levels of operations and management; the 'non-specialist'.

The exact origin of bow ties is an open discussion; however, it is believed that they were originally called "butterfly diagrams" and evolved from the cause consequence diagram of the 1970s. It is then thought that David Gill of ICI plc. further developed the process and called them bow ties in the late 1970's. It is generally accepted that the earliest mention of bow ties appears in the ICI HAZAN (Hazard Analysis) Course Notes 1979, presented by the University of Queensland, Australia.

The process was given a huge boost in the early to mid-1990's when the Royal Dutch / Shell Group developed its application following the Piper Alpha disaster. Shell is acknowledged as the first major company to integrate the use of bow ties into its business practices. As the 1990's grew to an end, the process' use became standard within many organisations. The bow tie was particularly popular in offshore oil and gas safety cases where they were, and still are, used to graphically present how the risk of potential major accidents is managed. Bow ties are currently used by a wide range of companies, industries, countries and regulators as a tool in the management of the risk of adverse events which may have a range of causes and consequences, (e.g. environmental, safety, business, political, security, etc.).

As shown in Figure 1, causes (often called threats), are identified and depicted on the pre-event (left) side of the bow tie. Credible consequences and scenario outcomes are depicted on the post-event (right) side of the diagram, and associated barriers[1] and their degradation controls[2] are included.

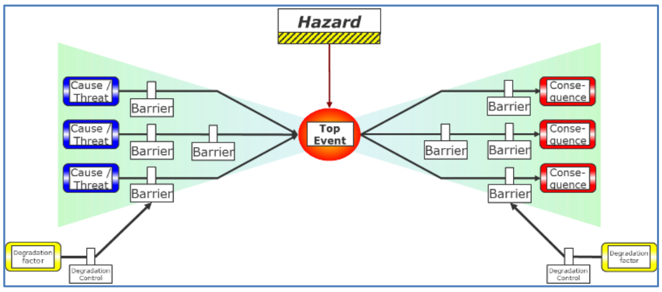

Figure 1 Bow tie image with diagram elements named

Over the last 30 years we have seen five to ten-fold improvement in safety performance in the process industries. Much of the improvement has been for occupational safety (see Figure 2). Based on data available, any improvement in major accident / process safety is less evident (see Figure 3). Such major accidents, although infrequent for individual organisations, have the potential to harm multiple people and the environment, and can have a material impact on an organisation's operations and its (and the industry's) reputation. Many organisations are, therefore, looking to use "barrier management" to improve their management of major accident risk.

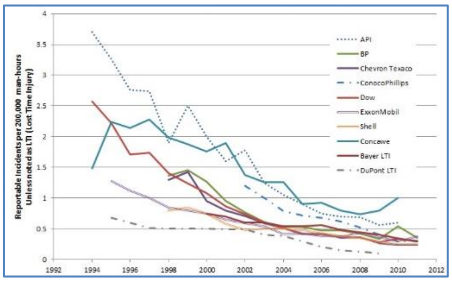

Figure 2 Occupational safety performance (produced by DNV GL based on data taken from public sources)

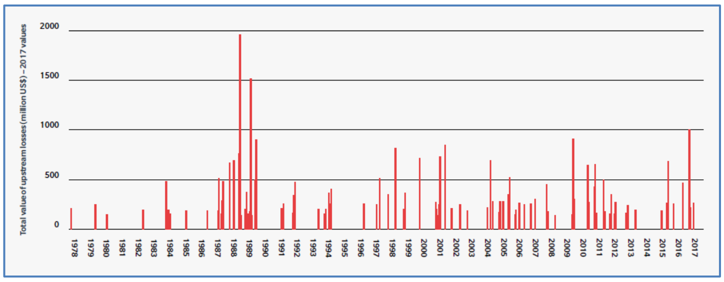

Figure 3 Time (and magnitude of insurance paid) for the 100 largest insured loss events in the hydrocarbons industry from 1978 to 2019 (Marsh 2019, "100 Largest Losses in the hydrocarbon Industry 1978 – 2019")

At the end of 2018 CCPS and the EI published "Bow Ties in Risk Management, A Concept Book for Process Safety". The book was written to address a range of issues with the variability and quality of bow ties being produced (see box with list or reasons for writing the book). Its aim is to "equip the novice or even experienced reader with the requisite skills and knowledge in order to develop quality bow ties".

"*Well constructed bow ties, which are clear and enable easy communication, can give the impression that they are easy to create. This is not the case. Too often bow ties are created with structural or other errors which can significantly degrade their value.*" (CCPS & EI, 2018).

Drawing on experience from different organisations in different industries and countries, the book defines best practice rules and describes a standard approach for developing bow ties. It also describes a wide range of uses for bow ties within an organisation's barrier and risk management activities.

Some of the reasons given for the writing of the book (based on Johnson, M, 2017 and Cowley, C, 2018):

- Confusion about who (and what) bow ties are for.
- Poor analysis; not fully benefitting from the method.
- No universal terminology.
- No generally accepted methodology, only proprietary company or software guides.
- 'Human and organisational factors' confused and ineffective, needs better treatment.
- Lack of rigour in constructing bow tie elements:
  - Hazard or Top Event description vague or confused with Consequence.
  - Consequence not the end point of the incident, too vague.
  - Threats / causes not a direct cause of the top event, a barrier failure not initiating event, not specific.
  - Incomplete barriers: barrier elements listed as 'the barrier'.
- Structural errors: e.g. degradation controls shown as barriers.
- Unfair criticism that bow ties over-simplify incident causation.

Some organisations have now been applying these rules and approaches for over a year. It is therefore appropriate to collect together and share the learning gained. The learning is shared in this paper based on the work and experience of DNV GL, SBM Offshore and CGE Risk Management Solutions.

[1] A "barrier" is a risk reduction measure (device, system or action) which directly prevents the occurrence of, or mitigates the consequence of, an undesired event. In the general risk world "barriers" are called "controls". The term "control" has a broader meaning also covers bow tie "degradation controls".

[2] A "degradation control" is a risk reduction measure to maintain the condition of a barrier (i.e. to prevent the impairment, failure or loss of effectiveness of a barrier). It is not a "barrier in its own right".

Quality Rules

The best practice guidance in the book can be summarised into a set of quality rules (see Table 1) which if followed help produce bow ties which clearly communicate how the risk of a potential adverse event is managed and are useable in many different practical situations.

Table 1 Summary of bow tie quality rules

Element (see Figure 1)	Element description	Rules / good practice
Hazard	An operation, activity or material with the potential to cause harm to people, property, the environment, business or other objectives and goals.	• Is what you seek to control, in its controlled state. • Must link directly to the (top) event. • Should be specific not generic. • Can include other information, e.g. situational context and indication of scale. • Note: one hazard can generate more than one top event.
Top Event	An event in which control of the hazard is lost.	• Is the moment when control over the hazard or its containment is lost releasing its harmful potential. • Should describe how / what control is lost. • Avoid common errors – should NOT be a threat (e.g. corrosion of the tank), a consequence (e.g. explosion) or a barrier failure (e.g. high-level alarm fails).
Cause / Threat	An initiating event, circumstance or situation that can potentially release a hazard and produce a top event.	• Should be sufficient to lead to the top event – be a specific direct cause. • Should potentially result in all the consequences. • Should be credible. • Avoid common errors – should NOT be a barrier failure (e.g. not wearing personal protective equipment (PPE)).
Consequence	A direct undesirable outcome of an accident sequence that results in harm to people, property, the environment, business (assets, operations or reputation), or other objectives and goals.	• Good practice to define as; "Damage" due to "event", e.g. environmental damage due to liquid spill. • Any or all consequences could result (multiple routes from the top event). • Should not be defined at too detailed a level (e.g. separate minor injury, major injury and fatality consequences) as mitigation barriers are likely to be the same and the number of branches will be unnecessarily increased.
Barrier	A risk reduction measure (devices, systems, or actions) which directly prevents the occurrence of, or mitigates the consequence of an undesired event. • *Prevention barriers* are barriers (to the left of the event on the diagram) which stop a threat(s) / cause(s) resulting in a top event. • *Mitigation barriers* are barriers (to the right of the event on the diagram) which stops a top event resulting in a consequence or reduces the severity of the impact of the consequence.	• Can be physical or non-physical measures made up of hardware, software and / or human actions. • Should be: o *Effective / fully functional* i.e. capable of completely stopping a threat / cause resulting in a top event or stopping or reducing the magnitude of a consequence resulting from a top event. o *Independent* of the threat / cause or other barrier on their branch. o *Auditable*. • Will deliver their function on demand in a passive (e.g. firewall), or active (e.g. fire sprinkler system) manner or operate continuously to deliver their function (e.g. an anode). • Active barriers should be complete systems, which detect a condition, decide what action is needed and act to deliver their prevention or mitigation function. • Can recur across different parts of the bow tie, however they should only appear on either the prevention or mitigation side of the bow tie, and only once on a threat / cause or consequence branch. • Good practice is to place in time sequence of their effect. • Avoid common errors - Should NOT be degradation controls, i.e. should not include words such as "training", "competency", "policy", "procedures", etc., and should NOT be incomplete barriers (e.g. fire and gas detection).
Degradation Factor	A situation, condition, defect or error that compromises the functionality of a barrier.	• Should be sufficient to lead to the impairment, failure or loss of effectiveness of the barrier(s) it is linked to – be specific.
Degradation Control	A risk management measure to maintain the condition of a barrier (i.e. to prevent its impairment, failure or loss of effectiveness) not a barrier.	• May follow rules for barriers, but current practice is less rigid.

Corporate standard bow ties

For many organisations, the assets they operate have commonality in the types of major accident they have to manage. For example; two offshore oil and gas platforms, operated by one company, may both have to manage the risk of a potential loss of containment of hydrocarbons from topsides process equipment. Although barriers used to manage the risk may not be identical on similar assets due to the differences between the assets (e.g. in their locations, physical layouts, number and presence of personnel, process fluids, age, design and more) it is likely that they would have many similarities. Given this, it would be expected that bow ties, which present how the risk from these common potential major accidents is managed, would be similar.

Corporate standard bow ties set out broad, generic and standard strategies for the management of the risk of common potential events through implementing "barrier functions" and provide options on how to deliver these functions using specific "barrier systems". These standard bow ties provide the core information from which asset bow ties can be developed as the asset can select the "barrier systems" they have in their design / in place. The asset can then add detail as needed, such as the "barrier elements" which make up these systems. This gives them the information they need to effectively manage the risk of their potential adverse events. Additionally, the corporate standard bow ties provide a common structure facilitating comparison and oversight of barrier management between and across all their assets.

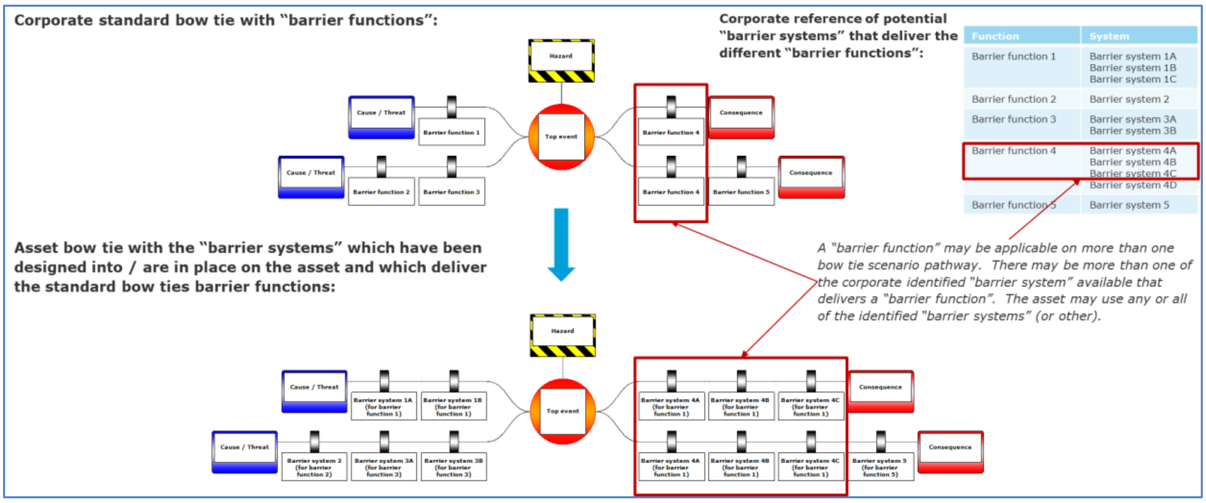

Figure 4 Illustration of the relationship between a corporate standard bow tie and an asset bow tie

The approach aligns well with the Norwegian Petroleum Safety Authority's (PSA's) three levels of definition of a barrier model (PSA, 2013, 2017), see Figure 5.

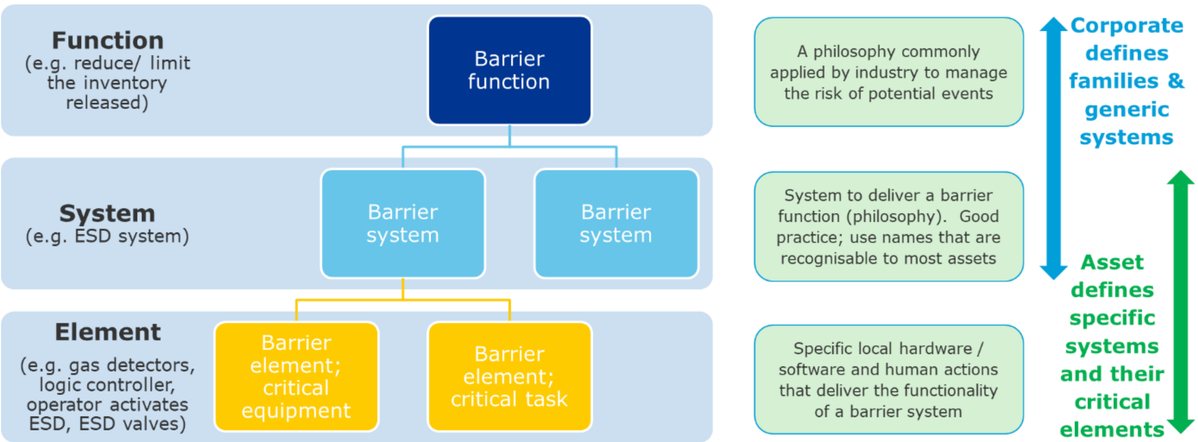

Figure 5 Illustration of the relationship between a corporate standard bow tie and an asset bow tie

Application in SBM Offshore

Historically in SBM Offshore bow ties had primarily been developed locally by assets with the assistance of a range of consultants to go into their safety cases for their assets. This is not uncommon for many companies. For SBM Offshore, these historical bow ties were developed in alignment with the contents of the International Association of Oil and Gas Producers' (IOGP's) document "Standardization of barrier definitions" (Supplement to report 415, report 544, 2016) and used to define hard barrier systems to go into their Assets Integrity Reporting.

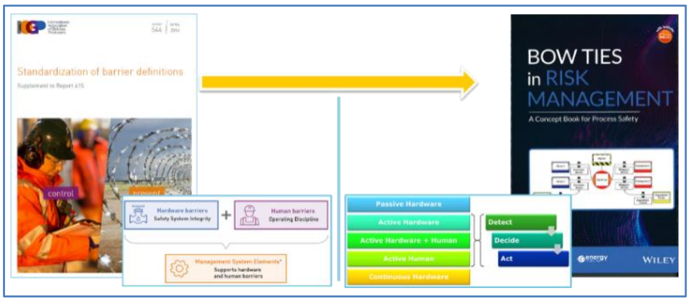

Figure 6 The evolution of barrier management in SBM Offshore

Building on this basis, SBM Offshore have been developing their Hazard and Effects Management Process (HEMP) to improve their process safety performance. Within this programme they have embraced the use of bow ties and have a vision to deliver an active barrier management system to provide their personnel with "live" information on the current status of critical barriers in order to assist in real-time decision making. They are also taking onboard the best practice as in the CCPS and EI book (2018) in this journey.

The developments and their implementations are being led by their "operational excellence" team and are highly supported by their top management, who are looking for implementation across all parts of their organisation, i.e. both projects and operations, which they refer to as "execute" and "operate".

The programme to achieving "live bow ties" is well underway and has included both training to build competence, development of bow ties, acquisition of software tools, and the development and documentation of work processes. Progress so far covers the first three steps in the barrier management cycle (see Figure 7) and work is progressing round the loop, with a 'proof of concept' on a live barrier model expected in the latter half of this year.

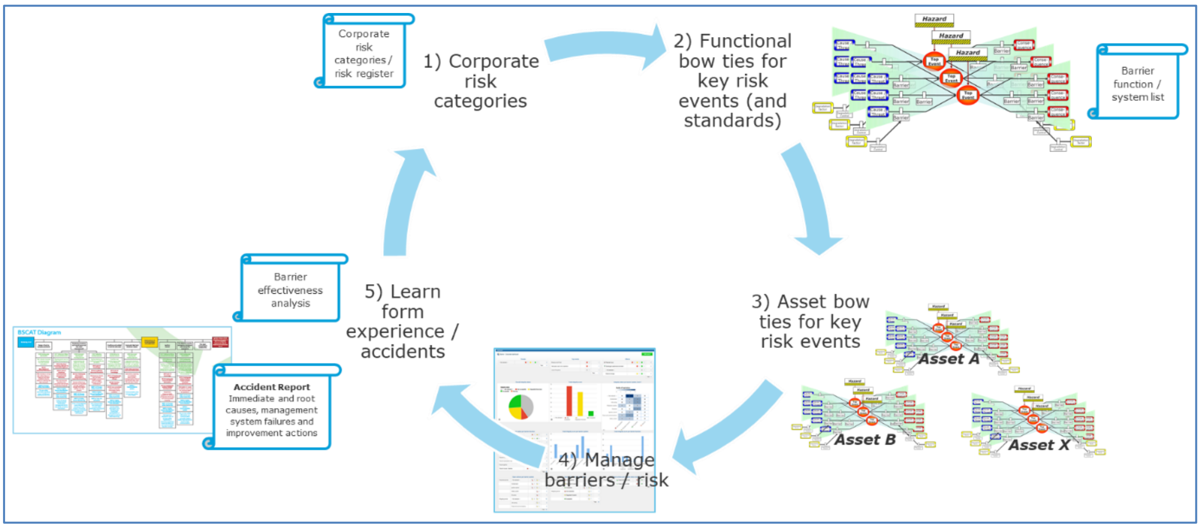

Figure 7 Typical barrier management cycle

The steps in the process covered so far are:

1. **Identification of the hazard – top event** for which bow ties are to be developed from SBM Offshore's level 1 Operations Hazard and Effects Management Register.
2. **Development of the corporate standard bow ties** with barrier functions. Called "parent" bow ties in SBM Offshore.
3. **Development of the asset bow ties** which show the asset's barrier systems (plus other meta data). Called "child" bow ties in SBM Offshore.

Each are now discussed in terms of the work done and the learning gained.

Identification of the hazard – top event for which bow ties are to be developed

The initial list of common hazards - top events were developed based on both a high level break down of the hazards and effects of their floating production storage and offloading unit (FPSO), augmented with a recent hazard identification study (HAZID) for a new FPSO design. The two were brought together as presented in Table 2, which also indicates the major accident events (MAEs) for which parent bow tie have been developed.

Table 2 FPSO hazard – top event list for MAE bow ties

Top level	Second level	Third level	Parent bow tie
Failure to control hazardous materials	Loss of containment of hydrocarbon well / process stream fluid / other hazardous fluids (flammable and may contain toxics)	• Loss of containment of from a production or injection well	*N/A for FPSO*
		• Loss of containment of from risers or subsea equipment	✓
		• Loss of containment in turret cylinder	✓
		• Loss of containment of on topsides	✓
		• Loss of containment of from hull storage tanks	✓
		• Loss of containment in machinery spaces and pump room	✓
		• Loss of containment of helifuel	✓
	Oxygen ingress to cargo tanks (creating flammable atmosphere)		✓
	Hydrogen release from batteries		*Not a MAE*
	Failure to control flaring or venting	• Flaring and venting to unsafe location	✓
		• Liquid carryover in flare system	*To be developed*
	Ignition of flammable open materials (e.g. explosives or furnishings)	• Ignition of furnishings etc. in the accommodation block	✓
		• Ignition of explosives in stores or on asset	*To be developed*
		• Ignition of electrical / mechanical equipment	*Not a MAE*
Failure to control structures	Loss of structural integrity	• Loss of topsides structure integrity	✓
		• Loss of hull structural integrity	✓
		• Loss of mooring	✓

Top level	Second level	Third level	Parent bow tie
Failure to control major operational activities	Loss of control of vessel	• Loss of control of vessel outside the exclusion zone	✓
		• Loss of control of visiting vessel	✓
	Dropped object	• Heavy lift dropped load (e.g. during construction / major modification)	*To be developed*
		• Drop of major load during drilling	*N/A for FPSO*
Transport of people accidents	Aviation accident	• Loss of control of helicopter	✓
	Maritime accident	• Loss of control of vessel when transporting personnel	*N/A - Not using marine transfer*
		• Loss of control of transfer method (e.g. gangway) when personnel getting on or off the asset	*N/A - Not using marine transfer*
Occupational H&S	Fall from height		*Not a MAE*
	Confined space asphyxiation		*Not a MAE*
	Food poisoning		*Not a MAE*
	Diving accidents	• Diver loss of breathable gas	*Not a MAE*
		• Diver comes to surface too fast (bends)	*Not a MAE*

Development of the corporate standard bow ties

The parent (corporate functional standard) bow ties were developed in workshops run in a similar manner to other hazard assessment such as HAZIDs or hazard and operability study (HAZOP).

Preparation for the sessions included:

- Creating the initial list of common MAEs (hazards / top events) for an FPSO as for a safety case and / or safety management system.
- Identifying subject matter experts (SMEs) with relevant experience and expertise required for the development of each parent bow tie.
- Developing a work plan / schedule for the session and identify the right people to invite to each part.
- Develop a presentation to kick-off the workshop sessions that explains the purpose of the sessions and the approach that will be taken, (including the quality rules).
- Making the administrative arrangements; schedule the session, send out invitations, book a room, etc.

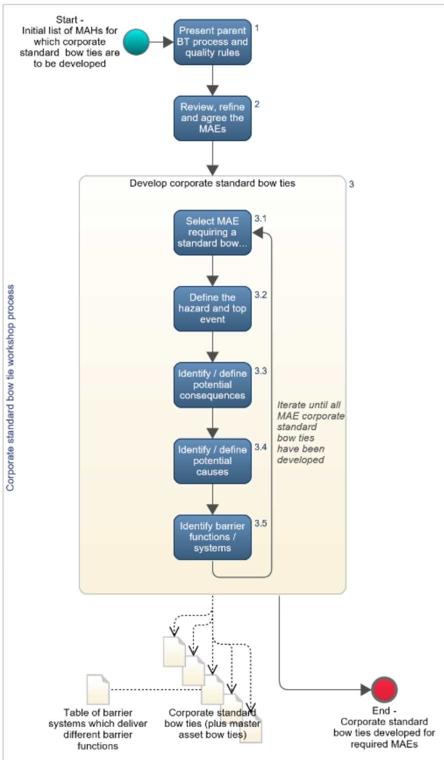

Figure 8 Parent / corporate standard bow tie workshop process

The workshop sessions followed a defined process.

- It started with the presentation on the purpose and process to be followed in the workshop.
- The initial list of high level MAEs was then reviewed and refined, and the MAEs for which parent bow ties were to be produced were agreed. The session's schedule was then defined based on the list of MAEs, so all knew when to attend.
- The parent bow ties were then developed for each MAE in turn along with a master table of potential barrier systems that deliver identified barrier functions, and to which bow tie (MAE) the systems apply. (Later, based on experience in developing the child bow ties, a "master child" bow tie was developed for each parent bow tie, this is discussed later).

Although written as a simple sequential process it should be noted that:

- The presentation of purpose and quality rules was revisited on occasions when new people joined the workshop sessions.
- The list of MAEs (hazard – top event combinations) for bow ties was revised when appropriate / necessary (e.g. when two parent bow ties were determined to be fundamentally the same or there was a need to separate MAEs to reflect differences in causes, consequences or barrier functions).
- As a quality step, the draft parent bow ties were reviewed and edited by risk / bow tie experts outside the sessions with changes shared back with and agreed with the SMEs. This also included taking on board the learning and discussion derived from the development of other / subsequent MAE parent bow ties.

As shown in Figure 8, the deliverables from the workshop were the parent bow ties with functional barriers (see Figure 9 and the table of barrier functions and barrier systems which deliver the functions.

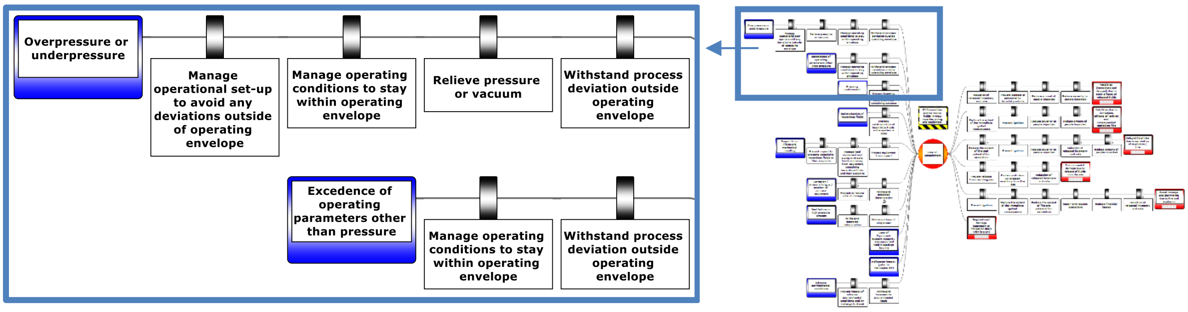

Figure 9 Illustration of a parent bow tie functional barriers (focus on two cause scenario paths)

Table 3 Extract from barrier function to barrier system spreadsheet

No.	Barrier Functions	Barrier Systems	Bow Tie: Risers and Flowlines	Turret Cylinder	LOC topsides	Cargo Tanks LOC	Flammable atm. in tanks	Venting	Pump Room LOC	Top sides structure	Hull Structure	Mooring	Vessel o/s 500m	Vessel i/s 500m	Helifuel LOC	Helicopter	Accommodation fire
M15	Prevent release from reaching sea	Plating, drains, coamings and bunds systems			✓	✓			✓						✓		
M16		Double walls and void spaces				✓					✓						
M17		Sealed compartment				✓											
M52	Reduce the extent of the immediate ignited consequence	Passive protections; fire walls, blast walls			✓	✓		✓	✓								
M54		Deluge on confirmed gas in order to reduce gas cloud size and blast overpressure	✓		✓	✓		✓	✓								

Good practices were used to help ensure that the right parent bow ties were developed, and they were well structured and presented so they could be easily used. Some of these are discussed and presented below:

1. **Ensuring that the MAE were comprehensive, yet not excessive, for the asset and its operations**. Table 2 shows how this was done for SBM Offshore's FPSOs using a hierarchy starting with the hazard over which control could be lost (e.g. hazardous materials, structure and major operational activities), then breaking it down based on hazard specifics, mechanisms of loss of control (the event) and its source / location. This is similar to how accidents are defined for a quantified risk analysis (QRA) or the sectioning of a process for a HAZOP, except at a higher level.

2. **Ordering consequences top down using the "PEAR" acronym and how the event would naturally develop**. PEAR stands for:

    a. "People" – covers all outcomes where there was potential harm to people, whether the harm occurs immediately or later in the events development.

    b. "Environment" – covers all adverse impacts on the environment.

    c. "Asset" – covers asset damage. As SBM Offshores standard risk matrix defines 'Finance' rather than 'Asset', the initial parent workshop also included discussion on lost production, and other financial losses (e.g. fines and legal bills); however, this was later removed as it was considered beyond the scope of managing MAE. For example, 'loss of water injection' may result in significant financial losses; however, it does not fit the generally accepted definition of a Major Accident Event in the industry;

    d. "Reputation" – covers the impact on the company's reputation. This consequence scenario branch was not developed in the work completed as, although relevant to SBM Offshore, it was outside the scope and control of those managing MAE. The enterprise risk function may pick this up in the future.

    The PEAR acronym helped in making sure all potential consequence outcomes had been covered and provided a consistent structure to the bow tie to support their understanding and use. For other organisations an alternative model could used to align with their corporate values.

3. **Ordering causes first considering operational, maintenance, primary control degradation, external and other causes**. These were:

    a. **Operational** causes (e.g. overpressure, excessive speed, …) – Aspects for which the operational personnel are likely to be responsible.

    b. **Maintenance activities** causes (e.g. breaking containment, …).

    c. **Primary control system degradation** threats (e.g. corrosion, erosion, fatigue and stress).

    d. **External** causes (e.g. external impact, earthquakes, …)

    e. **Other** causes as identified which do not fit to those categories given above

    Again, the approach helped make sure all relevant potential causes had been covered and provided a consistent structure to the bow tie to support their understanding and use.

4. **Ordering the barrier based on their purpose and the natural sequence in which they would be called upon**. The four possible purpose of barriers are depicted in Figure 10.

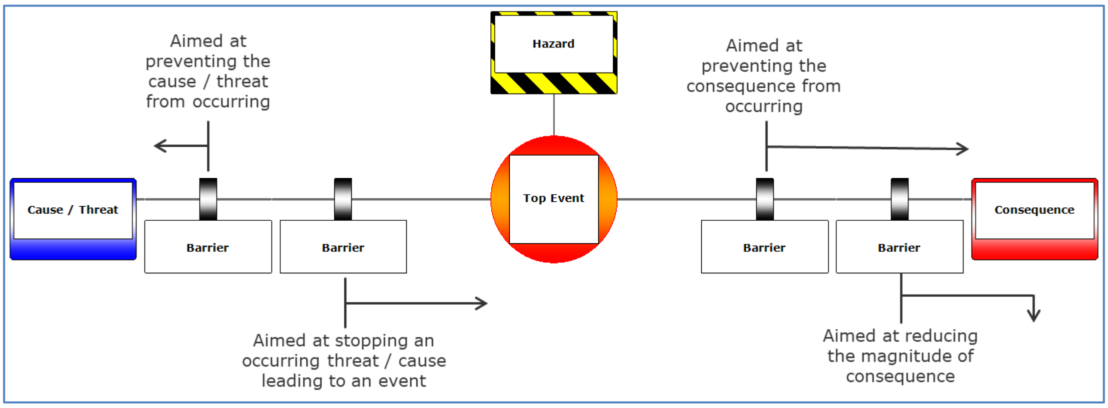

Figure 10 Four barrier purposes

5. **Consistent style in the barrier function naming** was used, as far as was practical. This was not implemented in a rigid manner and in some cases different initiating words were used. Using the verb at the beginning supported both consistency in style and helped ensure the wording was a function. The wording used is presented in Table 4.

Table 4 Barrier function naming approach

Start barrier function with:	Description / barrier system examples	Purpose
Prevention barriers:		
Remove …	Barrier function is to remove the causal source (e.g. remove of corrosive chemical such as hydrogen sulphide (H_2S) from process fluid).	Aimed at preventing the cause from occurring
Prevent …	Barrier function does not remove the causal source but resists the cause (e.g. corrosion resistant lining, chemical injection, and anodic protection).	
Manage …	Barrier function keeps conditions within operating envelope (e.g. operator monitors and adjusts process parameters, and safety instrumented system).	
Protect …	Barrier function ensures that although the cause has resulted in an unacceptable deviation it is controlled and does lead to top event (e.g. mechanical relief).	Aimed at stopping an occurring threat / cause lead to an event
Withstand …	Barrier function resist a level of the damage made by the cause, i.e. withstand or tolerates a deviation outside design parameters (e.g. safety factor on structural members or a corrosion allowance).	
Mitigation barriers:		
Prevent …	Barrier function stops the development of the scenario progressing to the named consequence (e.g. ignition control system).	Aimed at stopping an occurring event lead to a consequence
Reduce …	Barrier function does not prevent the scenario progressing to the named consequence but reduces the magnitude / severity of the consequence (e.g. separation of occupied areas from hazardous equipment, a fire suppression system).	Aimed at reducing the magnitude of the consequence
Remove …	Barrier function is to take the impacted element (or part of it) away from the consequence (e.g. on detection of the event the personnel evacuate the facility).	
Treat … **Clean-up …** **Repair …**	Barrier function is to recover from the damage (e.g. medical treatment, environmental clean-up business continuity / business resumption action).	

It should be noted that the term "inherent safety" as the name of a barrier system was avoided. Rather the inherent safety feature was named (e.g. separation of occupied areas from hazardous equipment). The later defines what needs to be managed / maintained.

Development of the asset bow ties

The child (asset) bow ties were developed in workshops. This has been completed for a four SBM Offshore FPSO at the time of writing this paper.

Preparation for the sessions was similar to that for the parent bow tie sessions described above, other than the first task (bullet) being to:

- Create, from the FPSO's (asset's) HAZID, the list of the FPSO's (asset's) MAEs / hazards - top events for which asset bow ties are required.

The workshop sessions followed a similar process to that for the development of parent bowties, see Figure 11.

- It started with the presentation on the purpose and process to be followed.
- The FPSO's MAEs were mapped to relevant parent bow ties.

- The child bow ties were then developed for each MAE in turn. The barriers were detailed (e.g. their types were defined, the equipment from SBM's standard safety and environmental critical element (SECE) list was attached to the relevant barriers, and other meta data added). Finally, a barrier criticality analysis was undertaken to identify the "critical" barrier systems[3].

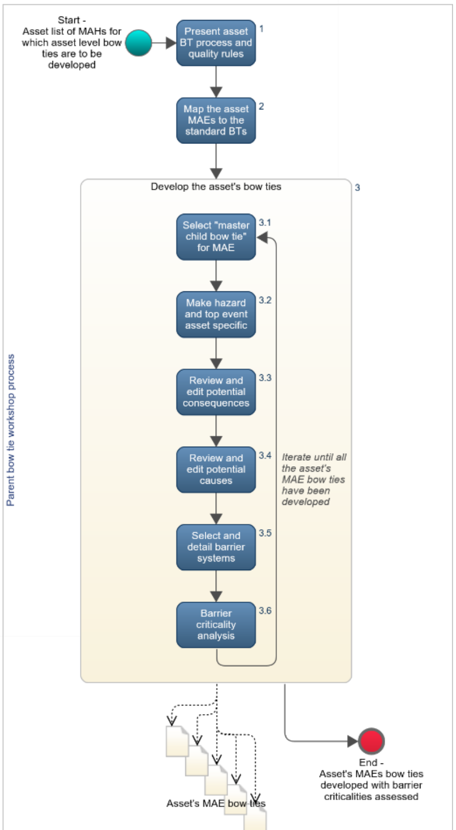

Figure 11 Child / asset bow tie workshop process

Good practices and the quality rules were followed to help ensure that the child bow ties were well structured, contained relevant details for their use and had the criticality of barriers assessed. Some of these are discussed and presented below:

1. **The MAEs hazard descriptions in the bow tie were defined to be clear on where they apply (Step 3.2)**. There is a need to define each child bow tie's hazard and top event such that it is clear where on the FPSO they may occur, and what equipment they cover. Writing in detail makes the hazard box large and reduces the communicability of the diagram. It was found for communicability / usability the text used for the hazard needed to be kept clear and simple, with added information on the MAE's definition stored elsewhere (can be in the bow tie software or separately). It was found that the top event name generally was <u>not</u> changed from that in the parent bow tie.

2. **Having a clear scope for the intended use of the bow ties helped the consequences and causes included (Steps 3.3 and 3.4)**. The scope for the child bow ties was to develop scenarios specific to the hazard management approach, rather than the traditional MAE grouping applied previously. For example, where-as previously SBM Offshore might have one bow tie for *Loss of Containment of Hazardous Fluids Topsides*, in the new process specific bow ties were developed for; *Flammable Fluids*, *Flammable Gas*, and *Toxic + Flammable Fluids.* This meant that the parent consequences were replaced with consequences specific to the hazard (e.g. dropping toxic consequences where there were none and limiting immediately ignited consequences to fires for liquid releases). The clear scope further enabled the separation of specific causes (where they were grouped in the master) because there were specific issues to be managed in the scenario (e.g. parent "corrosion, …" cause being split into separate causes for "internal corrosion", "external corrosion", …, so the different approaches to managing these through barriers could be shown.

3. **Efficiency in the selection and drawing of the child bow ties was enabled by starting with a "master child" bow tie).** The first asset child bow ties were developed from the parent bow tie with functional barriers and the barrier function – barrier system table. Although this allowed child bow ties to be developed more efficiently and consistently than in the past (when they were developed from scratch). It was determined that it would be even more efficient to have used a master child bow tie. By using Master Child bow ties, it was found that 23 asset specific bow ties were able to be produced in 5 days, which was the same amount of time used to produce 10 -15 bowties previously.

   A parent bow tie has barrier functions only, a master child bow tie has all foreseen barrier systems that deliver barrier functions, see Figure 12.

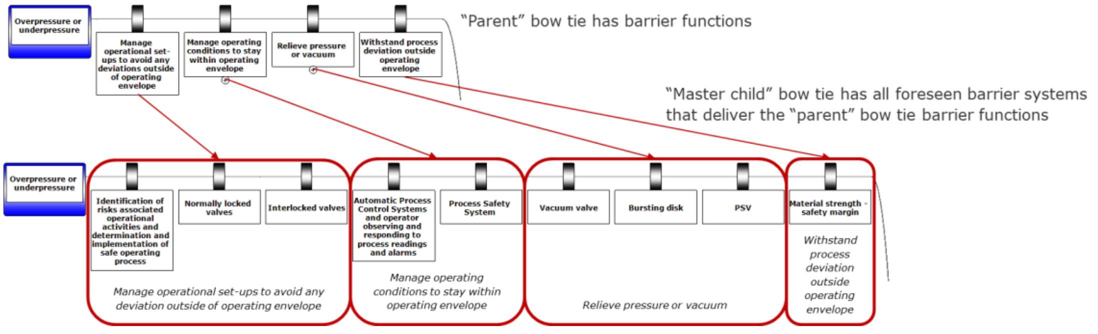

Figure 12 Parent bow tie to master child bow tie barrier relationship illustrated with a single cause scenario branch

The workshop simply keeps the barriers in the master child that they have and deleted they don't, see Figure 13.

[3] To date the criticality analysis has been at the barrier system level. A future potential step will be to assign criticality at the barrier element and degradation control level. Currently our thinking is that this will be an additional step best done by a specialist after the criticality assessment workshop.

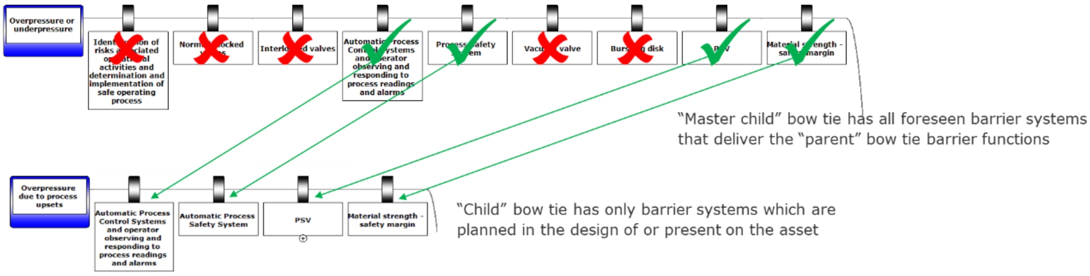

Figure 13 Editing a master child bow tie to produce a child bow tie, illustrated for a cause scenario branch

4. **Having a clear scope for the intended use of the bow ties helped define the barrier meta data recorded.** The use scope of the bow ties meant that meta data requirements were clear. For example, one planned use was to help identify the critical barriers and from there to develop their related SECE performance standards. To support this the SBM Offshore's default list of SECE was mapped to the relevant barriers, as was equipment types from their Maintenance Management System. (There was then some iteration based on the criticality assessment).

5. **Enabling the criticality analysis through use of a logical process aided by knowing the MAEs assessed risk levels and the importance of their causes and consequences.** A barrier system (or barrier element or degradation control) is seen as critical if, when it is not working, the MAE risk for the FPSO is noticeably increased; or, the risk is not noticeably increased, but there is an increased vulnerability, i.e. another barrier system failure and the risk will be significantly increased**.**

   To enable this analysis, firstly a discussion of the relative importance / contribution to the MAE risk of the FPSO was carried out by SBM personnel based on their experience. This discussion assessed (see Figure 14):

   - Firstly, each consequence in each bow tie as a Minor, Medium or Major concern to the overall facility MAE risk; and then
   - Each cause as a low, medium or high contributor to the overall facility MAE Risk

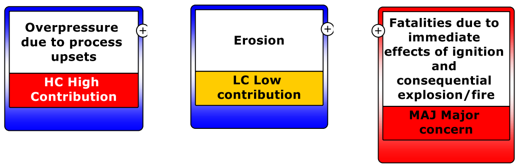

Figure 14 Illustration of causes and consequences importance classing

   The bow ties were then qualitatively reviewed following a structured process to identify which barrier systems were critical. This was achieved by reviewing each cause and consequence scenario branch in turn. Discussing the significance of the branch, the number of, and efficiency of each individual, barriers to define the criticality of each barrier system to the overall MAE risk of the facility.

6. **Including in the workshop process the asking of "what else" questions.** The parent / master child bow ties give a structure and standard. The standard is based on current good practices. They, therefore, may not cover everything an existing facility has in place or a new facility is being designed to include, or reflect how a risk may be managed in different environments, etc. It was therefore important to not be limited to the parent bow ties causes, consequences and barrier functions / barrier systems. The process followed always asked what else questions to help ensure the child bow ties captured what was important regarding an asset's MAEs and how their risk is managed.

Next steps and a vision for the future: "Live" barrier management

SBM Offshore undertake projects to design and build assets (which they call execute) and operate assets (called operate). The SBM vision for the future is to have a "live" barrier management system, where at any moment in time it is possible to see the current condition (or uncertainty on the condition) of all critical barriers relative to their required performance standard on their operating asset. This will allow operational personnel to understand if and to what degree they are "in control of their MAEs" and hence enable operational decision to be made and MAE risk kept As Low As Reasonably Practical (ALARP).

For their FPSO's, their approach to their business is to have a "standard" design (which they call Fast4ward), which is then modified to best suit the environment it is in, the operational conditions (flows, pressures, etc.) and customer requirements. The standard design provides for efficiencies in "execute" activities and consistency plus standardisation efficiencies for their "operate" activities. They have a continual improvement cycle to ensure the "standard" design gets better over time.

The parent / child bow tie approach fits well with this approach as it:

- Allows standard child bow ties and performance standards for SECEs[4] to be developed and maintained. These can then be updated through a management of change (MoC) process for the specific environment, design and operations of an FPSO. It therefore will allow SBM Execute projects to be delivered efficiently and in a timely manner, while building on their experience in MAE risk.
- Provides a structure for developing dash boards that are consistent across their operations and will allow corporate departments and management the ability to monitor barrier performance across their fleet. Such dashboards can

[4] Safety and environmental critical elements (SECEs) cover both hardware / software and human actions in barrier systems, barrier elements and degradation controls. Human action SECSs are sometimes called safety critical tasks (SCTs) or safety and environmental critical tasks (SECTs).

display the "live" condition of barriers and show these on "live" bow ties to support operational decisions and enable improved process safety (illustrated in Figure 15).

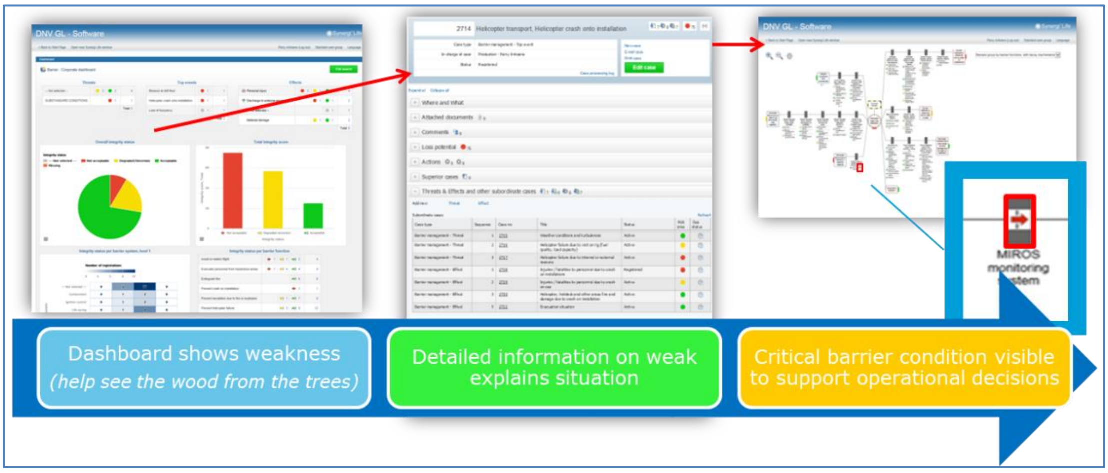

Figure 15 Illustration of a "live" barrier dashboard from DNV GL's Synergi Life

- Provides the basis for continual improvement through analysing and deriving learning from barrier performance across the fleet and from accidents and then implementing the learning in the parent bow ties and in Fast4ward FPSO design and its associated standard child bow ties and performance standards, i.e. moving round the barrier management cycle as shown in Figure 7).

These are in addition to the normal benefits of bow ties as a communication tool with regulators, operators, maintenance personnel, management, etc. to help them understand how the risks of MAEs (or other types of events) are managed and their roles in doing this.

SBM's next steps, which are being promoted and supported by its senior management are to:

- Continue to refine and improve their parent bow ties and their process to deliver the child bow ties.
- Review and enhance its approach to developing performance standards to ensure that they are produced in a timely manner during "execute" and provide the information on how to assure and verify performance in "execute" and maintain, assure and verify performance in "operate". The approach is being developed to cover the hardware / software SECEs (as has been the focus in the past) and the human action SECEs (which has been recognised in the industry as important to improving process safety performance).
- Document their work processes and produce guidance to help their personnel to deliver quality work, whether this be in producing child bow ties or writing performance standards, or in interpreting "live" barrier data and making operational decisions. The guidance and documenting of work processes is being developed with the collaboration of SBM personnel and external experts and is being produced as SBM Offshore documents which fit into their management system. There is a focus to make sure that barrier management and bow ties activities are embedded in and a natural part of the way SBM Offshore deliver their business.
- Improve their ability to manage the parent, master child and child bow ties through an enterprise wide implementation of CGE Risk Management Solutions' BowTieServer software.
- Put in place the system to operationalise bow ties; for monitoring barrier performance and supporting operating management and decisions. SBM Offshore are currently progressing delivering this using the e-vision software. Other software with capabilities to support barrier management include DNV GL's Synergi Life software and images from this software that are presented in Figure 15.
- Gathering learning on the performance of barriers and embedding these in their parent and master child bow ties, work processes and guidance documents, ongoing training programmes, and their Fast4ward FPSO designs.

All the above will be enabled by an ongoing training programme to give SBM Offshore personnel the ability to undertake all activities in their barrier management system and improvement loop. The programme covers barrier management and bow tie theory, significant time in practical exercises, discussion and reflection time, and additionally covers facilitation skills important to running child bow tie sessions. The training is currently delivered jointly by DNV GL, CGE Risk Management Solutions and SBM Offshore, but will transition to an internally led programme as SBM Offshore personnel build their knowledge and competence and complete a train the trainer programme.

Conclusions

Those involved in the work to date would recognise that there has been a major step forward in the quality of child (asset) bow ties developed, in the efficiency with which they have been developed and in their consistency, and that this is forming a solid basis for better barrier management, future "live" barrier management, all with the goal of delivering continually improving process safety performance. It is also recognised that this is a work in progress and that there are opportunities for further improvement in what has been delivered so far, as well as, through the implementation of the next steps and the realisation of "live" barrier management.

Benefits gained to date

1. The application of the quality rules has helped ensure bow ties (parent and child) are developed to a higher quality with far *less structural and other errors*. This is *improving clarity* on how the MAE risk is managed.

2. The application of the standard bow tie approach *helped ensure* the child (asset) *bow ties met the quality rules*, were *more consistent* in their form (across SBM Offshore assets), were *delivered efficiently* (it is estimated by those involved that the approach reduced the workshop time by at least 50%), can be *used effectively* as a communication and operational management tool, and are structured in a form that is s*upportive of SBM Offshore's long term vision of "live" barrier management and bow ties*.

3. The use of a Parent/Master Child that maps the barrier functions to barrier systems aids in communication of the critical function that barrier systems provide. This supports targeted discussions during operational risk assessments on SECE.

4. Improved *understanding* in SBM Offshore of the importance of barrier management, what a barrier is, how barrier management supports managing MAE risk and hence process safety performance, all the parts of good risk / barrier management (from HAZIDs, to bow ties, to identifying SECEs and setting performance standards, to verifying / demonstrating the are designed and built and subsequently operated and maintained right to gathering learning and implementing improvements).

5. Through the training and support, SBM Offshore now have personnel with *increased knowledge and competence* who are now taking forward the ongoing improvement and implementation of their HEMP process and specifically the barrier management and bow tie activities.

Learning gained applying the CCPS / Energy Institute book quality rules and standard bow tie approach

1. As for many changes, the *support of all levels of management* has been essential. To enable this the training was extended to share with them the work being done, allow them to have a go and to give them time to discuss and input to the solution vision ("live" barrier management and bow ties) and the delivery pathway.

2. The *quality rules* and the *standard bow tie approach* (parent – child approach) *improve* bow tie *quality* and *support more efficient and effective barrier management*.

3. The *good practices* shared in this paper and *followed* in SBM Offshore in delivering the work activities to date, which structured the workshop sessions and their deliverables, *helped deliver immediate benefits* (as well as setting the basis for moving to the "live" vision).

4. *Collaborative working* which included the support and guidance of experts, internal leadership and programme management and involving those with responsibility for designing, building, operating and maintaining barriers, helped ensure practical and accurate bow ties (i.e. bow ties that reflect what is actually in place and being done). This helped implementing the rules and processes, buy-in and starting operationalisation of barrier management.

5. *Training and documenting good practices* (in guidance and procedures) has helped and is helping SBM Offshore personnel build their knowledge / competence and undertake barrier management activities effectively themselves (e.g. facilitating child bow tie development, identifying critical of barriers / SECEs, producing practical performance standards, etc.).

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