OMAINTEC CONFERENCE 2024 EXHIBITION

THE 21ST INTERNATIONAL OPERATIONS & MAINTENANCE CONFERENCE IN THE ARAB COUNTRIES

Learning from Failure by Using A Hybrid Model Technique: The Suez Canal Incident

Ashraf Labib[1,3*], Azzam Saati[2], Akilu Yunusa-Kaltungo[2], Claudiu Herteliu[3]

[1]Faculty of Business and Law, School of Organisations, Systems and People, University of Portsmouth, UK
[2] Faculty of Science and Engineering, Department of Mechanical, Aerospace and Civil Engineering (MACE), School of Engineering, University of Manchester, UK
[3] Bucharest University of Economic Studies
[*]*Corresponding Author*

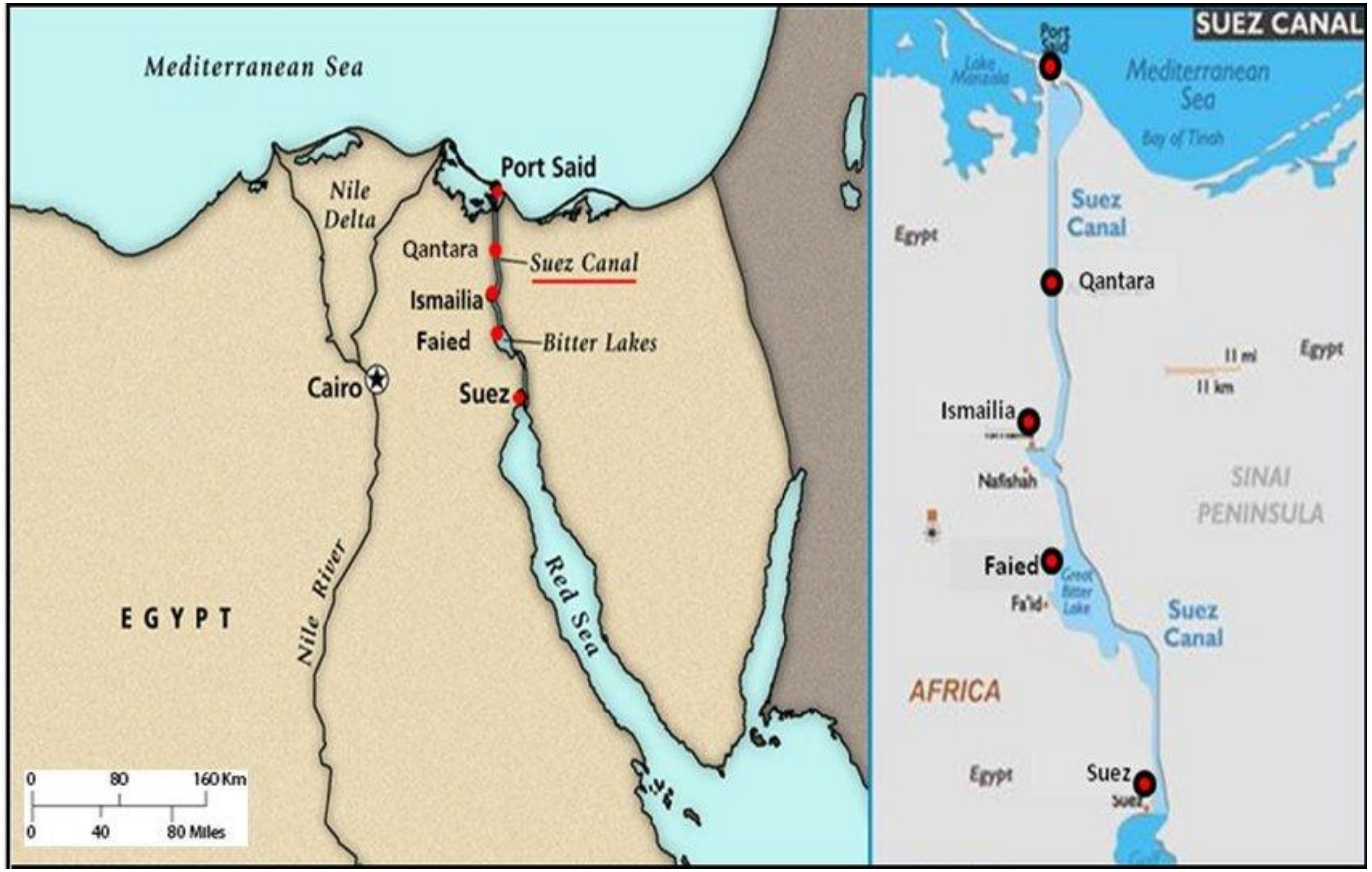
Abstract/Content:

- To investigate the Suez Canal incident by formulating a **hybrid model**, inspired by maintenance and reliability techniques, that can enable the process of learning from failures.
- The hybrid model uses a fault tree analysis (**FTA**), reliability block diagram (**RBD**), cut set analysis (**CSA**), and the bowtie method (**BTM**) integrated with the **Haddon Matrix**.
- The need for a such hybrid model is essential nowadays since incidents and disasters are becoming more complex, hence a deep analytic technique is required to cover all reliability factors.
- It can be argued that there is no perfection in using **only one technique** to address all the reliability aspects since every technique has its **own limitations**, and it is vital to integrate more than one technique, with its particular advantage, in order to have a clear, focused and comprehensive understanding of the area of concern.
- In addition, it is essential to derive from that level of analysis **lessons** that can help to improve the overall system reliability and prevent future undesirable events.
- The main finding of this work is the demonstration of the **synergy between the techniques** and how they can be incorporated in order to provide a better understanding of the incident and extract the lessons learned that can **prevent a reoccurrence** of such an incident, and **mitigate the consequences**.

Contents:

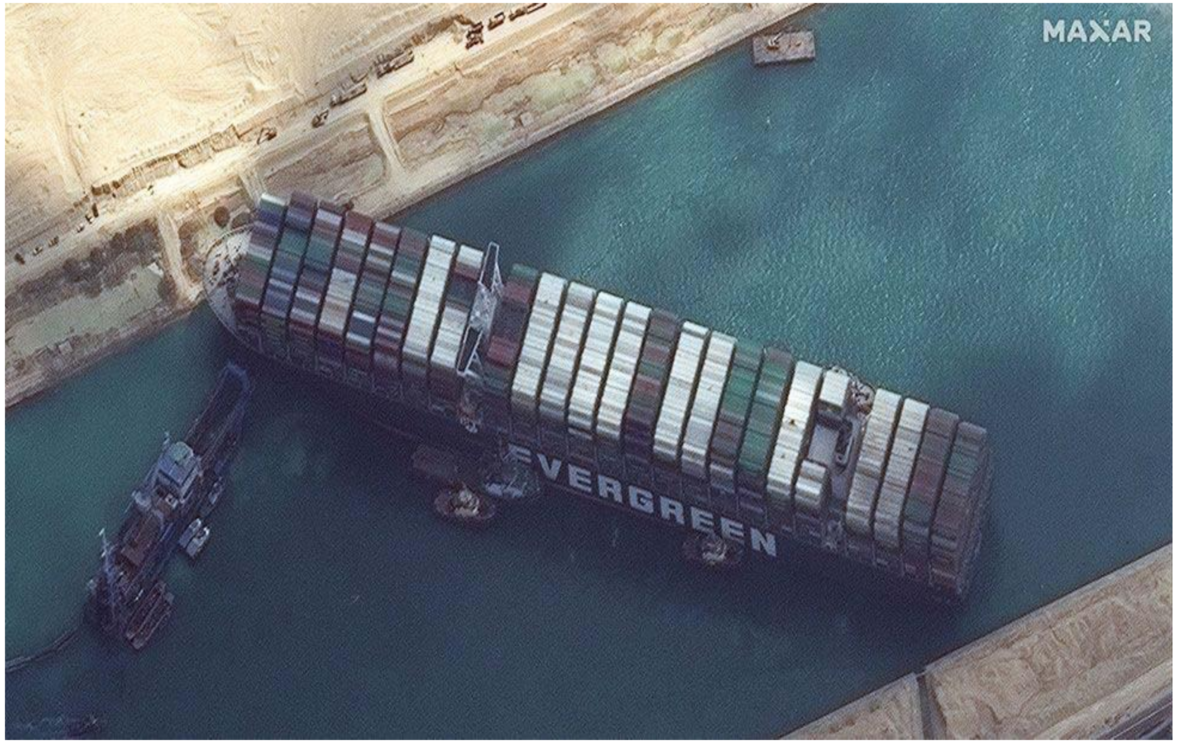
Features of Global Shipping The Suez Canal

- More than 80% of the global trade is delivered by ships (UNCTAD, 2022).
- Subsequently, any disruptions in ports or shipping lanes has a significant impact on food, energy, medicine and key essential items, which will not reach those in need, as well as major impact on the whole supply chain, survival of organizations, and the market in the form of increase prices for producers and consumers.
- The Gulf and African regions have a wide range of desert land and sandstorm frequently occurs during the period of the year.
- Thus, on sandstorm occasions, the safest decision to be taken is to delay or reschedule any planned trip for safety purposes.

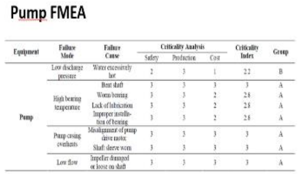


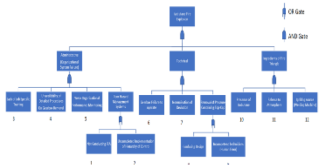
The Suez Canal Incident

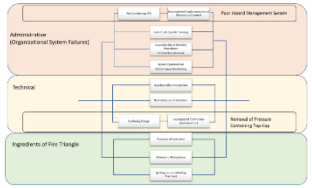
- On March 23, 2021, a high wind sandstorm occurred in the north-eastern of Egypt, affecting the busiest seaport in the world, the Suez Canal.
- On that day, 12 ships have navigated successfully through the canal while a high wind sandstorm affecting the vision clarity and ship navigation control.
- However, one of the giant ship containers in the world (Ever Given) was lined up in the queue to be the 13th ship to navigate through the canal sailing on its way to Rotterdam, Netherlands.
- Unfortunately, a few miles after entering the canal, the captainship lost control of the Ever-Given ship, causing a diagonal wedge ship position that blocked the entire waterway of the Suez Canal, as illustrated in figure.
- Risk of grounding and collision is one of the major failure modes in navigation of vessels.
- Moreover, around 46% of collisions occurred in restricted waters; rivers or fairways.
- Hence the analysis in this paper provides a set of integrated tools that can help in analyzing the causes of many similar accidents for both prevention and mitigation of risk.

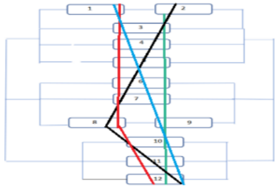


Hybrid Model



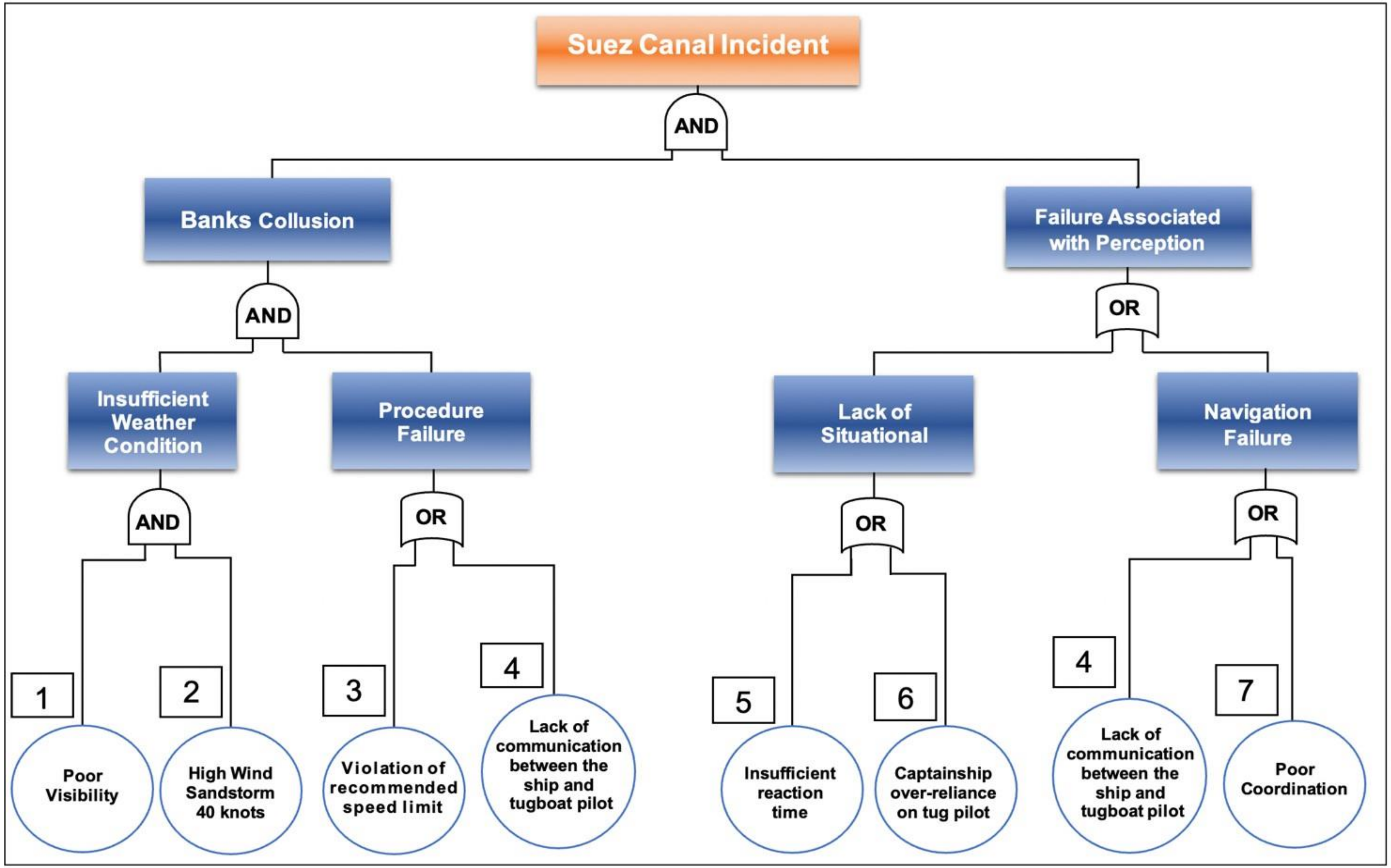






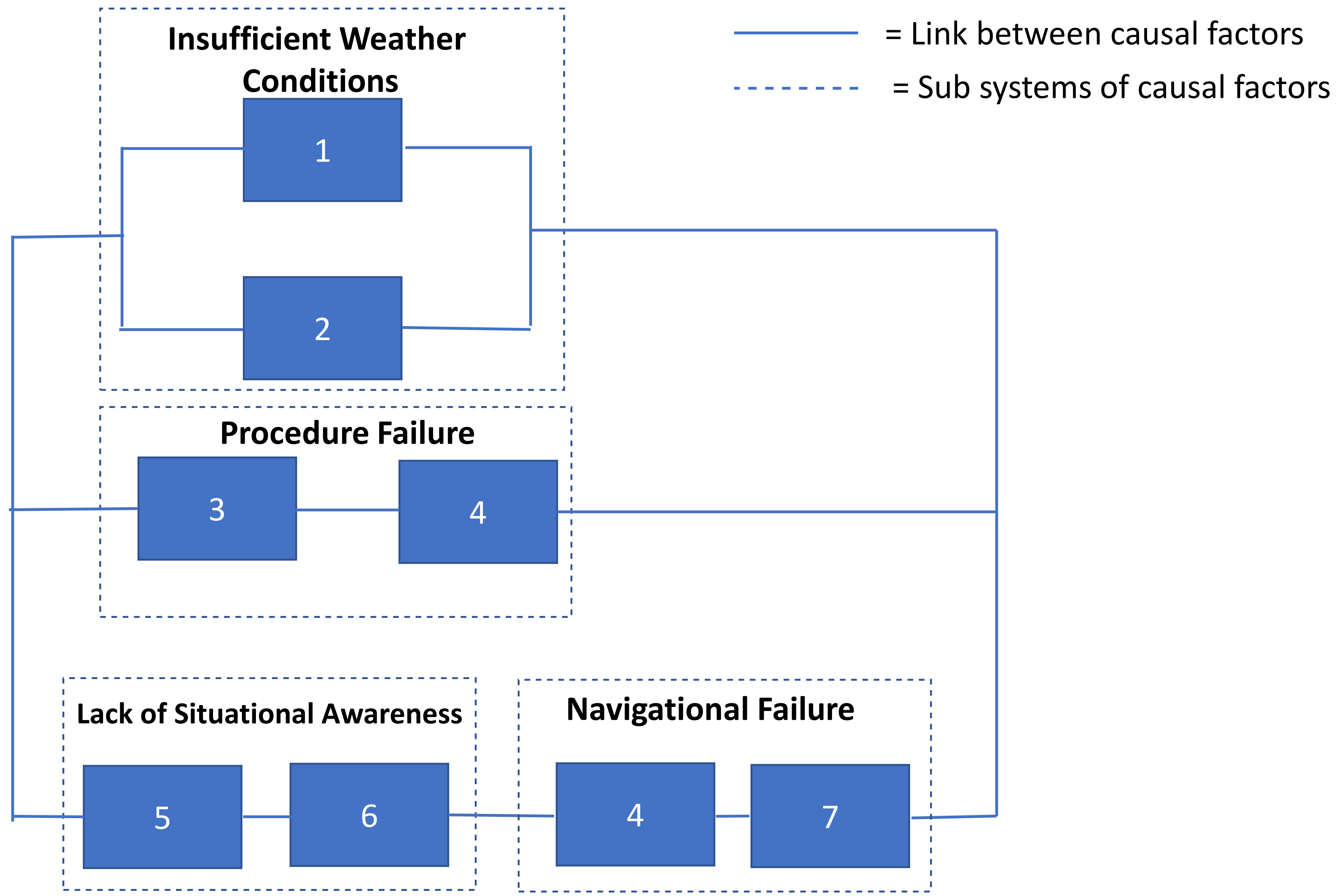
Failure Mode Effect Analysis (FMEA) → Fault Tree Analysis (FTA) → Reliability Block Diagram (RBD) → Cut Sets Analysis (CSA)

Problem Structuring: Brain-storming → Problem Structuring: Causal Factors → Problem Solving: Relationships Between Factors → Vulnerability Analysis: Recommendations & Barriers.


Suez Canal Incident
AND
Banks Collusion
Failure Associated with Perception
AND
OR
Insufficient Weather Condition
Procedure Failure
Lack of Situational
Navigation Failure
AND
OR
OR
OR
1
2
3
4
5
6
4
7
Poor Visibility
High Wind Sandstorm 40 knots
Violation of recommended speed limit
Lack of communication between the ship and tugboat pilot
Insufficient reaction time
Captainship over-reliance on tug pilot
Lack of communication between the ship and tugboat pilot
Poor Coordination

A summary of the Golden Rules when constructing FTAs and RBDs:

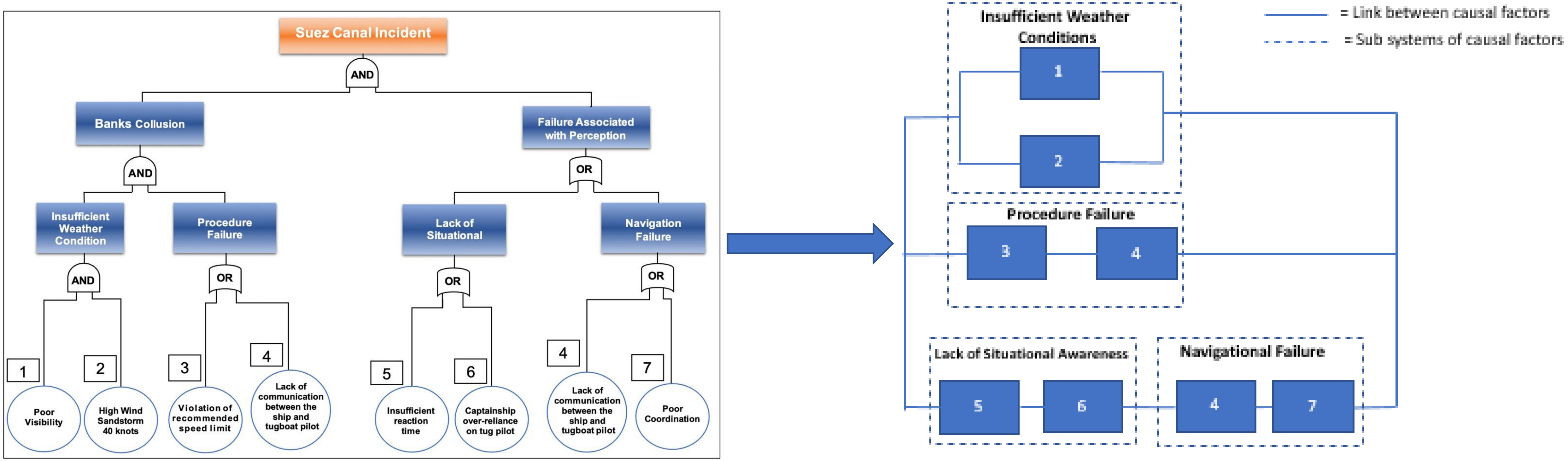
1. Every **OR** in an FTA is a **Series** configuration in the equivalent RBD.
2. Every **AND** in an FTA is a **Parallel** configuration in the equivalent RBD.
3. Start from the **Top** of the Tree.
4. Only model **Basic events**.
5. The **order** in an RBD does NOT matter.
6. Look for a **real** root cause.
7. Both FTA and RBD are mental models for **risk analysis** rather than risk assessment.


Insufficient Weather Conditions
1
2
Procedure Failure
3
4
Lack of Situational Awareness
5
6
Navigational Failure
4
7
= Link between causal factors
= Sub systems of causal factors

FTA → RBD

A summary of the Golden Rules when constructing FTAs and RBDs:

1. Every **OR** in an FTA is a **Series** configuration in the equivalent RBD.
2. Every **AND** in an FTA is a **Parallel** configuration in the equivalent RBD.



Cut Set Analysis (CSA)

- Note: in Boolean: Plus “+” represents “OR” gate Multiplication “.” represents “AND” gate.
- Therefore, the logic expression has been derived for the Suez Canal Incident as below cut set.
- SCI = [(1.2)] . (3+4) . (5+6+4+7)
- SCI = [(1.2)] . (3.5 + 3.6 + 3.4 + 3.7 + 4.5 + 4.6 + 4.4 + 4.7) [Applying: a.a = a]
- SCI = [(1.2)] . (3.5 + 3.6 + 3.4 + 4 + 3.7 + 4.5 + 4.6 + 4.7) [Applying: a + a.b = a]
- SCI = [(1.2)] . (3.5 + 3.6 + 3.7 + 4 + 4.5 + 4.6 + 4.7) [Applying [T9]: a + a.b = a]
- SCI = [(1.2)] . (3.5 + 3.6 + 3.7 + 4 +4.6 + 4.7) [Applying [T9]: a + a.b = a]
- SCI = [(1.2)] . (3.5 + 3.6 + 3.7 + 4 + 4.7) [Applying: [T9]: a +a.b = a]
- SCI = [(1.2)] . (3.5 + 3.6 + 3.7 + 4) [Applying [A5]: a (b + c) = ab + bc]
- SCI = [(1.2.3.5 + 1.2.3.6 + 1.2.3.7 + 1.2.4)] [Applying [A5]: a (b + c) = ab + bc]

Table 1: Axioms Of Boolean Algebra

[A1] ab = ba	Commutative Law
[A2] a + b = b + a	Commutative Law
[A3] (a + b) + c = a + (b + c) = a + b + c	Associative Law
[A4] (ab) c = a(bc) = abc	Associative Law
[A5] a (b+c) = ab + ac	Distributive Law

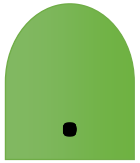
Table 2: Theorems Of Boolean Algebra

[T1] a + 0 = a	
[T2] a + 1 = 1	
[T3] a . 0 = 0	
[T4] a . 1 = 1	
[T5] a . a = a	Idempotent Law
[T6] a + a = a	Idempotent Law
[T7] a . a = 0	
[T8] a + a = 1	
[T9] a + ab = a	Absorption Law
[T10] a (a + b) = a	Absorption Law
[T11] a + ab = a +b	Absorption Law

Idempotent Law

X . X = X

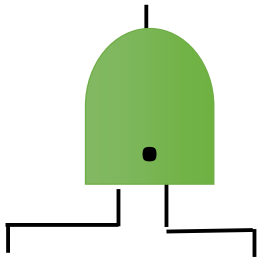
= OR Logic Gate



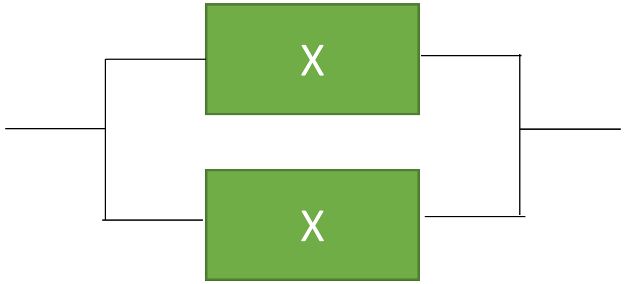
= AND Logic Gate

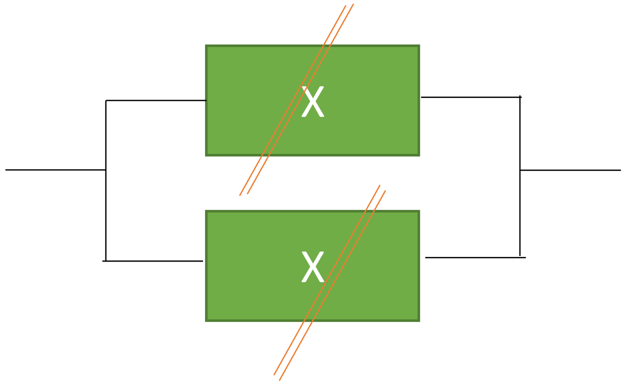
FTA → RBD → CSA → MCS

TE = (Top Event)



X X



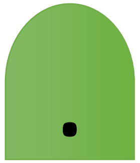


'X . X = X'

+ = OR Gate
. = AND Gate
TE = Top Event
FTA = Fault Tree Analysis
RBD = Reliability Block Diagram
CSA = Cut Set Analysis
MCS = Minimum Cut Set

Absorption Law $x + x.y = x$

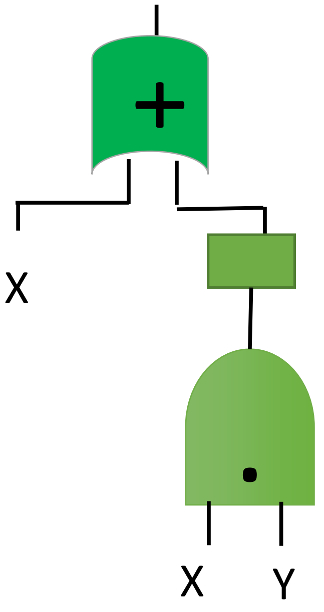
= OR Logic Gate

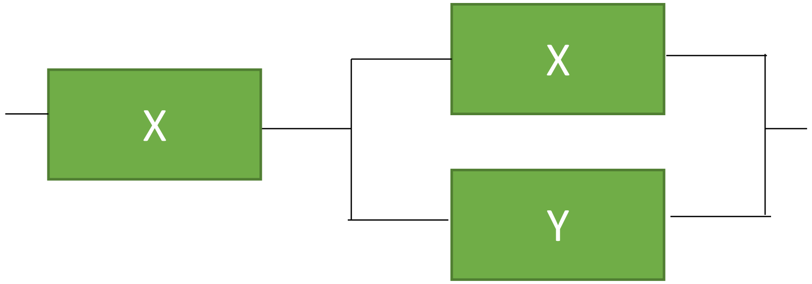


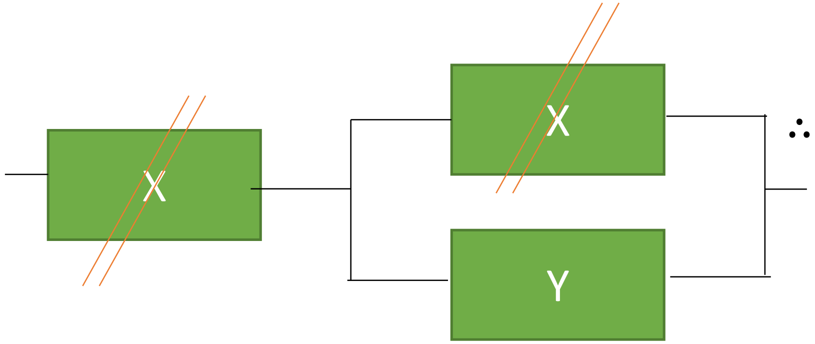
= AND Logic Gate

FTA → RBD → CSA → MCS

TE = (Top Event)







$\therefore\ 'X + X.Y \Leftrightarrow X'$

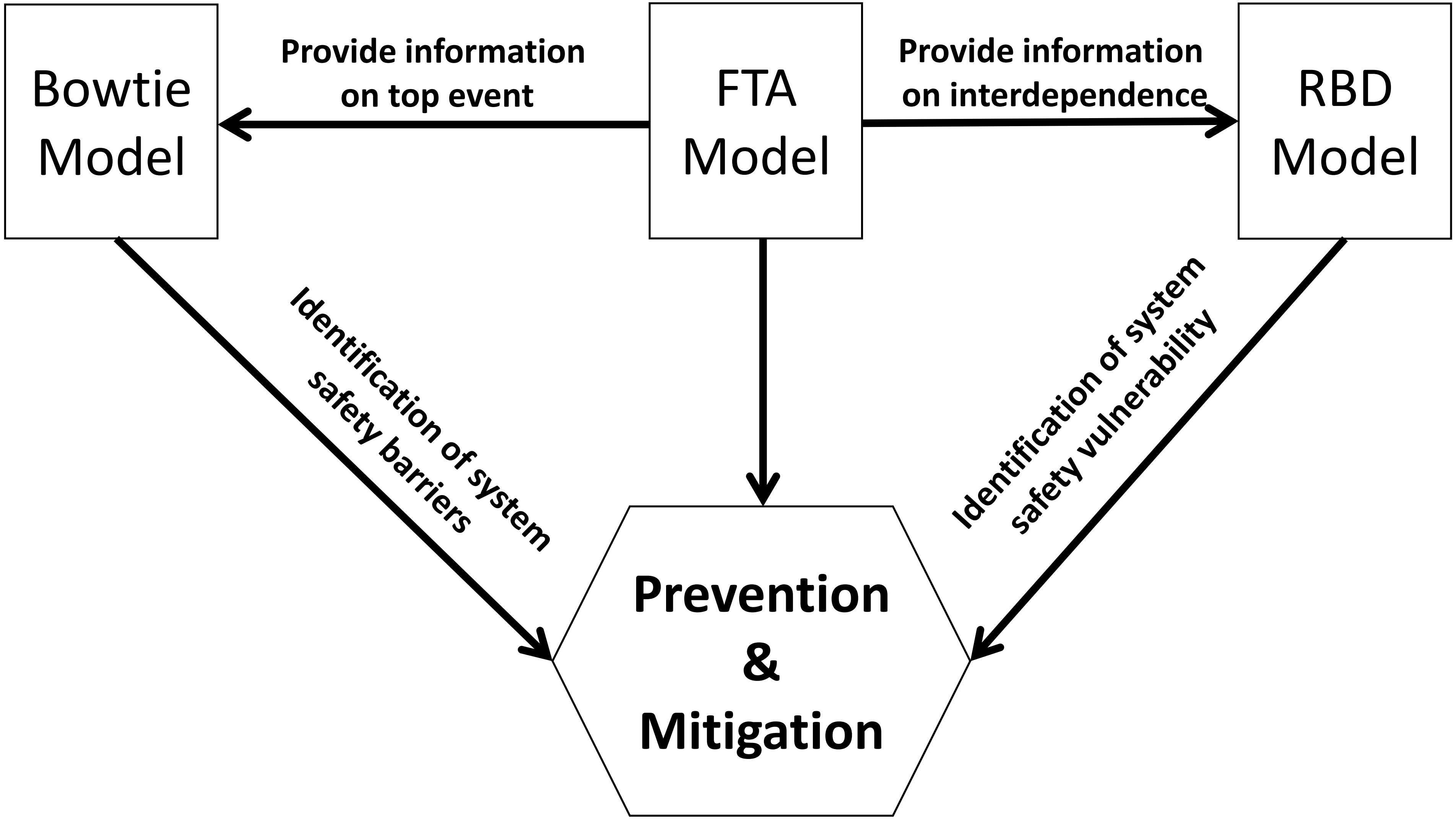
+ = OR Gate
. = AND Gate
TE = Top Event
FTA = Fault Tree Analysis
RBD = Reliability Block Diagram
CSA = Cut Set Analysis
MCS = Minimum Cut Set

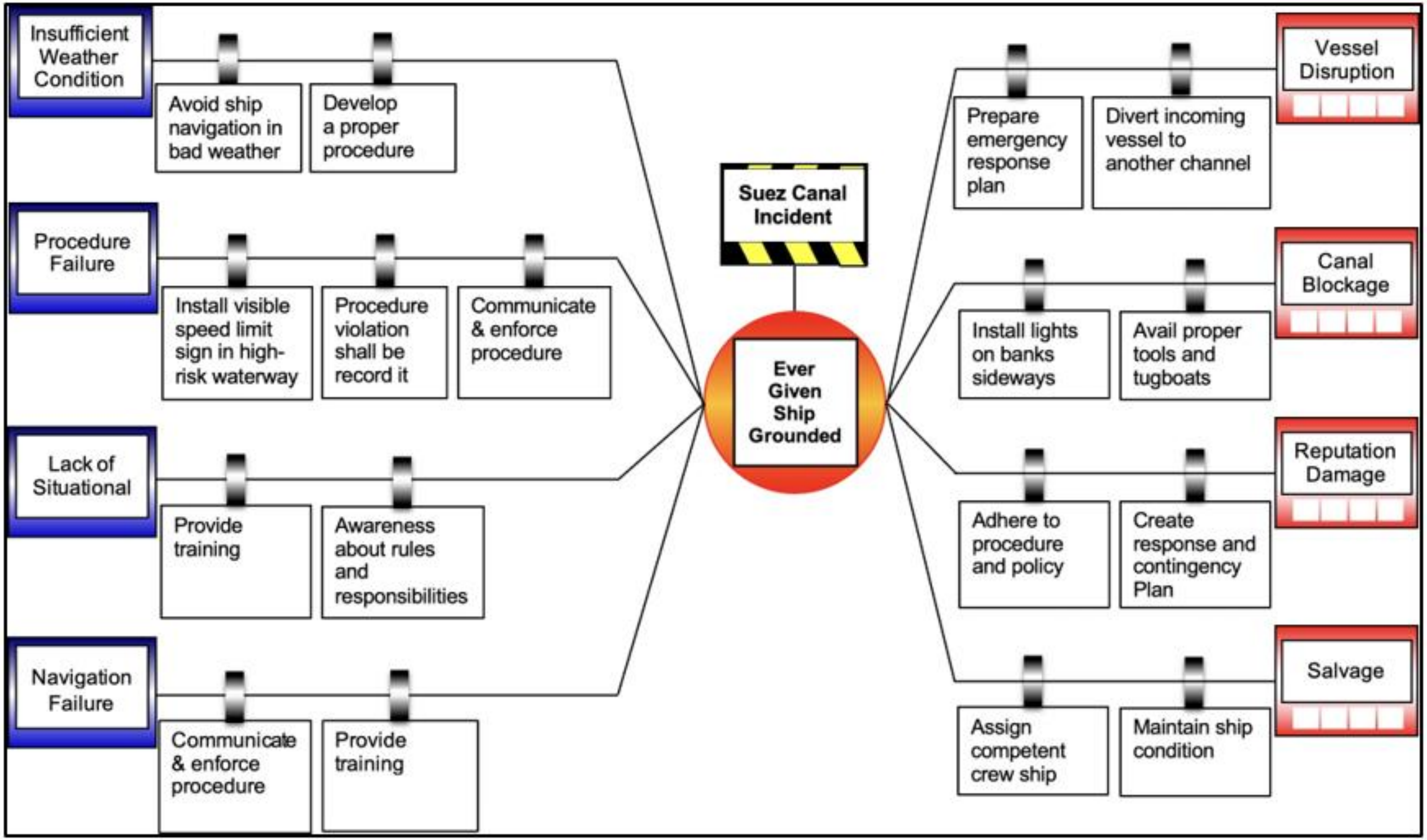
Scenarios based on Cut Set Analysis

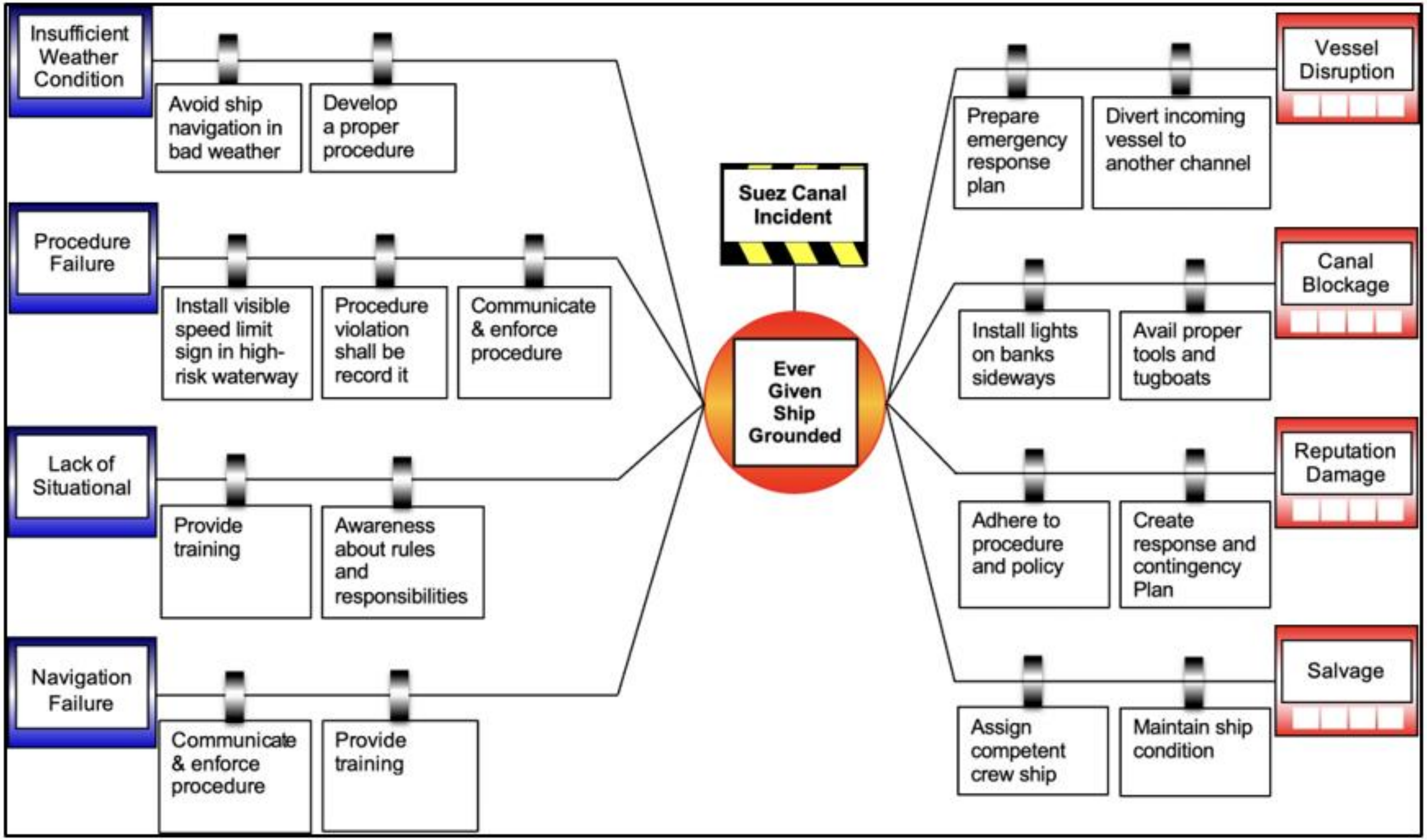
Therefore, the minimum cut set are as the following four scenarios of combination of causal failures: 1.2.3.5; 1.2.3.6; 1.2.3.7; 1.2.4

- Scenario 1: Poor visibility. High wind sandstorm. Violation of recommended speed limit. Insufficient reaction time.
- Scenario 2: Poor visibility. High wind sandstorm. Violation of recommended speed limit. Captainship over-reliance on tug pilot.
- Scenario 3: Poor visibility. High wind sandstorm. Violation of recommended speed limit. Poor coordination.
- Scenario 4: Poor visibility. High wind sandstorm. Lack of communication between the ship and tugboat pilot.

Here each of the above four scenarios contains the least combination of factors that are necessary and sufficient to cause the top event (disaster) to occur. It is interesting to observe that the two factors of poor visibility and high wind sandstorm are common in all four scenarios, and that the violation of recommended speed limit comes as a second highest in terms of priority as it is common in three of the four scenarios.


Bowtie Model
Provide information on top event
FTA Model
Provide information on interdependence
RBD Model
Identification of system safety barriers
Identification of system safety vulnerability
Prevention & Mitigation


Insufficient Weather Condition
Avoid ship navigation in bad weather
Develop a proper procedure
Procedure Failure
Install visible speed limit sign in high-risk waterway
Procedure violation shall be record it
Communicate & enforce procedure
Lack of Situational
Provide training
Awareness about rules and responsibilities
Navigation Failure
Communicate & enforce procedure
Provide training
Suez Canal Incident
Ever Given Ship Grounded
Prepare emergency response plan
Divert incoming vessel to another channel
Vessel Disruption
Install lights on banks sideways
Avail proper tools and tugboats
Canal Blockage
Adhere to procedure and policy
Create response and contingency Plan
Reputation Damage
Assign competent crew ship
Maintain ship condition
Salvage



Insufficient Weather Condition
Avoid ship navigation in bad weather
Develop a proper procedure
Procedure Failure
Install visible speed limit sign in high-risk waterway
Procedure violation shall be record it
Communicate & enforce procedure
Lack of Situational
Provide training
Awareness about rules and responsibilities
Navigation Failure
Communicate & enforce procedure
Provide training
Suez Canal Incident
Ever Given Ship Grounded
Prepare emergency response plan
Divert incoming vessel to another channel
Vessel Disruption
Install lights on banks sideways
Avail proper tools and tugboats
Canal Blockage
Adhere to procedure and policy
Create response and contingency Plan
Reputation Damage
Assign competent crew ship
Maintain ship condition
Salvage

Safety Barriers: Prevention /Proactive and Corrective / Mitigation

Table 3: Classification of Safety Barriers (Preventative/ Proactive)

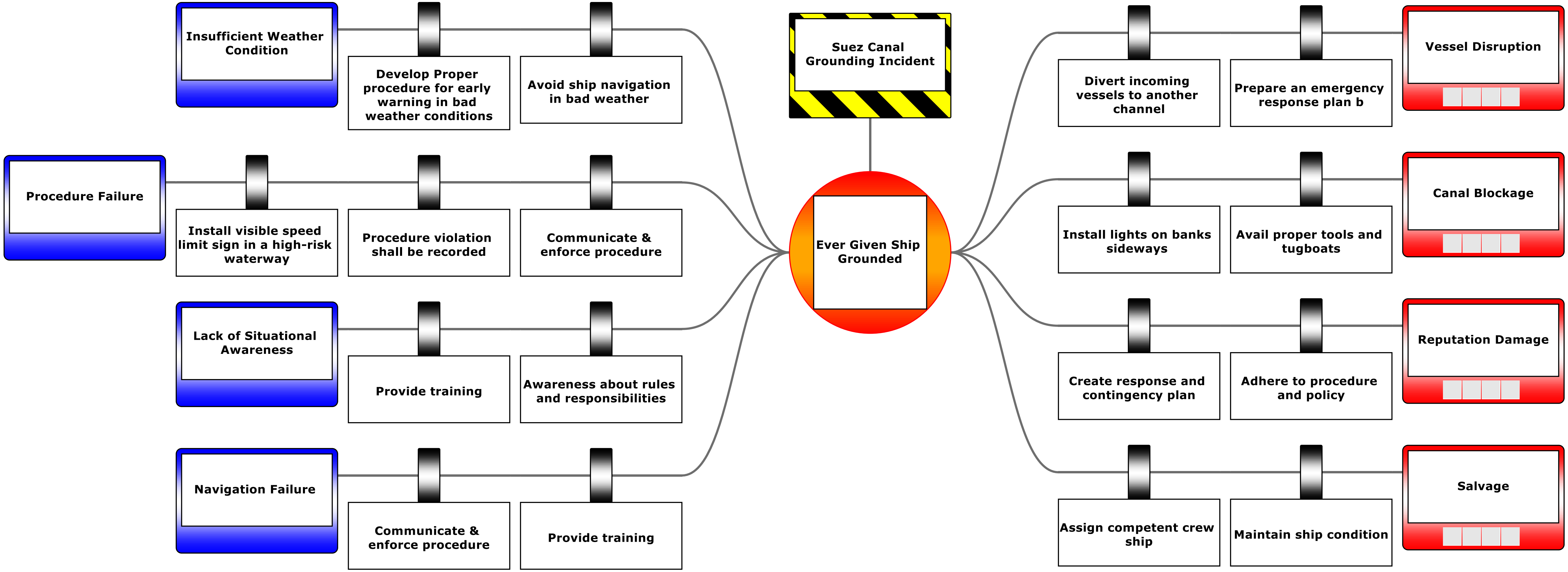
Threat		Barrier	Type	Escalation Factor
Insufficient Weather Condition	a.	b. Avoid ship navigation in bad weather c. Develop a proper procedure	Preventative	Loss of ship navigation control
Procedure Failure	a.	b. Install visible speed limit sign in a high-risk waterway. c. Procedure violation shall be recorded. d. Communicate & enforce procedure.	Preventative	a. A prohibition from using the Suez Canal waterway. b. Pay fine.
Lack of Situational Awareness.	a.	b. Provide training. c. Awareness about rules and responsibilities.	Preventative	Human error
Navigation Failure	a.	b. Provide training. c. Communicate & enforce procedure.	Preventative	Human error

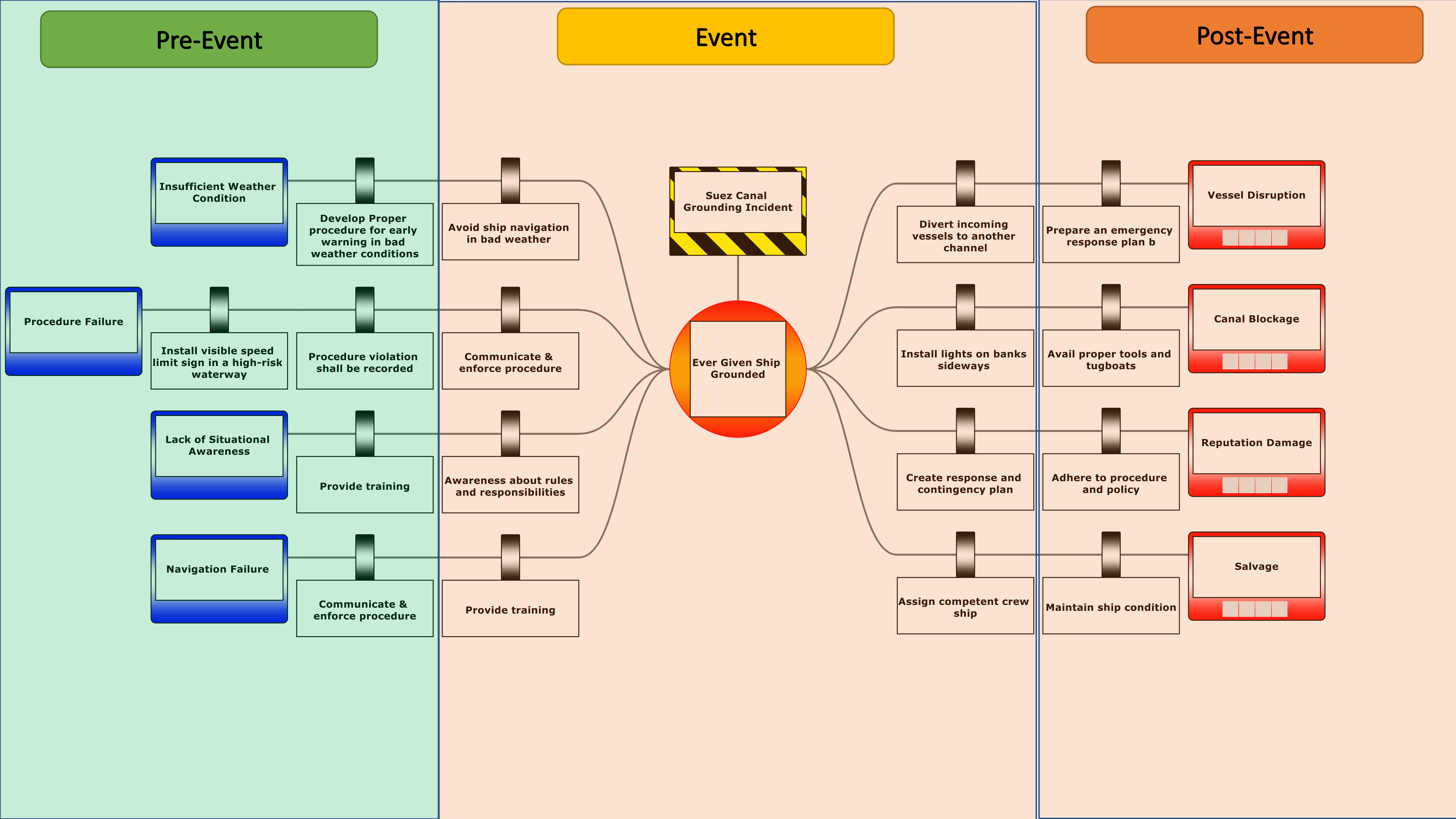
Table 4: Classification of Safety Barriers (Corrective / Mitigation)

Consequence	Barrier	Type	Escalation Factor
Vessel Disruption	a. Prepare an emergency response plan b. b. Divert incoming vessel to another channel	a. Control b. Mitigate	a. Traffic jam b. Uses longer channel (Cape of Good Hope)
Canal Blockage	a. Install lights on banks sideways b. Avail proper tools and tugboats	a. Mitigate b. Control	a. Disturbed global maritime trade b. Affect global stock markets
Reputation Damage	a. Adhere to procedure and policy b. Create response and contingency plan.	Control	Customer uses another carrier
Salvage	a. Assign competent crew ship. b. Maintain ship condition.	Mitigate	a. Settlement/award b. Bankruptcy.

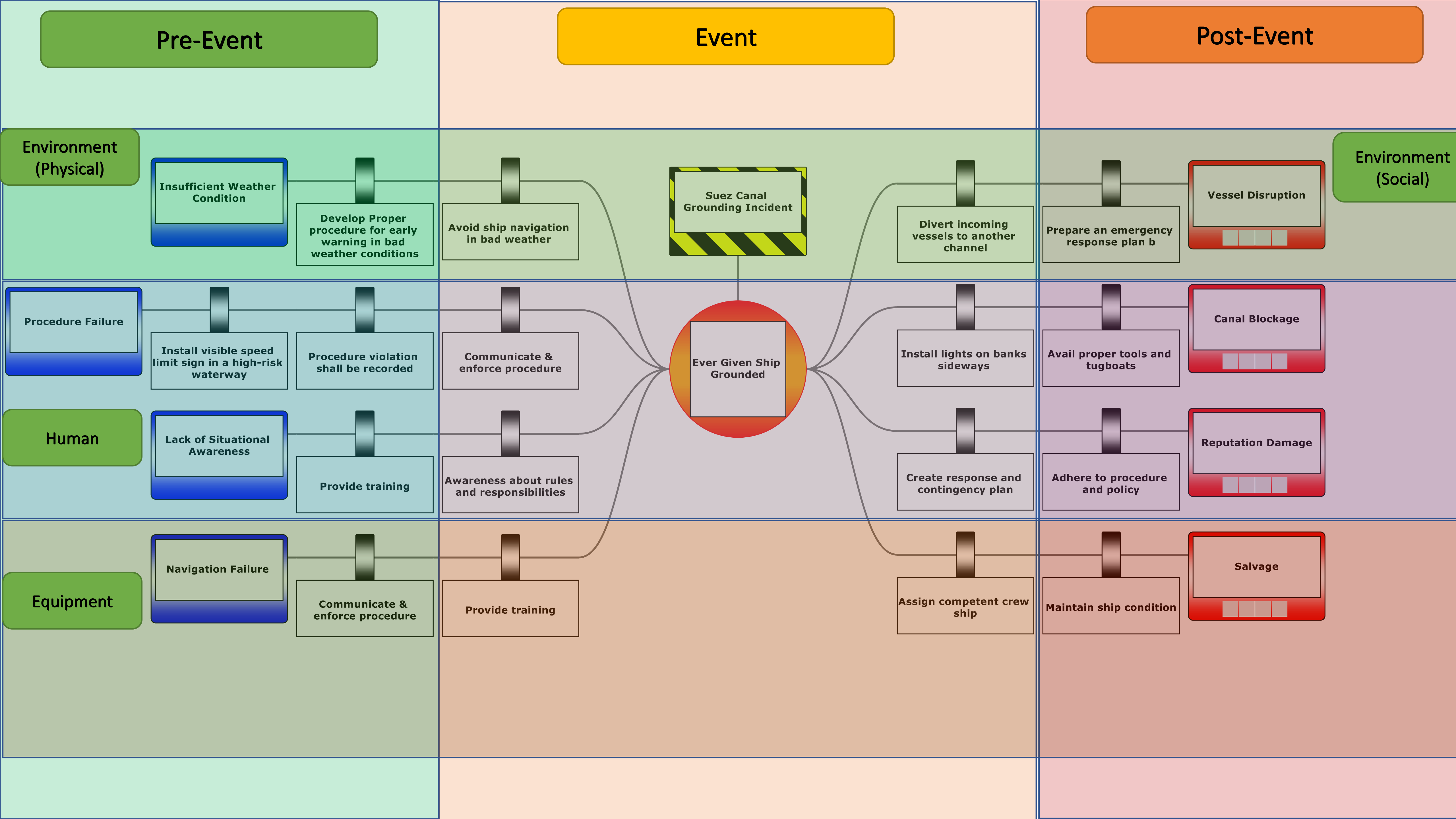
Haddon Matrix

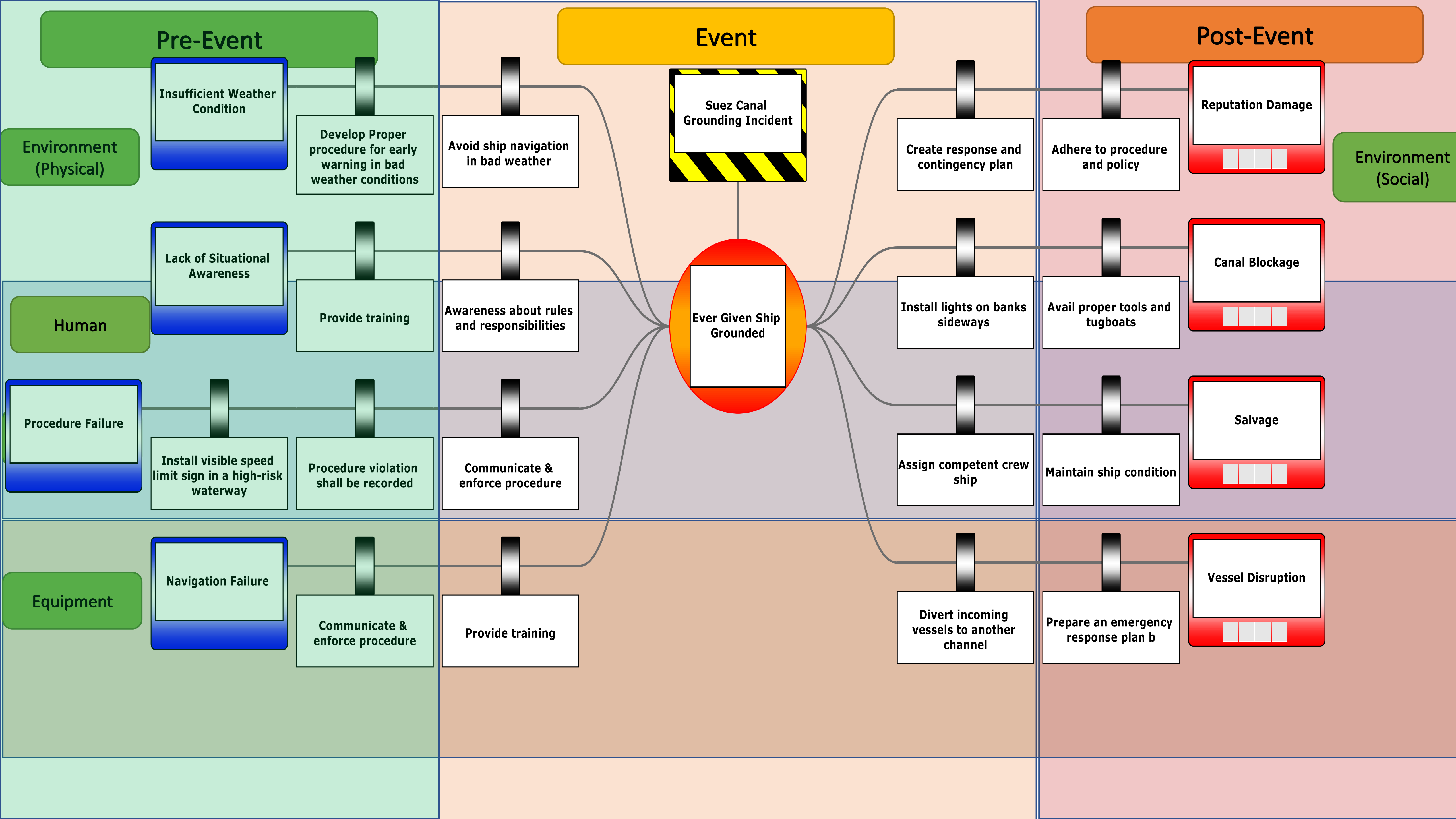
	Host	Equipment	Environment: Physical	Environment: Social
Pre-Event				
Event				
Post-Event				


Suez Canal Grounding Incident
Ever Given Ship Grounded
Insufficient Weather Condition
Develop Proper procedure for early warning in bad weather conditions
Avoid ship navigation in bad weather
Procedure Failure
Install visible speed limit sign in a high-risk waterway
Procedure violation shall be recorded
Communicate & enforce procedure
Lack of Situational Awareness
Provide training
Awareness about rules and responsibilities
Navigation Failure
Communicate & enforce procedure
Provide training
Divert incoming vessels to another channel
Prepare an emergency response plan b
Vessel Disruption
Install lights on banks sideways
Avail proper tools and tugboats
Canal Blockage
Create response and contingency plan
Adhere to procedure and policy
Reputation Damage
Assign competent crew ship
Maintain ship condition
Salvage



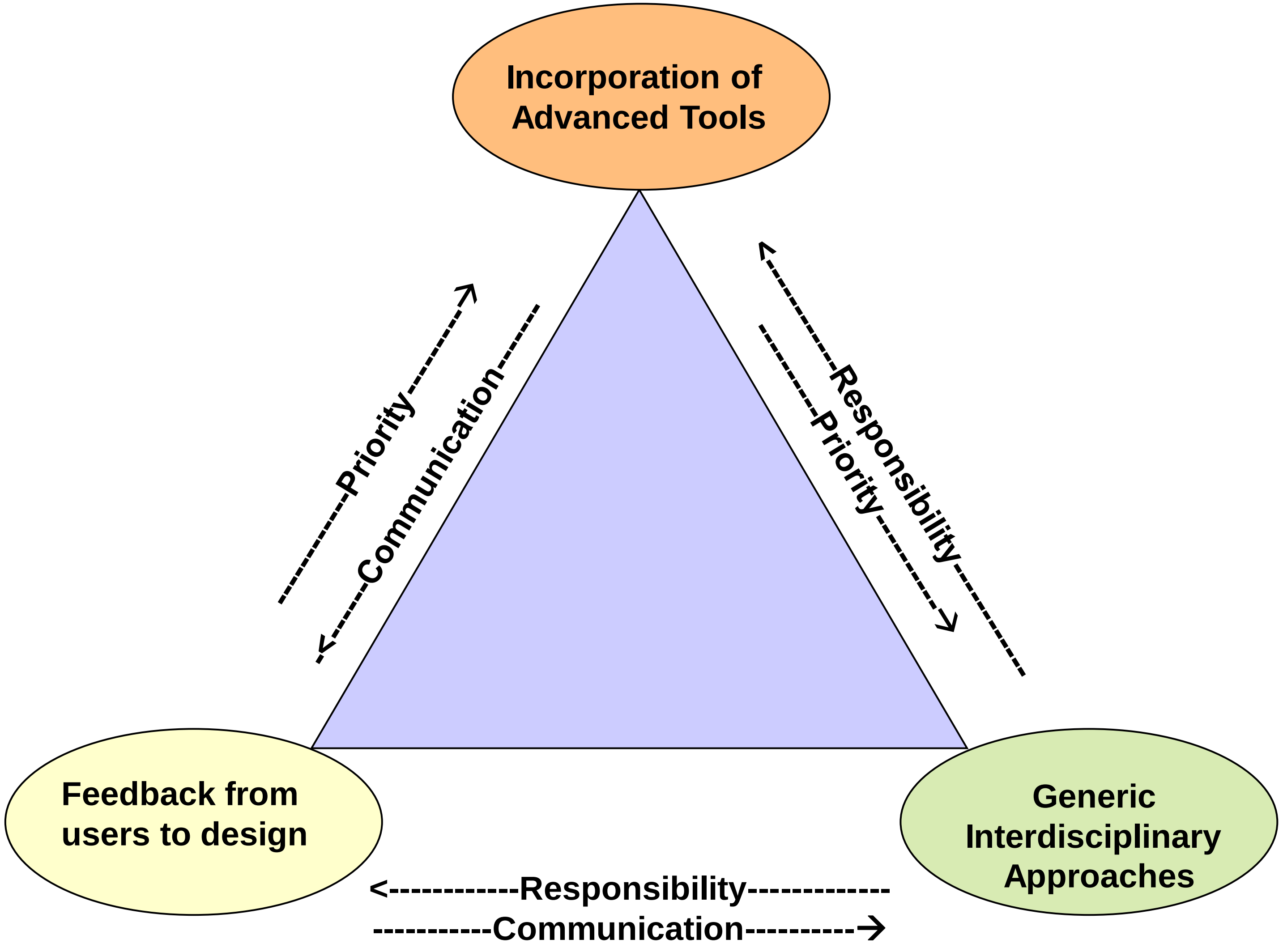
Pre-Event
Event
Post-Event
Insufficient Weather Condition
Develop Proper procedure for early warning in bad weather conditions
Avoid ship navigation in bad weather
Procedure Failure
Install visible speed limit sign in a high-risk waterway
Procedure violation shall be recorded
Communicate & enforce procedure
Lack of Situational Awareness
Provide training
Awareness about rules and responsibilities
Navigation Failure
Communicate & enforce procedure
Provide training
Suez Canal Grounding Incident
Ever Given Ship Grounded
Divert incoming vessels to another channel
Prepare an emergency response plan b
Vessel Disruption
Install lights on banks sideways
Avail proper tools and tugboats
Canal Blockage
Create response and contingency plan
Adhere to procedure and policy
Reputation Damage
Assign competent crew ship
Maintain ship condition
Salvage

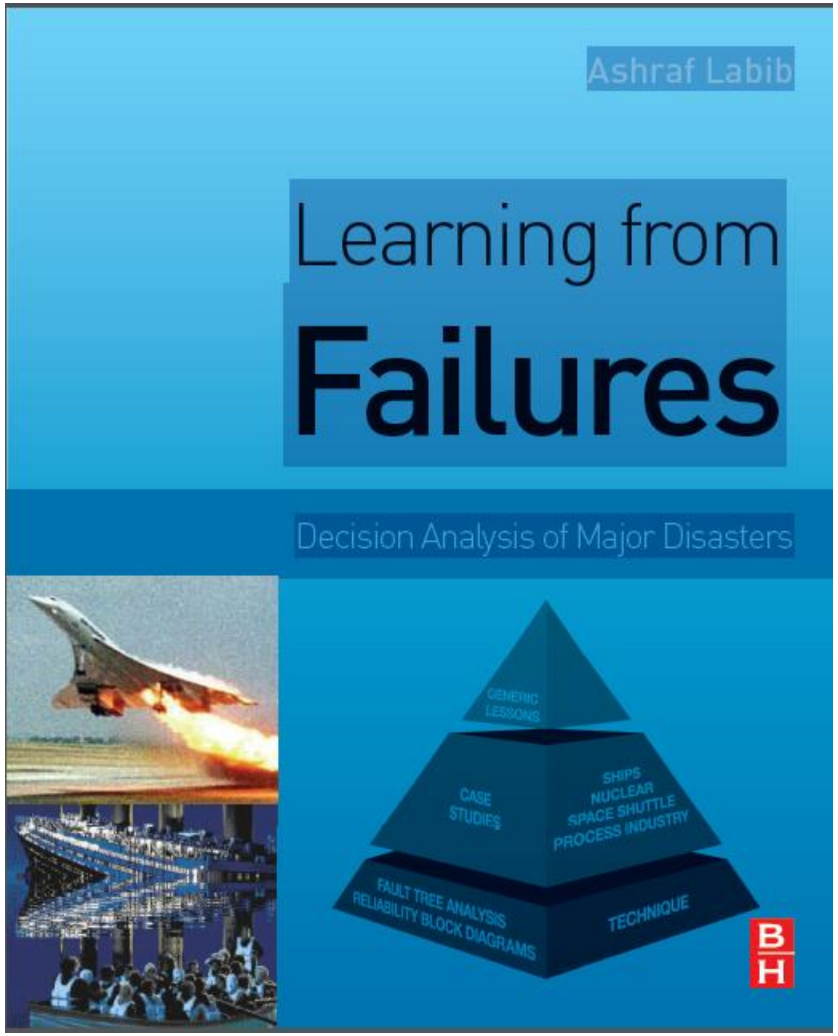

Pre-Event
Event
Post-Event
Environment (Physical)
Insufficient Weather Condition
Develop Proper procedure for early warning in bad weather conditions
Avoid ship navigation in bad weather
Suez Canal Grounding Incident
Divert incoming vessels to another channel
Prepare an emergency response plan b
Vessel Disruption
Environment (Social)
Procedure Failure
Install visible speed limit sign in a high-risk waterway
Procedure violation shall be recorded
Communicate & enforce procedure
Ever Given Ship Grounded
Install lights on banks sideways
Avail proper tools and tugboats
Canal Blockage
Human
Lack of Situational Awareness
Provide training
Awareness about rules and responsibilities
Create response and contingency plan
Adhere to procedure and policy
Reputation Damage
Equipment
Navigation Failure
Communicate & enforce procedure
Provide training
Assign competent crew ship
Maintain ship condition
Salvage



Pre-Event
Event
Post-Event
Environment (Physical)
Human
Equipment
Environment (Social)
Insufficient Weather Condition
Develop Proper procedure for early warning in bad weather conditions
Avoid ship navigation in bad weather
Lack of Situational Awareness
Provide training
Awareness about rules and responsibilities
Procedure Failure
Install visible speed limit sign in a high-risk waterway
Procedure violation shall be recorded
Communicate & enforce procedure
Navigation Failure
Communicate & enforce procedure
Provide training
Suez Canal Grounding Incident
Ever Given Ship Grounded
Create response and contingency plan
Adhere to procedure and policy
Reputation Damage
Install lights on banks sideways
Avail proper tools and tugboats
Canal Blockage
Assign competent crew ship
Maintain ship condition
Salvage
Divert incoming vessels to another channel
Prepare an emergency response plan b
Vessel Disruption

Process of Learning from Failures





Concluding Remarks:

- Our analysis complements a recent work conducted on the Suez Canal incident using Bayesian Network (BN) analysis, which was indented to extract lessons learned, and have identified them as being due to insufficient information, poor communication, a complacent issue, and in adequate safety culture for the Ever Given organization management (Fan *eta*l, 2022).
- Furthermore, the analytical techniques used in this case study identified several safety barriers recommendations in table 3 and table 4 to prevent the reoccurrence of such an indecent. In addition, to the below lesson learned that can be summarized as the following:
  - Clear communication between the captainship and the tugboat pilot was extremely important during the canal navigation.
  - Captain of the ship shall always adhere to the Suez Canal navigation procedures.
  - Insufficient weather can cause unpredictable consequences.
  - Improve Suez Canalside banks design by:
    - Installing lights to provide better vision during night, fog or sandstorm.
    - Safety signs
    - Wind protection to minimize the wind speed.
- Furthermore, during the analysis of the minimum cut sets, we identified four scenarios of the least combination of factors that are necessary and sufficient to cause such a major accident. Each of these scenarios can be embedded in the planning of future training simulation exercises and drills for different stakeholders.

OMAINTEC CONFERENCE EXHIBITION 2024

THE 21ST INTERNATIONAL OPERATIONS & MAINTENANCE CONFERENCE IN THE ARAB COUNTRIES

THANK YOU!

#OmaintecConf

An Initiative by

OMAINTEC
المجلس العربي للتشغيل والصيانة
Arab Operations & Maintenance Council

Organized by

EXICON
International Group
مجموعة أكزيكون الدولية