Risk Management With Bowtie Diagrams of Fall From Height

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Abstract- *The industrial site records high accident and incident rate due to lack of safety measures. Safety assessment rating is significant for every industry to know safety status of the particular site. The Bowtie analysis is a qualitative risk assessment method that gives a platform to effectively communicate our complex risk scenarios. It is an easy-to-understand through graphical representation and shows the relationship between the causes (threat), consequences (unwanted event) and escalation potential for loss and damage. Bowtie diagram gives the proper path which helps in preventing the top event at its initial stage.*

Purpose of the work is to list out the site specific hazard and analyze their ranking in particular site after that minimizing the risk at working site. Research and methodology: 1.Bowtie analysis diagram that focuses on environmental losses and damage resulting from possible scenarios. 2. Threats and control measures for the particular threats. 3. Recovery and consequences measures

Keywords- Bowtie Analysis, Fall from height, hazard identification and risk assessment, accident analysis, Safety barriers.

I. INTRODUCTION

Construction and Production site consist of large number of workers involving in height work, hot work, chemical handling and heavy machineries etc. As workers in the Construction sites are from different cultural background, language, experience and competency, these factors might lead to the risks for workers in Construction sites [R. Gao et al 2018]. Risk management is a key factor to minimize the injuries and accidents in construction sites. It includes hazard identification, assessment and suggesting suitable mitigation measures [M. Kraus 2018]. The two major contributory factors for accidents are unsafe acts and unsafe conditions. It is said that nearly 80% of the accidents are due to unsafe acts of the workers in the site [R. M. Choudhry & D. Fang 2008] but still it is the duty of the organization to look into unsafe conditions to reduce the 20% of the accidents and to make construction and production site into a risk free zone. Safety can’t be enhanced only by considering the previously occurred accidents because the sites have different nature of work and working environment.

The safety performance level can be determined using TR safety index method. This method is a simple standardized method for site observation. In this approach a checklist is made in which if the particular activity satisfies the safety standard, it was scored as correct and the others are scored as not correct. The percentage of the correct score denotes the safety index.

TR Index = Agree/(Agree+Disagree) x 100 [M. Gunduz & H. Laitinen,2018].

The Bow-Tie diagrams provide an organization with greater visibility and understanding. Experience show that Bow-Tie is ideal for structured assessment and communication of risks, clearly demonstrates the link between control measures and management system arrangements and can be used to quantitatively assess and demonstrate control of all types of risk. [Vivek K Sankar1 and Dr. Nihal Siddiqui2 2016]

A thorough literature review is initially conducted to identify the risk factors that affect the performance of construction industry as a whole. The survey questionnaire is designed to probe the cross-sectional behavioral pattern of construction risks construction industry. The questionnaire prepared for the pilot survey was formulated by seeing the relevant literatures in the area of construction risk management. This research seeks to identify and assess the risks and to develop a risk management framework which the investors/ developers/ contractors can adopt when contracting construction work in India. [Shankar Neeraj1,and Balasubramanian. M2 2015]

Review of literatures it is noted that most of the studies focused on unsafe behavior of the workers. But the factors behind every accident are unsafe acts of the workers and unsafe conditions of the site. As Unsafe Conditions (UC)

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contributes to the accidents, this research focuses on unsafe conditions of the workplace in order to make industrial site as risk free zone. Bowtie analysis is becoming more prevalent for industries as a tool to define the major accident hazards of a process, the potential causes (threats) and consequences of the major hazards and the barriers to reduce the likelihood of the causes and reduce the consequences.

A typical bowtie diagram is shown below in ***Figure 1.***

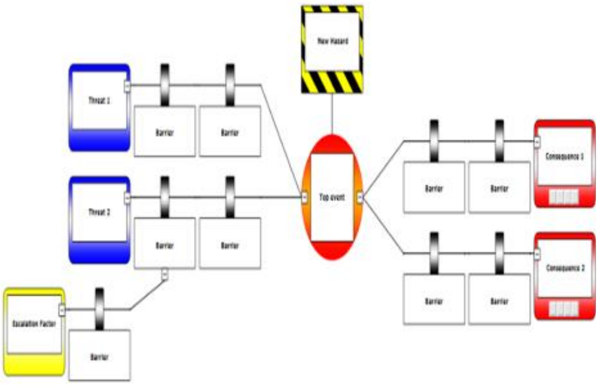

Fig: 1 Generalize diagram of Bowtie

The main objectives of this research are as follows

- To evaluate the site performance using TR safety index.
- To determine the cause and consequences of unsafe conditions.
- To Deign Bowtie and implemented at the industrial site.

Risk management plans should be developed for each of the "*above the line*" prioritized risks so that proactive action can take place.

II. ASSESSMENT OF RISK AT SITE

A. Questionnaire survey

A questionnaire survey is conducted with the workers in the industrial site to know about the existing safety conditions. All the unsafe conditions that can lead to serious consequences in the industrial sites are listed in the Table I. Only two options are given for each questions indicating whether the conditions exists or not. As workers involve in each and every activity they are well aware about the safety condition of the Industrial site.

Table 1 Questionnaire Survey for Risk Assessment at Industrial Site.

S. No.	Unsafe Condition	Information code for Unsafe Condition (UC)	References
1.	Inspection of hoist	UC_1	Indian Standard 7205
2.	Pathway for carrying reinforcement	UC_2	Indian Standard 7969
3.	Hit by rolling object	UC_3	Factories Rules 1950
4.	Separate place for stacking the materials	UC_4	Indian Standard 7969
5.	Certification of cranes	UC_5	Indian Standard 7969
6.	Proper PPE for welding	UC_6	Indian Standard 7205
7.	Shed for bar bending	UC_7	Indian Standard 3696
8.	Maintenance of floors	UC_8	Factories Rules 1950
9.	Maintenance of vehicles	UC_9	Indian Standard 7205
10.	Storing paint waste away from the premises	UC_{10}	Indian Standard 7969
11.	PPE for Drilling	UC_{11}	Adopted in this research
12.	Fall From Height	UC_{12}	Adopted in this research
13.	Barricading the Excavation work	UC_{13}	Indian Standard 3764
14.	Contact with electricity	UC_{14}	Indian Standard 7205
15.	Extreme muscular exertion	UC_{15}	Indian Standard 3696

B. Determination of Severity Rate or Consequence of Unsafe Conditions

It is determined by the nature of injury as mentioned in Table 2. The severity rate for each unsafe condition is obtained through the severity table.

Table 2 : Severity Rate Identification

S. No	Severity Rate or Consequences	Terms	Description
1.	1	Negligible	Improbability of injuries
2.	2	Minor	Impermanent Discomfort
3.	3	Moderate	Deafness, Burns and sprains
4.	4	Major	Serious injuries
5.	5	Catastrophic	Fatality

C. Site Assessment through TR safety index

The questionnaire survey is used for the analysis of risk assessment through TR index equation. The TR Index is used for determine the site performance of the workers. The TR index shows that 60% of the site conditions are safer for the workers and rests of them are unsafe. The remaining 40% fail to fulfill the conditions or marks as unsafe conditions. The safety index is calculated by dividing the number of "Agree" observations by the total number of observations. The TR index level is calculated by the formula below:

TR Level = (Number of Agree Items)/(Total Number of Observations) *100= __%

Table 3 List after Questionnaire Survey for Unsafe Condition

S. No	Task	Agree	Disagree	TR Index(%)
1.	UC_1	80	20	80
2.	UC_2	12	88	12
3.	UC_3	90	10	90
4.	UC_4	60	40	60
5.	UC_5	70	30	70
6.	UC_6	60	40	60
7.	UC_7	67	33	67
8.	UC_8	80	20	80
9.	UC_9	60	40	60
10.	UC_{10}	71	29	71
11.	UC_{11}	44	56	44
12.	UC_{12}	35	65	35
13.	UC_{13}	30	70	30
14.	UC_{14}	90	10	90
15.	UC_{15}	40	60	34

Ranking of Unsafe Conditions

Severity rate for each unsafe condition is determined and ranking is done as shown in Table IV. Then the unsafe condition which has high severity rate is analyzed using qualitative bowtie method to find the causes and consequences of an unwanted event.

Table 4: Severity Rate and Ranking of Unsafe Conditions

S. No	List of Unsafe Condition	Severity rate	Ranking
1.	UC_1	1	4
2.	UC_2	2	3
3.	UC_3	3	2
4.	UC_4	1	4
5.	UC_5	1	4
6.	UC_6	2	3
7.	UC_7	1	4
8.	UC_8	2	3
9.	UC_9	1	4
10.	UC_{10}	1	4
11.	UC_{11}	4	1
12.	UC_{12}	4	1
13.	UC_{13}	3	2
14.	UC_{14}	4	1
15.	UC_{15}	1	4

Hazard Analysis Using Bowtie

The Bow-Tie method is a risk evaluation method that can be used to analyse and demonstrate causal relationships in high risk scenarios. There are three unsafe conditions in which the bowtie is applied. First of all, a Bow-Tie gives a visual summary of all plausible accident scenarios that could exist around a certain Hazard. Second, by identifying control measures (Barrier) the Bow-Tie display what a company does/can do to control those scenarios. Third Consequences what will be come after any scenario was happened.

Besides the basic Bow-Tie diagram, management systems should also be considered and integrated with the Bow-Tie to give an overview of what activities keep a control working and who is responsible for a control. Integrating the management system in a Bow-Tie demonstrates how Hazards are managed by a company. The Bow-Tie can also be used effectively to assure that Hazards are managed to an acceptable level (ALARP). By combining the strengths of several safety techniques and the contribution of human and organizational factors, Bow-Tie diagrams facilitate workforce understanding of Hazard management and their own role in it. It is a method that can be understood by all layers of the Organization due to its highly visual and intuitive nature, while it also provides new insights to the HSE professional.

III. METHODOLOGY

The following basic bowtie structure was developed in Risk view and graphically show (from left to right) all causes, preventative barriers, the top event (loss of containment), mitigated barriers, and final consequences. The model considers intermediate events including fire and explosion, and also considers a range of consequence categories namely;

- Loss of Personnel;
- Loss of Asset;
- Loss of Company Reputation;
- Damage to Environment.

All the calculation should be done by using risk matrix

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Table: Risk matrix for risk calculation

Loss of Personnel (I)	Loss of Asset (P)	Damage to Environment (E)	Loss of Company Reputation (C)	Likely Hood Severity	Never Heard of in Industry (A)	Heard of in Industry (B)	Incident has occurred in our Company (C)	Happens several Times in a year (D)	Happens several Times in a year (E)	Happens Several times in a Month (F)
No Health Effect	No Damage	No Effect	No Impact	0						
Slight Health Effect	Slight Damage	Slight effect	Slight Impact	1						
Minor Health Effect	Minor Damage	Minor Effect	Limited Impact	2						
Major Health Effect	Localized Damaged	Localized effect	Considerable	3						
Fatalities	Major Damage	Major Damage	National Impact	4						
Multiples Fatalities	Extensive Damage	Massive Effect	International	5						

Definition of Colors

I-Manage for continuous improve

II- Demonstrate ALARP

III- Intolerable

Formula for Calculation of Percentage Total Risk Score

Probability Value X Severity Total X Frequency Value ÷ 500 =Total Risk Score (%)

PRIORITY OF ACTION			ACTION TO BE TAKEN
Risk Value	A. 75 - 100%	Immediate	Training, Safe Work Permit & Detailed Action Plan
	B. 60-74%	Within 1 week	Training, Safe Work Permit & Detailed Action Plan
	C. 45-59%	Within 1 month	Training, Safe Work Permit, Registers
	D. 30-44%	Within 6 months	Training & Safe Operating Procedures
	E. 15-29%	Within 12 months	Training
	F. 0-14%	As seasonable	Training

Hazard Identification and Risk Assessment (HIRA) for the top event.

Table 6: Hazard Identification and Risk Assessment for Height Work at Working Site before implementation of Control Measures

1	2	3	4	5	6	7	8	9
#	Potential Hazard	Consequence	Controls to be Implemented to Eliminate / Reduce / Control Risk / Hazards	Probability index	Severity index (SI) =I+P+E+C	Frequency index	Risk Score Score ÷ Max Score=%	Risk Value
1	Following of unsafe work methods	Injury or Fatal	1. Permit to work should take prior to erection work. 2. Ensure close supervision 3. Dynamic HIRA/ pre-task HIRA prepare before commencing of work by a Cross functional team. 4. To ensure fulfill of pre task checklist.	3	15	5	45%	C
2	Fall from height	Injury or Fatal	1. Height pass shall be implemented, 2. Work shall be carried out under direct supervision.	3	15	5	45%	C
3	Hitting the object.	Injury or Fatal	1. No obstruction should be made in the passage at height,	2	15	5	30%	D
4	Falling objects from height	Injury or Fatal	1. No person shall work under the suspension load, 2. All height works shall be carried out in presence of supervisor and Safety Nets shall be fastened where ever it is required. 3. No loose materials shall be placed at edge. 4. Proper housekeeping to be ensured 5. Multi-layer protection system to be in place.	3	15	5	45%	C

Hazard Identification and Risk Assessment for Height Work at Working Site After implementation of Control Measures

1	2	3	4	10	11	12	13	14
#	Potential Hazard	Consequence	Controls to be Implemented to Eliminate / Reduce / Control Risk / Hazards	Probability index	Severity index(SI) =I+P+E+C	Frequency index	Risk Score Score ÷ Max Score= %	Risk Value
1	Following of unsafe work methods.	Injury or Fatal	1. To ensure fulfill of pre task checklist.	2	15	5	30%	D
2	Fall from height	Injury or Fatal	1. To ensure fulfill of pre task checklist.	2	15	5	30%	D
3	Hitting the object.	Injury or Fatal	1. To ensure fulfill of pre task checklist.	1	15	5	15%	E
4	Falling objects from height	Injury or Fatal	1. To ensure fulfill of pre task checklist.	2	15	5	30%	D

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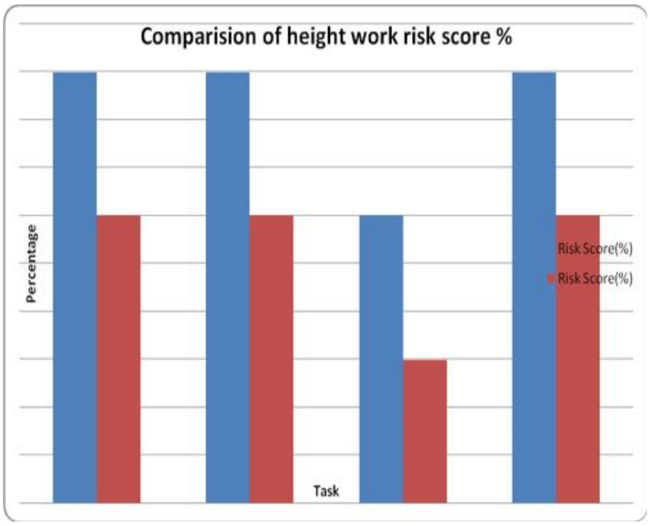


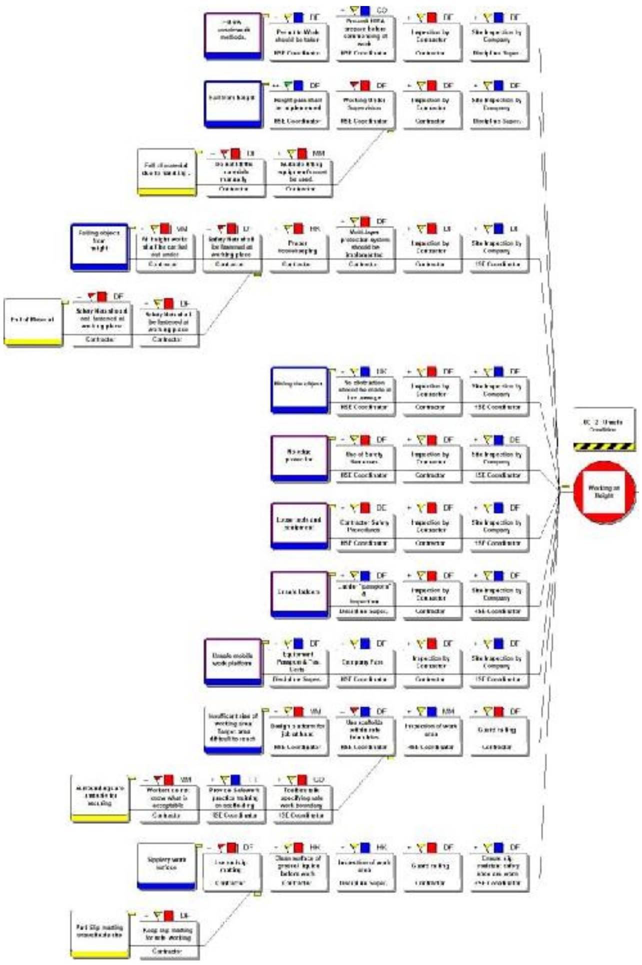
Result: After implementation of HIRAat the site, so many observations come out in which the risk is reduces up to the optimum label. Its shows in the diagram such interpretation noticesd

- **Personal follows unsafe work methods** before implementation of control measure site risk score is 45% and after implementation of control measures site risk score reduced 30 % so the site should be safer than the previous condition.
- **Fall from height** before implementation of control measure site risk score is 45% and after implementation of control measures site risk score reduced 30 % so the site should be safer than the previous condition.
- **Hitting the object** before implementation of control measure site risk score is 30% and after implementation of control measures site risk score reduced 15 % so the site should be safer than the previous condition.
- **Falling objects** from height before implementation of control measure site risk score is 45% and after implementation of control measures site risk score reduced 30 % so the site should be safer than the previous condition. Average risk score should be reduces 42.5% to 25% but every industry requires risk free zone in their sites, it can be achieved by application of Bowtie.

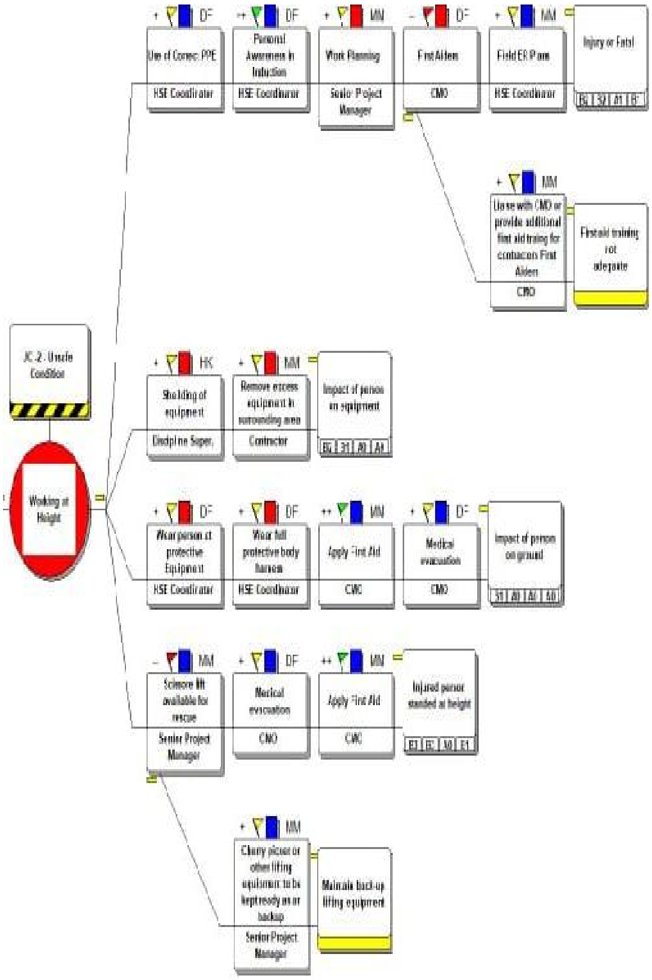
The proactive measures as suggested through the bowtie are discussed with a panel of safety experts and are implemented in the particular site to reduce the percentage of risk. A check list is prepared by listing the UC as mentioned in the questionnaire survey and walk around audit is done. Check list is a systematic evaluation of established criteria. Through the check list method of evaluation it is known that the level of agreement has been increased to a higher percentage as mentioned in Fig.5, this indicates that the percentage of risk and the number of Unsafe Condition have been reduced. If these mitigation measures are adopted and followed, the risk in industrial site will reduce considerably.

The purpose of rating control effectiveness is to highlight areas of strength and weakness within the bowtie, potentially using this information as a basis for a matrix based risk assessment.

Bowtie Diagram for Event Tree Analysis



Fault Tree Analysis



The results are typically displayed according to a color code (e.g. red for poor, yellow for good and green for the very good at the top of the box with flag). This makes the results very easy to interpret even for users with little prior exposure to the methodology. When creating the effectiveness, scale consider the usefulness of allocating “average” as a score. Two main considerations for rating control effectiveness are adequacy and assurance.

The categorization and barrier colour coding were made in collaboration with the risk and management team of industry coworker. The categorization was based on the responsibility and exerting agency of the threat or barrier. This decision was made, after a discussion with the industry experts, about the Bowtie elements that could be placed in more than one category, such as task-related threats. In this particular example, the threat could be placed in the man category since the inspection personnel performs the task. On the other hand, it could also be a method-related threat, since a task is part of a process or procedure. Based on the decision above, we categorized it, as a man-related threat, since the human performs the task and human performance is always critical in the industry**.**

IV. DISCUSSION

Advantages of Bowties in Safety Management

There are numerous of advantages of using bowties as a tool for effective process safety management. These are discussed below:

- **Effective communication:** The simple representation of the safety processes makes them ideal to use in Safety Cases and Reports. The popularity of bowties is due to their ability to simplify and make risk related communication effective associated with Major Accident Hazards are managed on a particular facility or during a particular operation.
- **ALARP reviews**: They are an effective and visual way of representing the risk management process and provide a strong starting point for ALARP reviews.
- **Identification of Safety Critical Elements:** Bowties offer a systematic way to identify safety critical elements (SCEs) and activities and then to use this information to develop the SCEs and associated performance standards
- **Workforce engagement:** Bowties are powerful in engaging the workforce. The development and refining of bowties should include the workforce who then take ownership of the bowties. Bowties are a great basis for training and explaining the importance of safety critical equipment/activities
- **Communication with management:** Bowties provide a framework for process safety conversations with senior management whose main focus is an overview rather than detailed analysis of processes. They may also be used as part of the safety induction process for new managers.

Limitation of the bowtie

The process of developing a Bowtie diagram following the proposed structure can be time consuming and people may focus too much on trying to fill in all gaps, although it is realistic and acceptable that there is not a threat, consequence, or barrier in each category type for every case.

This approach covers the most common risk areas based on previous experience. However, this involves the risk of missing Bowtie elements that have not previously occurred.

The use of strictly defined categories may limit the imagination when identifying threats, consequences, or barriers. Analysts will need to ensure they are not so fixated on the method that they fail to anticipate new threats.

V. CONCLUSION

Hence by identifying the possible causes, the Safety Engineers should review the previous accidents and compare it with the present accident. From the comparison it is known that whether the accident occurred due to the listed causes or else from the new cause. It is also suggested that the safety manager should implement the safety systems as prescribed by national safety codes. Furthermore through bowtie analysis the causes for accidents can be mitigated by establishing safety & risk management to make the activity as risk free zone. The categorisation and barrier colour coding were made in collaboration with the risk and management team of our industry coworker. The categorization was based on the responsibility and exerting agency of the threat or barrier. This decision was made after a discussion with the industry experts, about the Bowtie elements that could be placed in more than one category, such as task-related threats. In this particular example, the threat could be placed in the man category since the inspection personnel performs the task. On the other hand, it could also be a method-related threat, since a task is part of a process or procedure. Based on the decision above, we categorized it as a man-related threat, since the human performs the task and human performance is always critical in the industry**.**

Discussion Summary of Outcomes

While constructing the Bowtie diagram, it was found that there is inconsistency and confusion about the hazard and top event relationship. A consistent interpretation was provided to overcome this problem. Furthermore, it was found that there are cascading consequences for different stakeholders. Depending on the focus of the risk analysis and the target audience, there are different consequences, which we demonstrated in this work. Moreover, the visualization and receptivity of the diagram was improved by assigning different colours to each barrier category, which supports the main purpose of the Bowtie method, i.e., functioning as communication tool. Finally, the proposed conceptual framework was tested by applying it to the specific case of visual Height work.

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