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THE BOWTIE DIAGRAM: A SIMPLE TOOL FOR ANALYSIS AND PLANNING IN ANAESTHESIA

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ABSTRACT The Bowtie method is a qualitative incorporating management system technique becoming more popular, but it lacks a consistent approach. The bowtie has become popular as a structured method to assess risk where a quantitative approach is not possible or desirable. The Royal Dutch/Shell Group was the first major company to integrate fully the total bow-tie methodology into its business practices and then the bowtie has become popular as a structured method to assess risk where a quantitative approach is not possible or desirable. Its essence is to establish how many safety barriers there are available to prevent, control or mitigate the identified scenarios, and the quality of those barriers.

KEYWORDS :

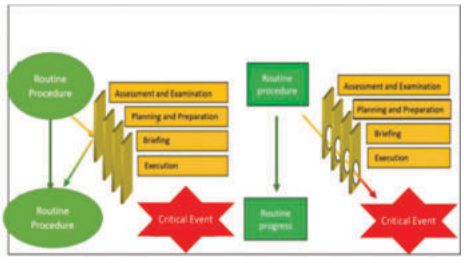
INTRODUCTION

Bow-tie analysis is a risk evaluation and management tool that has been readily adopted into routine practice in many high reliability industries such as engineering, aviation and nuclear energy. However, it has received little exposure so far in healthcare. Nevertheless, its simplicity, versatility, and pictorial display may have benefits for the analysis of a range of healthcare risks, including complex and multiple risks and their interactions. The bowtie method is one of the methods that has become popular in high hazard industries like oil & gas, aviation and mining. Bowtie diagrams were first suggested in 1979 [1] and have been used in high-risk industries such as aviation [2] and accident probability analysis since then [3].

The advantage of a bow-tie diagram is that it can display any of the factors that can influence outcome, from potential hazards and prevention measures, through to mitigation resources and recovery plans. Recently, they have been applied to healthcare [4,5] and anesthesia [6,7]. The diagram comprises a combined fault tree [8,9], which is similar in concept to a Swiss cheese diagram and an event tree [10,11], which are not commonly used in health but similar in concept to disaster response plans or emergency management pathways.

FAULT TREE

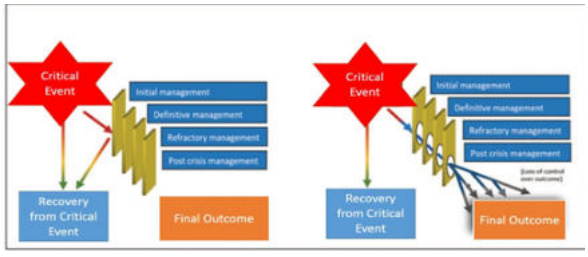
Figure 1 shows a 'Swiss Cheese' diagram (adapted from James Reason) [12].



The equivalent of the Swiss Cheese slices is shown with yellow panels and each panel represents a barrier to the hazards moving from routine progress to a critical event.

Event Tree

The section beyond a critical event is shown in Fig. 2 as an event tree and attempts at rescue are shown which indicate a deteriorating condition, wherein harm is not only occurring but compounding on itself. Figure 2:



This condition requires immediate action to either prevent harm or to reduce the severity and duration of the harm. Using the Swiss cheese diagram, conceptual slices are used to depict barriers to reduce harm by escalation measures in the rescue section to try to recover from the crisis.

Swiss Cheese

The Swiss Cheese diagram has been a useful first step in understanding how adverse events might occur through a breakdown of 'defences-in-depth' [12]. In clinical practice, hazards can be defended against through a series of generic practical steps. These included the Australian Society of Anaesthists (ASA) National Scientific Meeting (NSC) 2012 [13], Australian and New Zealand College of Anaesthetists (ANZCA) Annual Scientific Meeting (ASM) (Singapore 2014) and the New Zealand Society of Anaesthetists (NZSA) ASM (Dunedin 2013). The principles of the Bowtie diagram [6] and an example depicting hypertension during anaesthesia were published in 2016 [7]. The Resilient Anaesthetist model [13] used the principles of a fault tree but stressed that prior to the critical event that there is still an opportunity to escalate attempts to avoid the incident and finally, immediately prior to the critical event and when it is inevitable, that there is still an opportunity for mitigating the outcome. However, it is possible to have no harm as a final outcome of the event. Once the management of the event is complete, it is possible to reach a new zone of stability, but it is not completely the same zone as prior to the event and there might be harm that is present but not detectable clinically at that point in time. The Vortex [13] is a similar analogy relating to the vortex of a plug hole in a sink or bath.

Bowtie Analysis

Bow-tie analyses are primarily qualitative. However, they can be used to support quantitative studies where the frequency of various hazards and outcomes are considered, along with efficacy or otherwise of control measures. Bow-tie diagrams can be developed using binary logic gates (e.g. yes or no for control present and successful). On the left-hand side of the

bow-tie, the gates can be constructed within each control area, with progression from left to right as all effective controls are breached.

A Bowtie diagram represents the fusion of both a fault tree and an event tree, with the Top Event as the 'knot' connecting the two. The concept appears to have been first presented in a lecture course at the University of Queensland in 1979 [1] and has been used in high-risk industries such as the airlines [2]. The Bowtie diagram concept has been applied to medication safety [5], followed by studies in other medical specialities [4] and has more recently been described for the assessment of incidents, crisis and emergency management in anesthesia [6,7,14]. Figure 3 shows a generalized Bowtie diagram, which is designed to map anesthetic incidents in a logical, sequential and complete manner.

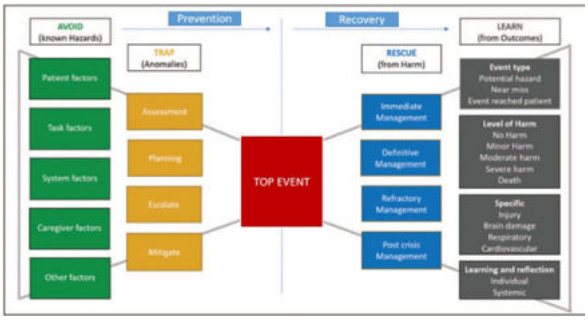


Figure 3:

Each of the components has been slightly modified from previous articles, [6,14] to improve the match to existing anesthetic nomenclature. [15] The first column on the left-hand lists the possible causal factors, which are called 'hazards' in Bowtie nomenclature. This has been renamed 'AVOID hazards', as there may or may not be latent factors (hazards) in one of the arbitrarily divided categories, patient factors, task factors, caregiver factors, system factors and other factors.[16] These potential hazards have not yet progressed to the point where in an adverse event might occur. Therefore, the anaesthesiologist and patient find themselves in a well tolerated zone, with anaesthesia still proceeding normally and without the various potential hazards necessarily leading to an unstable situation. Any of these hazards have the potential to lead to a critical incident. The second section lists various methods or specific barriers devised to detect or trap abnormal states that may represent developing hazards; these are known as 'Preventive' Controls in conventional Bowtie nomenclature. The two columns on the left-hand side of the diagram consist of strategies to prevent the critical incident, which is named a 'Top Event' in a Bowtie diagram. In traditional Bowtie diagrams, lines are drawn to show a one-to-one pathway from Hazards towards the Top Event. These are known as quantitative Bowtie diagrams. However, the complexity of anesthetic emergencies makes a set of pathways difficult to depict without a large number of lines. Instead, we have used conceptual pathways with blocks to show the type of each barrier. Each block could subsequently be expanded to show the components either in a supporting document or a hyperlink could be used in a web application. In this way, the progression of the hazards to a critical event are not intended to be a strict one to one pathway in this diagram, but each of the components in the second columns might be active in preventing any of the potential hazards progressing to a critical event. It is therefore a series of concepts of prevention rather than a fixed pathway [6,14] and these are known as qualitative Bowties [15]. It is possible to expand one of these concepts into a separate one to one quantitative Bowtie to explain one section in detail as a supporting diagram to the qualitative overview. Should the barriers fail, a Top Event may occur, which represents a crisis. Management options designed to control the Top Event are listed on right side columns labelled Rescue Controls, tailgated by outcomes of the incident on the far right. Note that failure to manage the Top Event in the Rescue column might trigger other Top Events. For example, failure to manage a Top Event of 'anaphylaxis' promptly may lead to a Top Event of 'severe bronchospasm'; failure to manage bronchospasm may lead to a 'hypoxia' Top Event; failure to manage hypoxia may trigger 'cardiac arrest', and so on. Alternatively, anaphylaxis may lead to cardiac arrest through a 'severe hypotension' Top Event. Each of these Top Events would carry their own Bowtie. Death or irreversible brain injury arising from cardiac arrest are irreversible consequences, which are then depicted as the outcome in the aftermath. The Bowtie diagram has been previously described as a tool, which depicts critical incidents in anesthesia and has gained significant popularity since the ANZCA ASM in 2011. It is regularly used to analyse cases reported to WebAIRS, a Web Based Anaesthetic Incident Reporting System (www. anztadc. net) used in Australia and New Zealand, and has recently been identified as an excellent mapping tool for the classification and management of unanticipated airway events [15]. Figure 4 is included (with permission) as an example [15].

Figure 4

This figure includes an earlier version of the nomenclature for each of the five columns, but the functionality of each column is identical. Following feedback from this publication, small changes regarding the nomenclature of each column and the addition of arrows to show the direction of flow should a critical event evolve have been added as shown in Fig. 3.

The Bowtie diagram may also be used as a risk assessment and management tool and will provide clear visualization and understanding of hazards, preventive factors, management and outcomes of critical events such as a pandemic. [16] A practical and topical example of a Bowtie diagram is shown in Fig. 5 using the updated nomenclature. Although Corona Virus Disease 2019 (COVID-19) infections may resolve without hospital management, a significant number progress to other major complications such as cytokine storm, cardiac events, respiratory failure and the infection of healthcare workers. The Bowtie diagram can be expanded further by cascading into other Top Events and a new diagram created to prevent and manage each new scenario. These are shown as additional Top Events in red underneath the rescue column.

Figure 6 shows an example of a cascading Top Event whereby a healthcare worker is infected with COVID-19. Additional diagrams can be created for additional Top Events as they are either observed or predicted as possibilities. In this way Bowtie diagrams can be used for both known events, for future events that might be predicted, even if they have yet to occur.

Relevance Of The Bowtie Diagram In Anesthesia

Anaesthesia as a specialty has been extremely successful in reducing the impact of both human and system errors on patients presenting with a wide range of risks and comorbidities for a wide range of procedures. This has been due largely to the introduction of effective controls, rather than the elimination of all hazards. [17]

Bow-tie diagrams are a relatively new approach to risk management analysis. They provide a pictorial representation of hazards and strategies to prevent adverse events, as well as the preparedness to deal with adverse events should they occur. [18] Although the merits of pictorial analyses of these types are difficult to grade or compare, the uptake of bowtie diagrams by a wide range of industries suggests that this methodology may have advantages over many other risk management models. Like the engineering, aviation, and defence industries, healthcare operates within socio-technical networks with objectives that rely on human performance, team interactions, and intricate equipment and technology. [19,20]

Bowtie diagrams relating to anesthesia have been published in both American [7] and Australian publications [6] since 2016. Recently, an article has been published using a set of Bowtie diagrams relating to airway management [15]. In the Bowtie diagram, the various hazards are listed in the left-hand column, which if not controlled by preventive barriers, escalation controls and mitigation in the next column, will progress to the Top Event, which is in the centre of the diagram. Although the items in the left-hand column indicate latent factors, at this point, the potential hazards are under control, and therefore, well tolerated if avoided at this point. [16] Within the trap zone in the second column, some hazards might start to be expressed and the situation is potentially progressing to a Top Event if the barriers and controls fail. This section which includes the avoid hazards and trap anomalies columns is designed to prevent the Top Event occurring. If these interventions fail, the Top Event is reached, but there is still an opportunity to mitigate the harm by strategies to rescue the situation and to prevent further harm. [21] This is in the recovery section after the Top Event. After this phase is complete, the outcome is depicted in the final column wherein the degree of harm might vary from no harm to death. This is also the zone in which there is reflection, learning from the event and designing strategies in each zone from prevention to recovery wherein the event might be either trapped or rescued.[22]

Potential use of bow-tie analysis in anaesthesia risk management [23,24]

There are several potential uses for bow-tie diagrams in anaesthesia risk management.

These include:

1. Understanding risks and how they can be prevented or minimised
2. Pre-emptive identification of weaknesses in risk management
3. Investigation of clinical incidents
4. Teaching risk management
5. Demonstration of risk management strategies to other parties

CONCLUSION

Bowtie diagrams have an advantage over existing methods to analyse and understand critical incidents as they combine possible causes and methods to prevent similar events in the future, with management strategies and learning from outcomes. All clinicians and organisations should appreciate that risk management involves patient, procedural, human, system and chance factors, and that errors are inevitable. Bow-tie analysis draws attention to opportunities for managing these factors at all stages of an accident trajectory, and that avoiding harm requires effective barrier, escalation, mitigation and recovery controls.

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