# LECTURE NOTES: EMGT 234

## MODELING THE CAUSAL CHAIN

SOURCE:

Chapter 2: "Causal Structure"
Perilous Progress, Managing the Hazards of Technology
Kates, Hohenemser, Kasperson

# 1. INTRODUCTION

If a Tree falls in a forest, is there a sound?
or
If a Tree falls in a forest, is there a hazard?

**Answer:**
For there to be a sound somebody must be there to experience it. Likewise, for there to be a hazard somebody must be there to experience the potential consequences.

HAZARD consist of:

- **An Event:** Tree Falling
- **Exposure:** Being close enough to the occurrence of the event
- **Adverse Consequences:** Being Crushed by the Tree.

HAZARD MANAGEMENT (= RISK MANAGEMENT):

(1) Prevent Events
(2) Prevent Exposure
(3) Prevent Consequences
(4) Mitigate Consequences

Prevention is more fundamental then mitigation:
**"An ounce of prevention is worth a pound of cure"**

# 2. THE CAUSAL ANATOMY OF HAZARDS

- Technological Hazards and Natural Hazards may differ fundamentally in feasibility of Risk Management Strategies:

**Example:**

- **Nuclear Power :** (3) and (4) are not feasible, efforts concentrate on (1) and (2).
- **Geophysical events:** (1) not feasible and (3) of limited impact due to size of forces.

- Above examples are extremes, for other hazards all Risk Management Strategies may be feasible.

**Example:**

- Automobile Accidents:

(1) Elimination of curves in Highways
(2) One way Traffic Lanes
(3) Seatbelts and Airbags
(4) Car Insurance

**Question:**
How do prevention and mitigation occur?

## Answer:

- Events, Exposure and Consequences are connected through a causal sequence.
- Prevention and Mitigation through interruption of Causal Pathways

## Terminology:

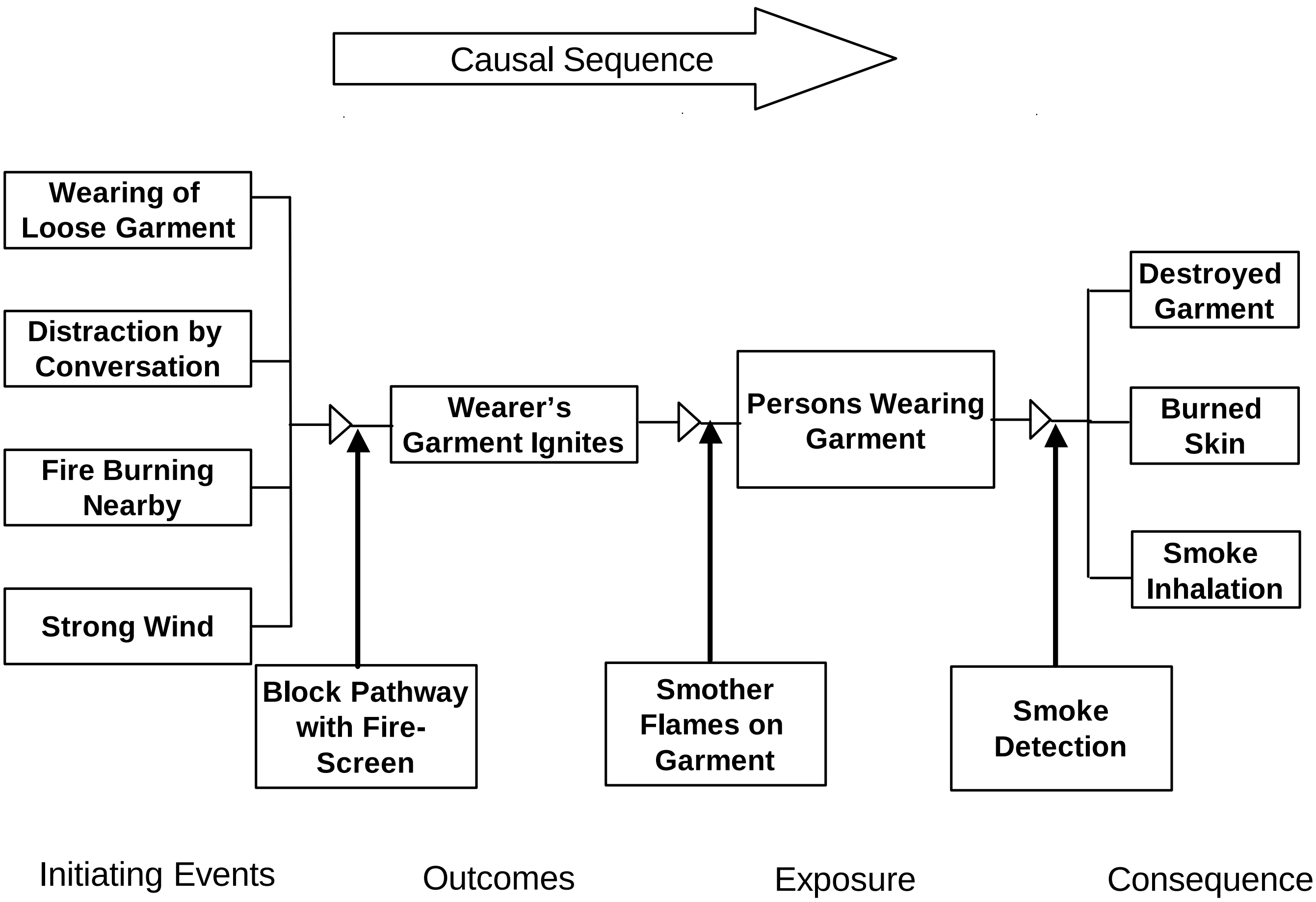
- **Initiating Events:** A combination of events or sequence of events that trigger the occurrence of potential hazardous events

- **Outcomes:** The result (= an event) of the combination of initiating events that poses a hazardous condition

- **Exposure:** The presence of people to experience the potential consequence (= an event)

- **Consequence:** The adverse event that may follow from and outcome and the exposure to the outcome

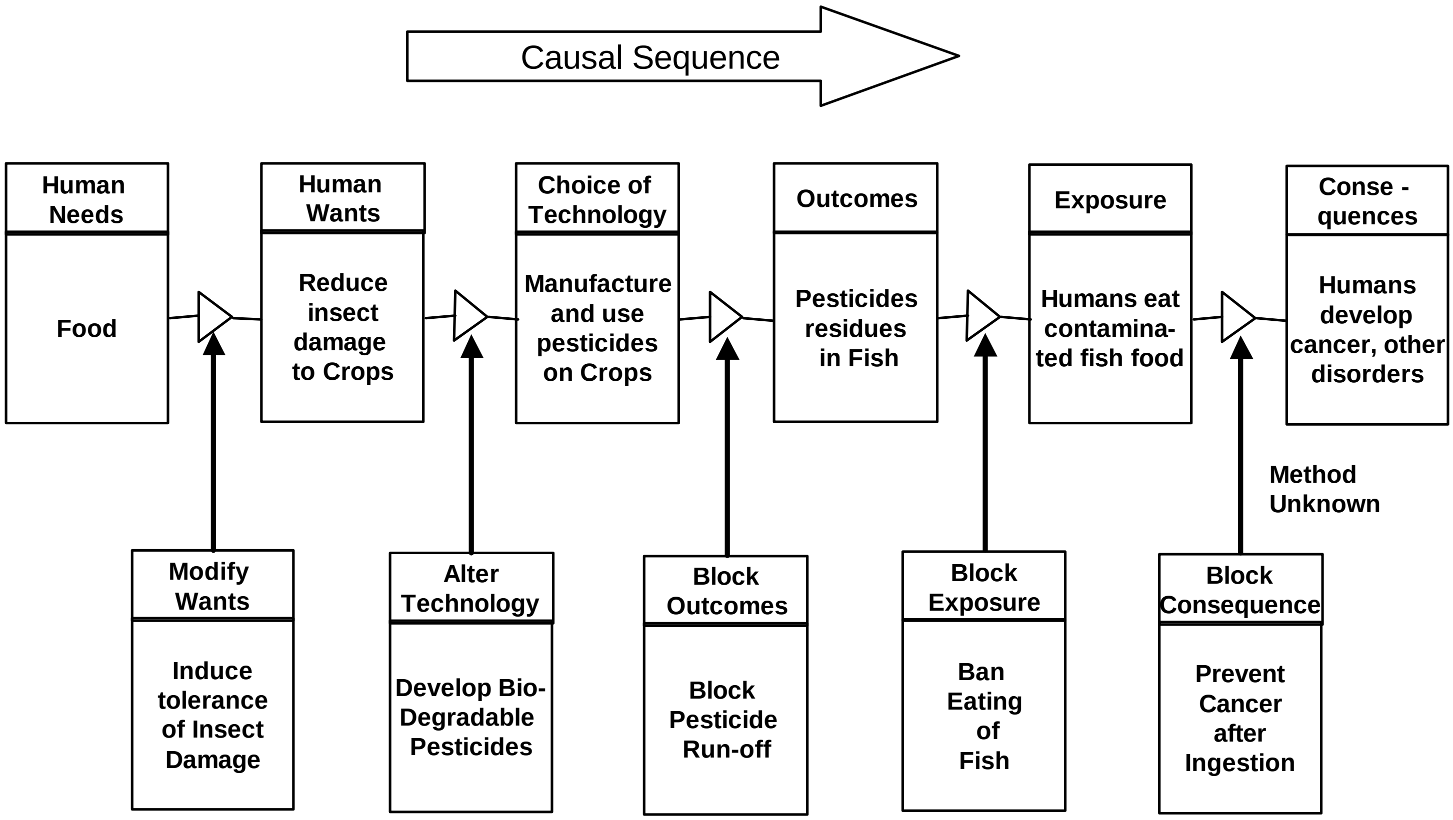
# EXAMPLE 1: FIRE PLACE ACCIDENT




**Note:**

- The sequence of events + consequences (=an event) contribute to the fire place accident
- Combinations of initiating events form the triggering event.
- Outcome Prevention: Fire Place Screen
- Exposure Prevention: Smother Flames on Garment
- Consequence Prevention: Smother Flames on Garment
- Consequence Prevention: Some Detection to reduce potential consequences to other occupants in the house.

# EXAMPLE 2: CANCER INCREASE BY USE OF PESTICIDES

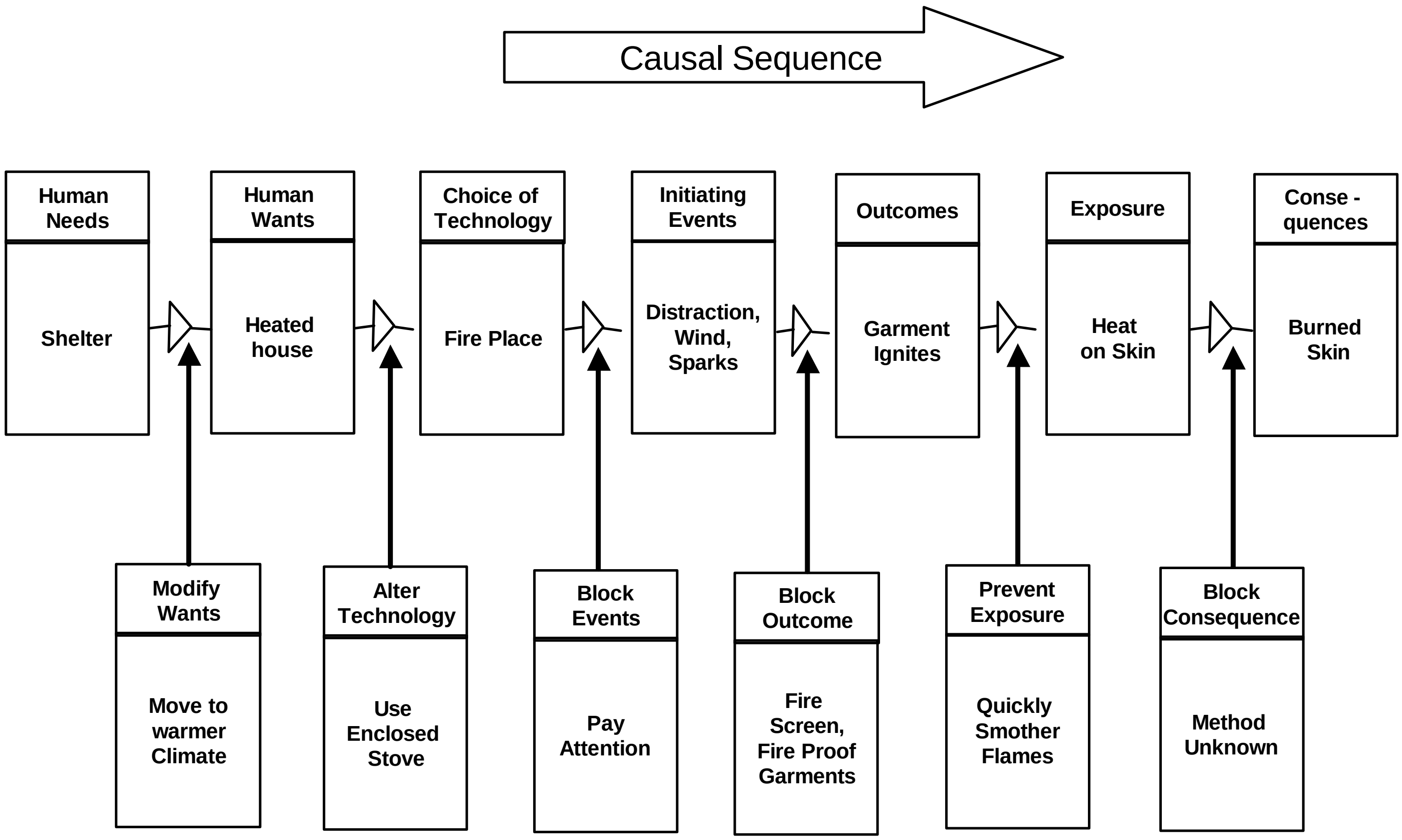



## Note:

- Causal Chain expanded to the left to include, Human Need, Humans Wants, and Choice of Technology.

- Upstream Development of Causal Chain is important if Downs Stream intervention of Causal Pathways pose control problems or are poorly understood.

# EXAMPLE 3: FIRE PLACE EXAMPLE REVISITED



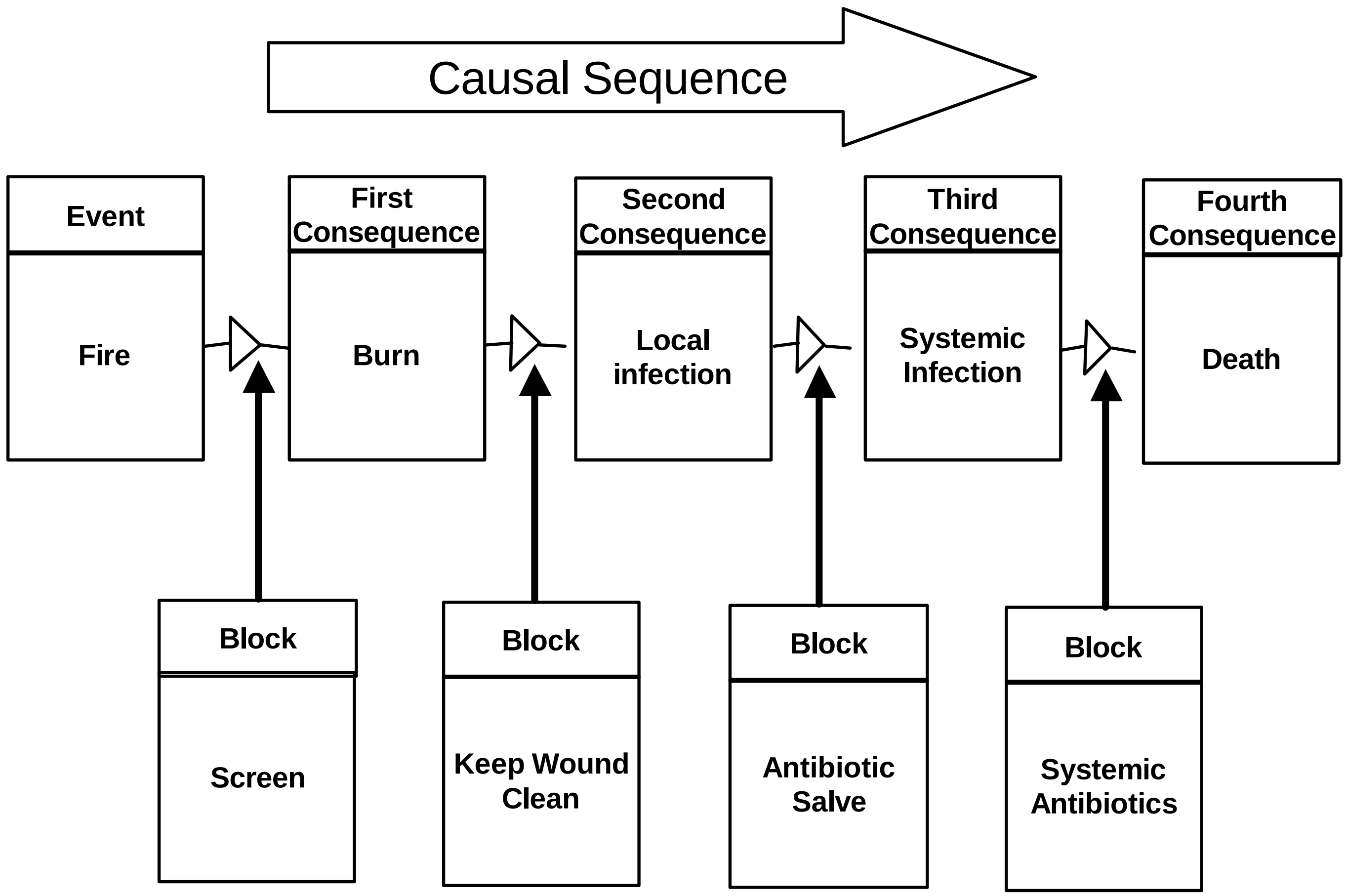

## Note:

- Example 1 is extended to seven stage Causal Chain
- Extending Chain helpd identifying additional control measures:

(1) **Triggering Prevention:** Pay Attention
(2) **Prevention by altering Choice of Technology:** Use enclosed Stove (Immediate Causes)
(3) **Prevention by modifying human demand:** Move to warmer climate (Root Causes)

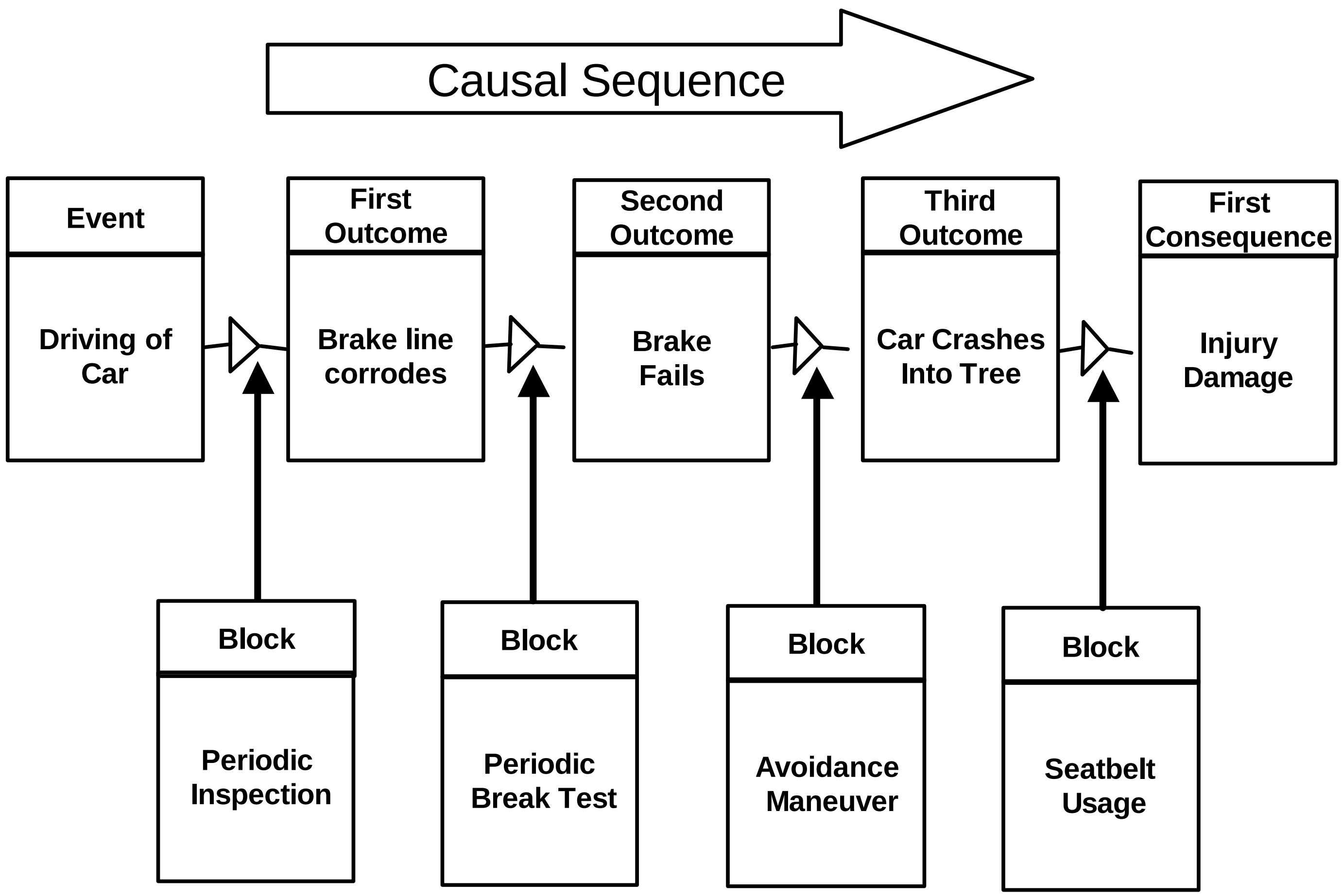
- Further expansion may be desirable **if useful** for identifying control measures.

## EXAMPLE 4: FIRE PLACE EXAMPLE REVISITED



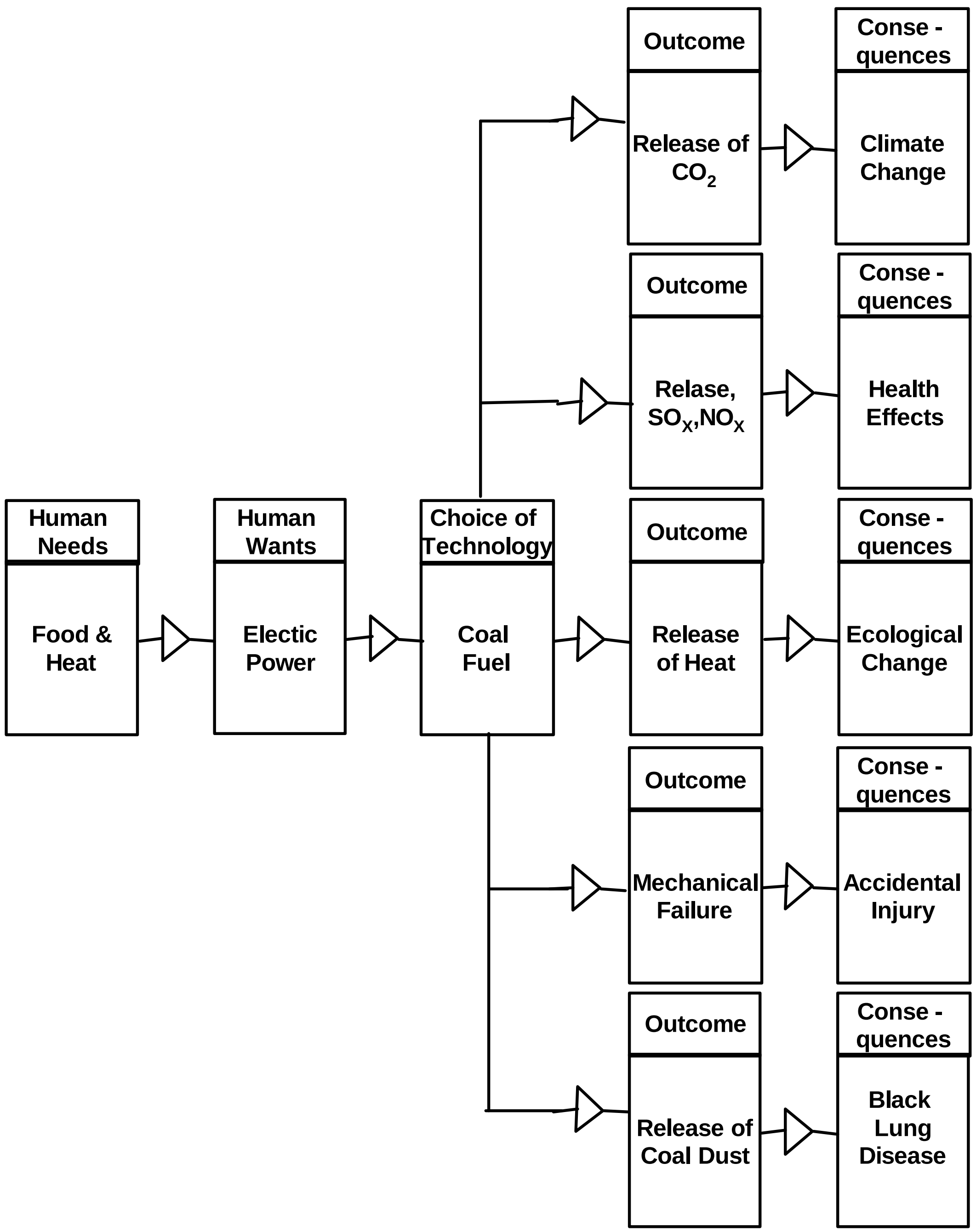
- Further expansion may be desirable **if useful** for identifying control measures.

# EXAMPLE 5: AUTOMOBILE CRASH DUE TO BRAKE CORROSION



- Previous examples involve a single causal chain. However, multiple chains may be connected at early stages in the causal chain.

# EXAMPLE 6: COAL FUEL TO GENERATE ELETRIC POWER



# SUMMARIZING

- **More generally, the topology of hazard chain may follow a tree structure. One may focuss on a particular path with the tree (=limitation of work scope)**

- **Causal Chain structure of Hazard is related to methods widely used in technological risk assessments:**

1. Combination of Intitiating events may lead to an outcome (See Fire Place Example): Related to Fault Tree approach.
2. An event may lead to mutliple causal pathways. (See Elecetric power Example): Relates to Event tree approach.

- **Fault Tree and Event Trees strive for completeness to allow for probabilistic risk analysis (PRA).**

- **Causal Chain Approach : Simplified event trees or simplified fault trees focussing on a particular path tree or focussing on a collection of paths presented in a single chain context:**

1. To identify potential control measures (Risk Reduction Measures) does not require full detail.
2. Introducing all contributing multiple causes would complicate diagrams beyond easy comprehension and is better left for such time as a full fault tree is needed.

- **Causal Chain Approach is more comprehensive than fault trees or event trees as it includes upstream options such as control of human demands and choice of technology.**

# 3. DYNAMICS OF HAZARD CONTROL

- Risk Reduction Measures distributed over Causal Chain
- Simple Sequence from downstream to upstream does not represent the control process

**Rather:**

- A hazard is first recognized by the experience of adverse consequences
- A control action follows by inserting a block at upstream stages.

**Conclusion:**

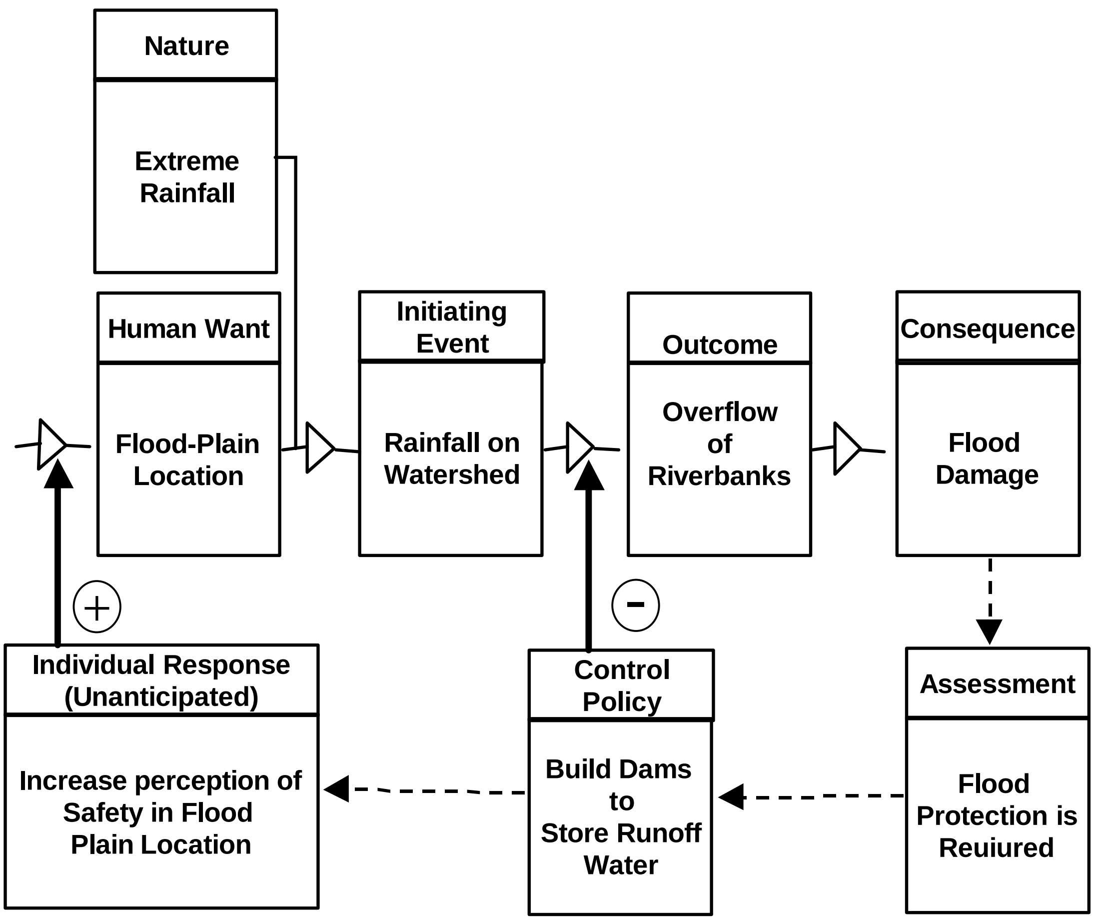
Dynamic Control Process involves Feedback Control Loop

- Feedback in principle can be positive or negative

- For reducing a hazard one desires a control intervention with negative feedback (=risk reducing).

- Unfortunately, some control intervention may produce unintended positive feedback, canceling the negative feedback and resulting in an overall risk increase.

# EXAMPLE 7: FLOODING CONTROL LOOP

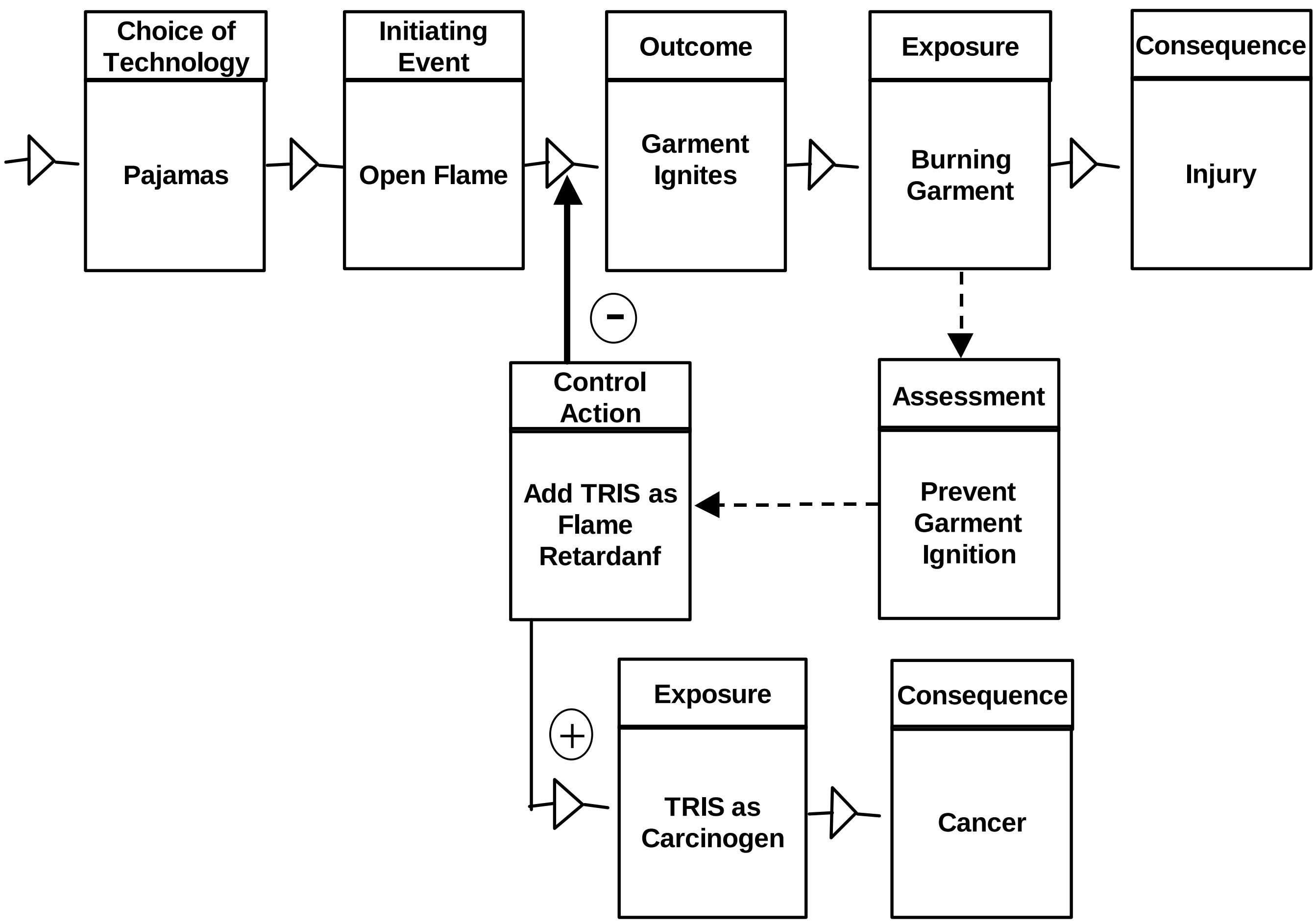



- 1936 Flooding Control Act: Army Corps of Engineers start building flood dams, levees, and channels to protect flood plain
- 20 years later: Research Studies showed that flood damages increased due to increase of floodplain development as a result of perceived safety.

- **Unintended impacts of control loops are of two kinds:**

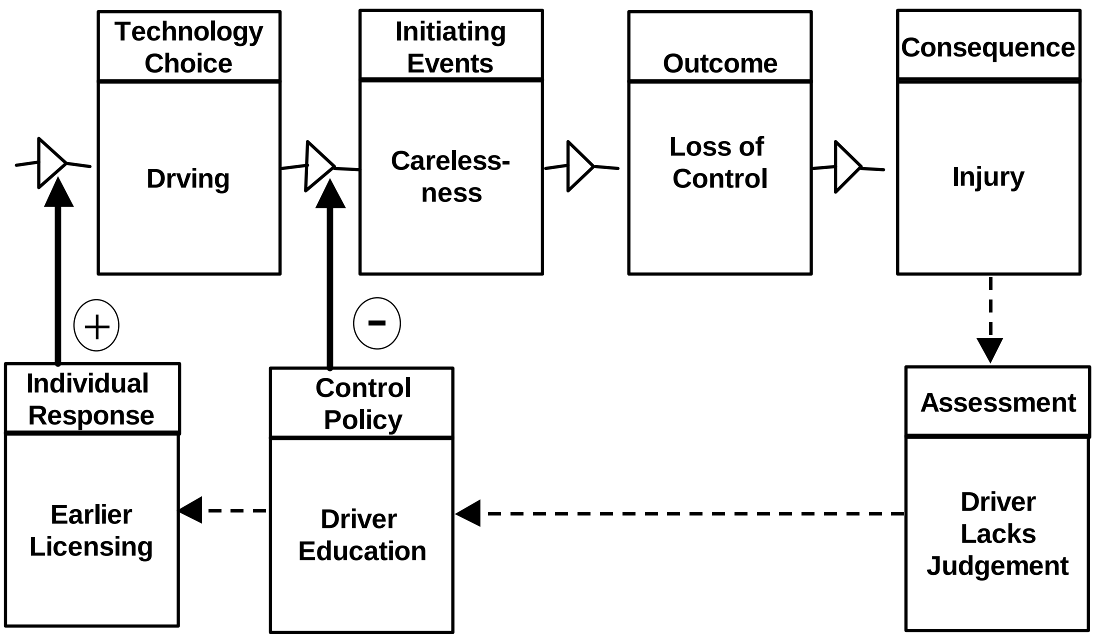
1. Amplification of existing causal chain (Example 7)
2. Creation of new hazard chains

## EXAMPLE 8: USE OF TRIS AS FIRE RETARDENT

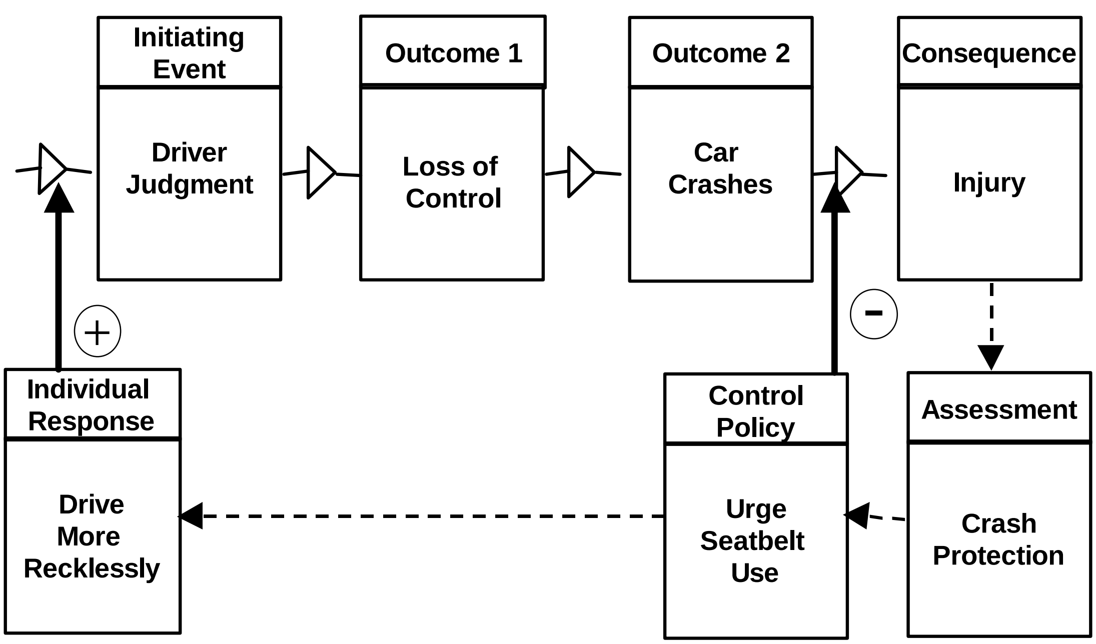


- Negative Feedback may occur at any point in the causal chain.

## EXAMPLE 9: DRIVER EDUCATION



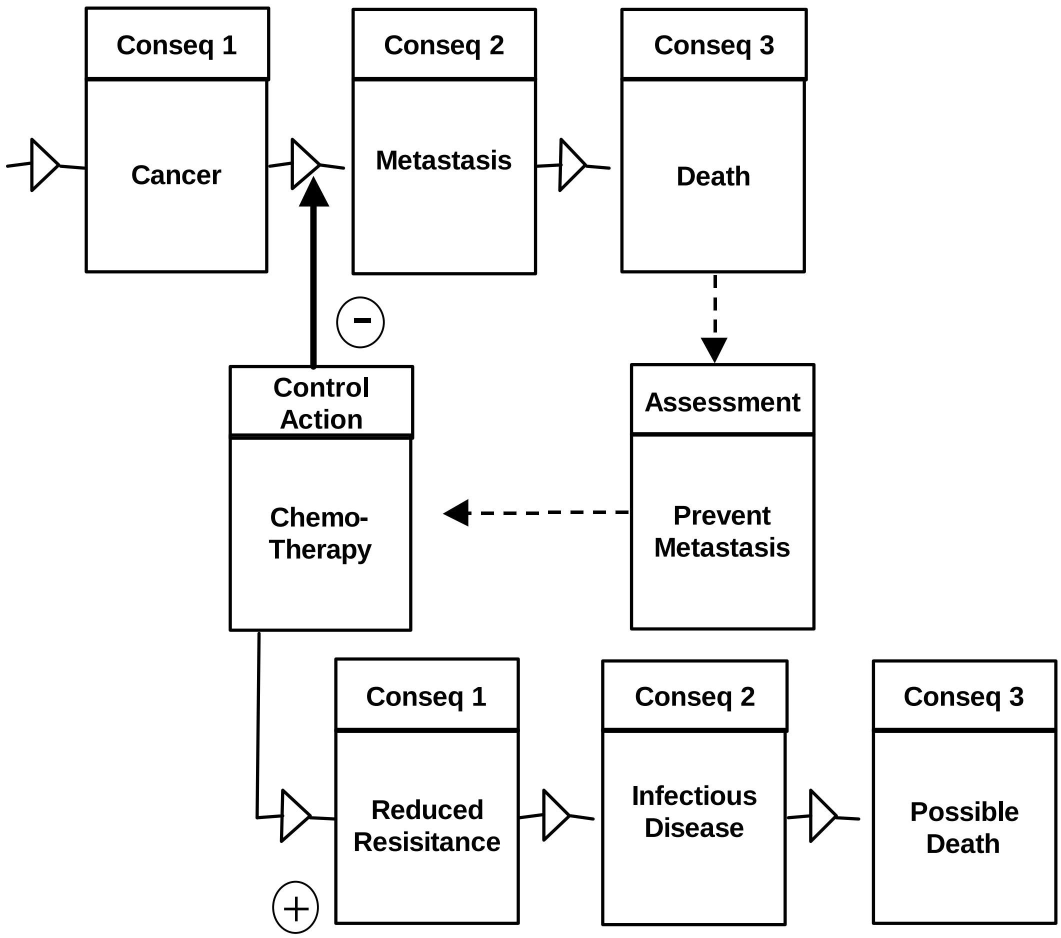

## EXAMPLE 10: SEAT BELT USE



- **Benefit of diagramming feedback Loops:**

1. Discovering unintended positive feedbacks.
2. Acceptability of Control Intervention requires the acceptance of possible positive feedback loops.

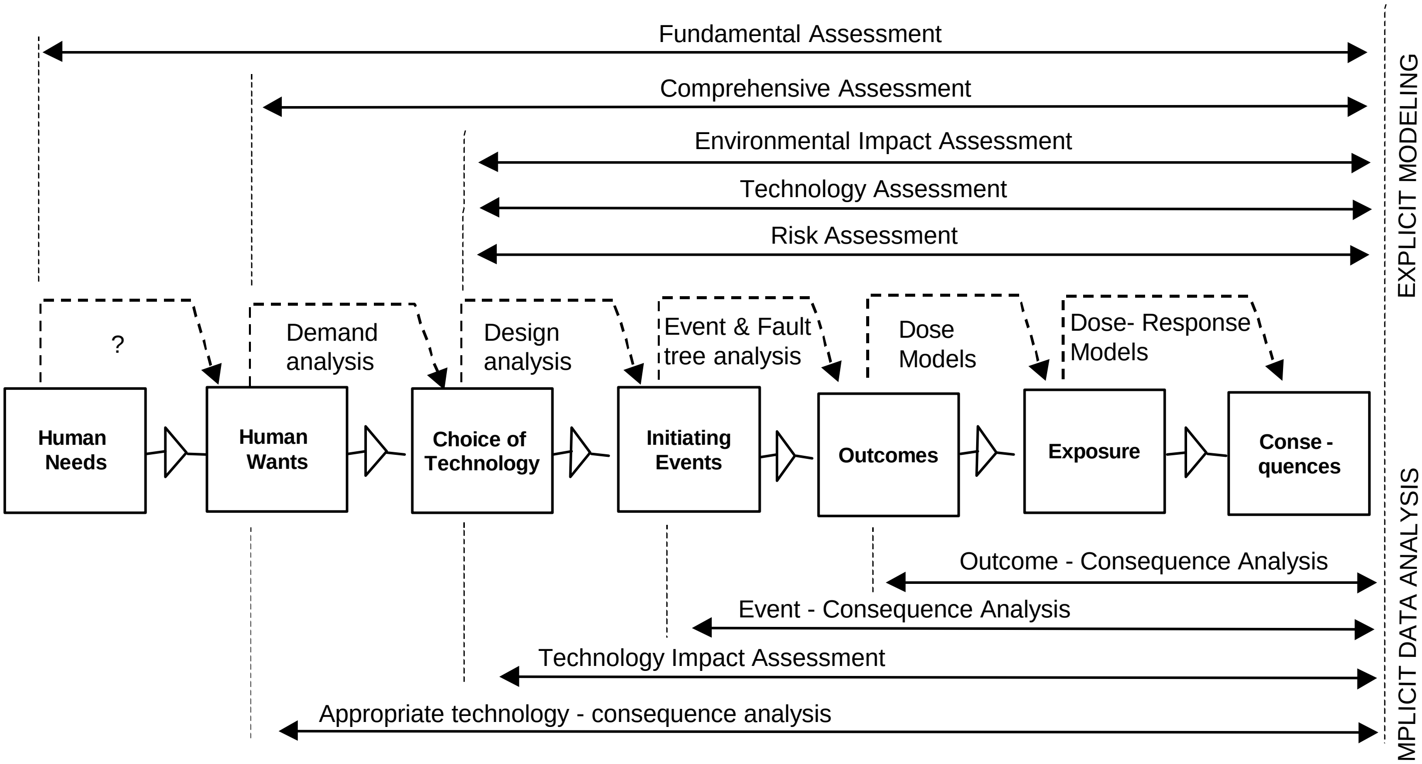
## EXAMPLE 11: USE OF CHEMOTHERAPY




**Conclusions:**

- "Pure" Control Measures probably do not exist. Recognizing the adverse effects of a risk reduction measure such be part of any control assessment.
- Diagramming a wide variety of control measures may yield a small catalog of recurring interventions, useful for the estimation of efficiency of proposed interventions.

# 4. SCOPE OF HAZARD ANALYSES




- **Risk Assessment:**

Focusses on specific technology with subsequent chances of causal chain. Explicit Modeling though use of e.g., event trees & fault tree analysis. Probabistic Risk Assessment (PRA) = RA + probability assessment of each event in causal chain + aggregation of assessments.

- **Technology Assessment:**

Similar to Risk Assessment but foccussed on several design alternatives with associated consequence scenarios for each. Also considers benefits besides risks. Level of detail may less than Risk Assessments

- **Environmental Impact Assessment:**

Same as technology assessment except that consequence analysis is broadened to include environmental and social values to the fullest extent.

- **Comprehensive Assessment**

An effort is made to move further upstream to include assumed human wants (or demands) in economic terms or human needs in psychological terms.

- **Fundamental Assessment**

An effort is made to include biological needs

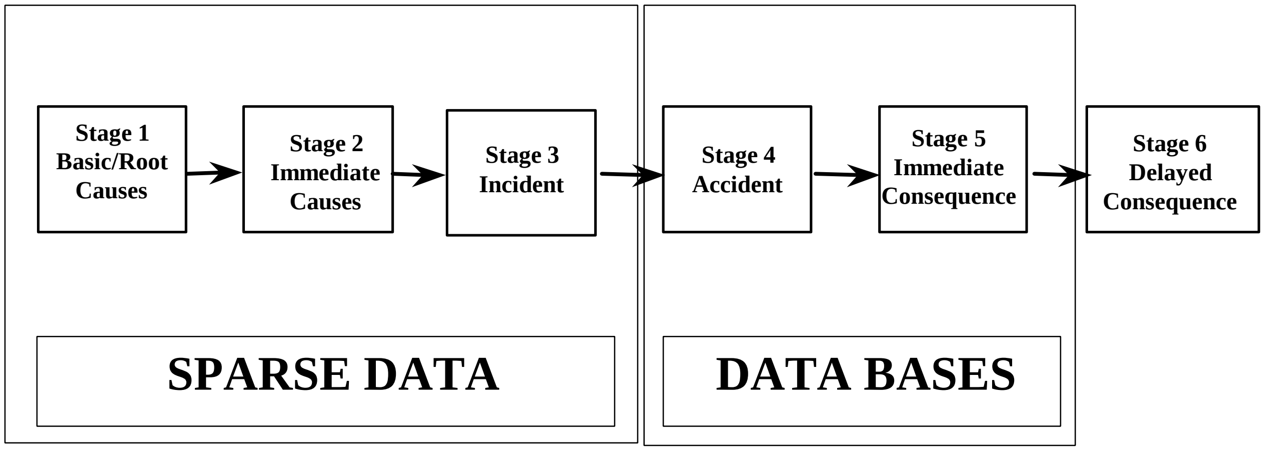
- **Implicit Data Analysis**

Seek empirically derived correlation between earlier and later stages in the causal chain.

**Example:**

Actuatial Statistics linking, sex, age specific accident rates to geographical locations.

- Useful to alert society of potential problems and issues, but are typically not sufficient for hazard control due to lack of explicit modeling.



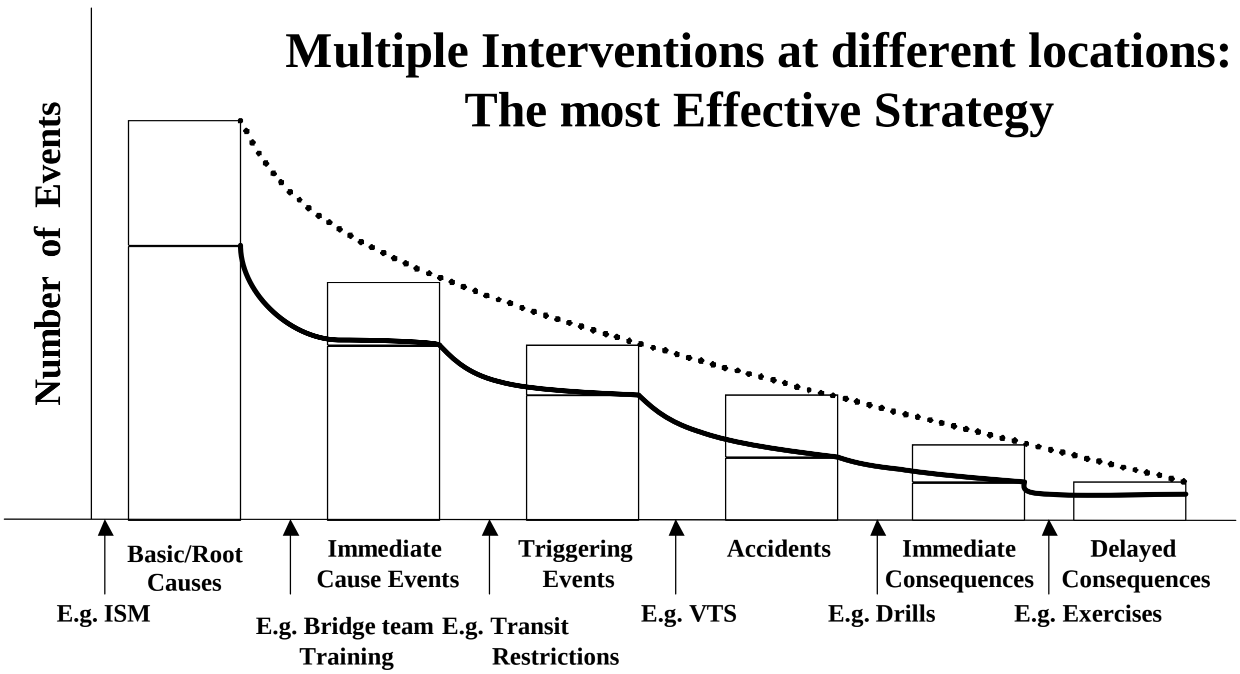

## MOVING UPSTREAM OF THE CAUSAL CHAIN USING EXPLICIT ANALYSIS TECHNIQUES

- Involves a larger range of potential control measures allowing hazard control in those instances where causal chain relations upstream are not well understood.

- Establishing explicit model may require experiments that are increasingly unacceptable to the public e.g. effects of toxic chemicals

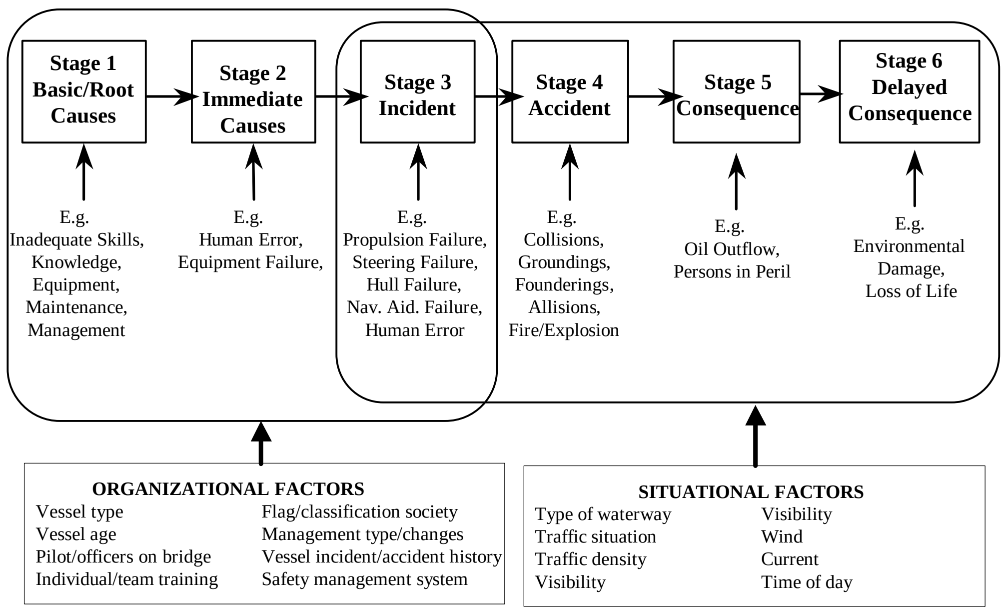
- Impact of control measures on earlier stages on the causal chain are better understood. After that, let the modeling due to talking.

# Effective Risk Management\ Hazard Control

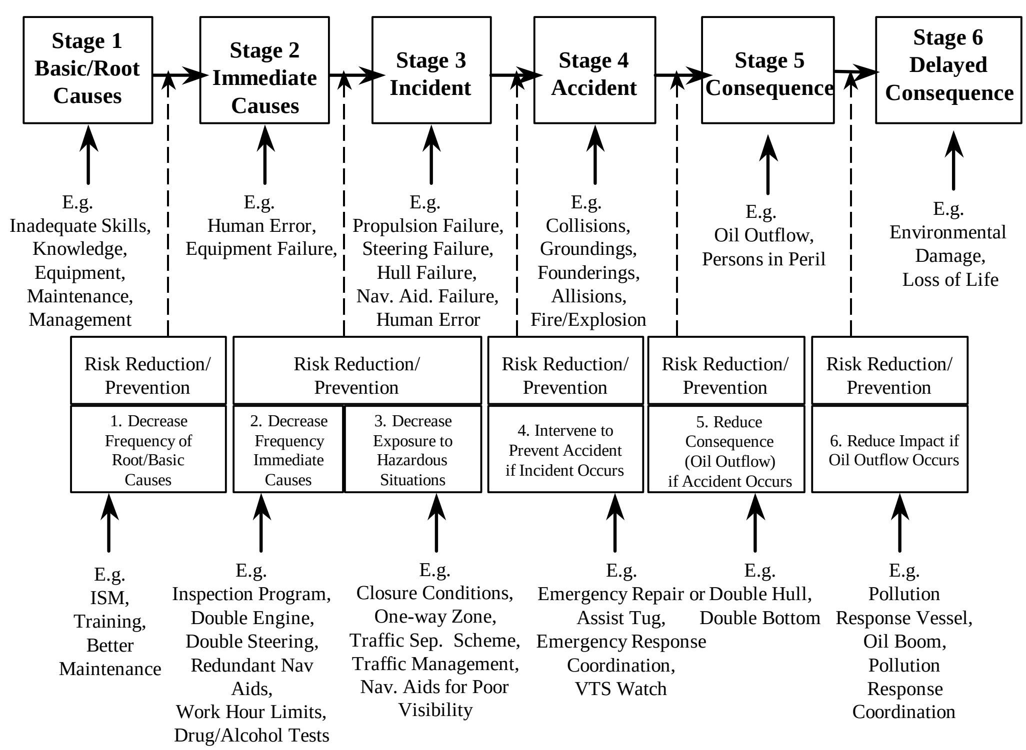



**CONTROL ANALYSIS SHOULD MOVE UPSTREAM!**

# The Maritime Accident Event Chain

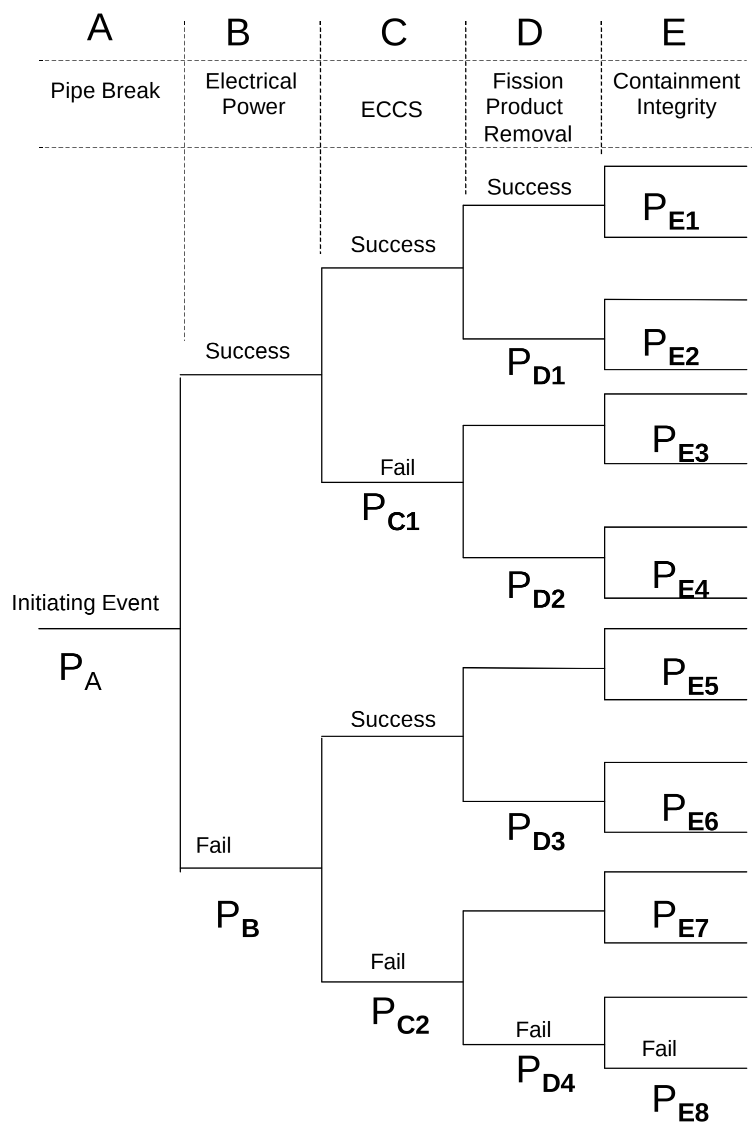



# Risk Reduction Interventions



# EVENT TREE ANALYSIS

Event Trees use forward logic (inductive). They begin with an initiating event (an abnormal incident) and propagate this event through the system under study by considering all possible ways in which it can effect the behavior of the system

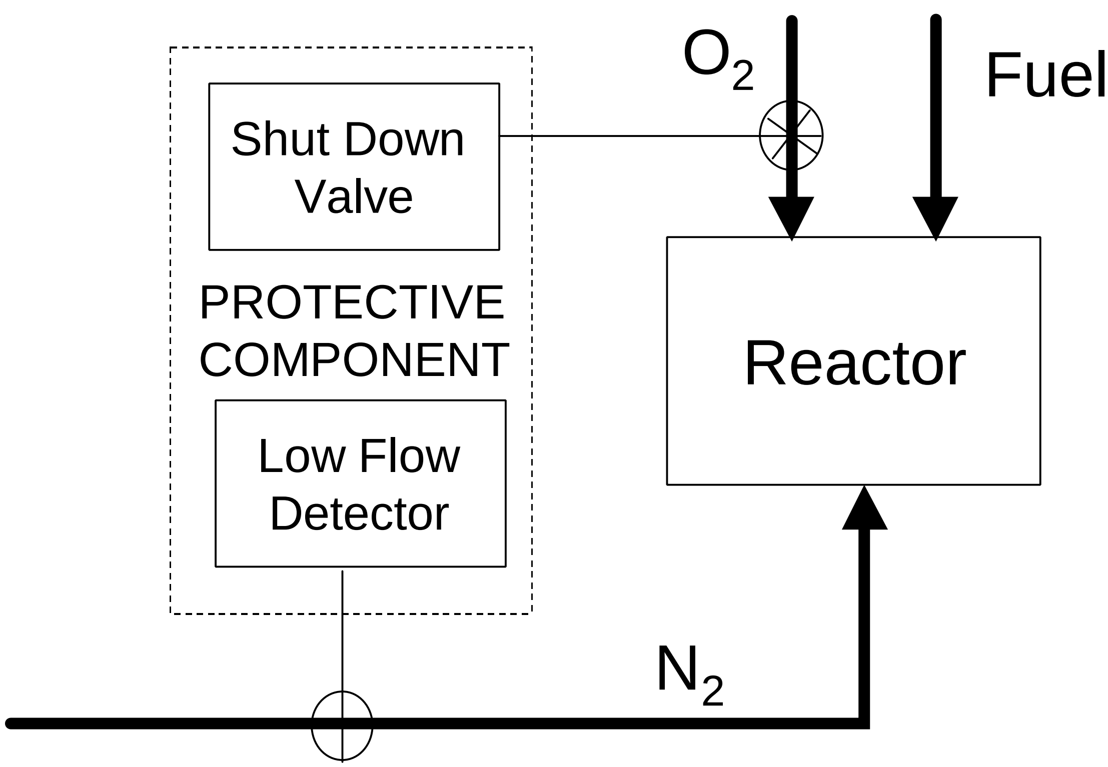


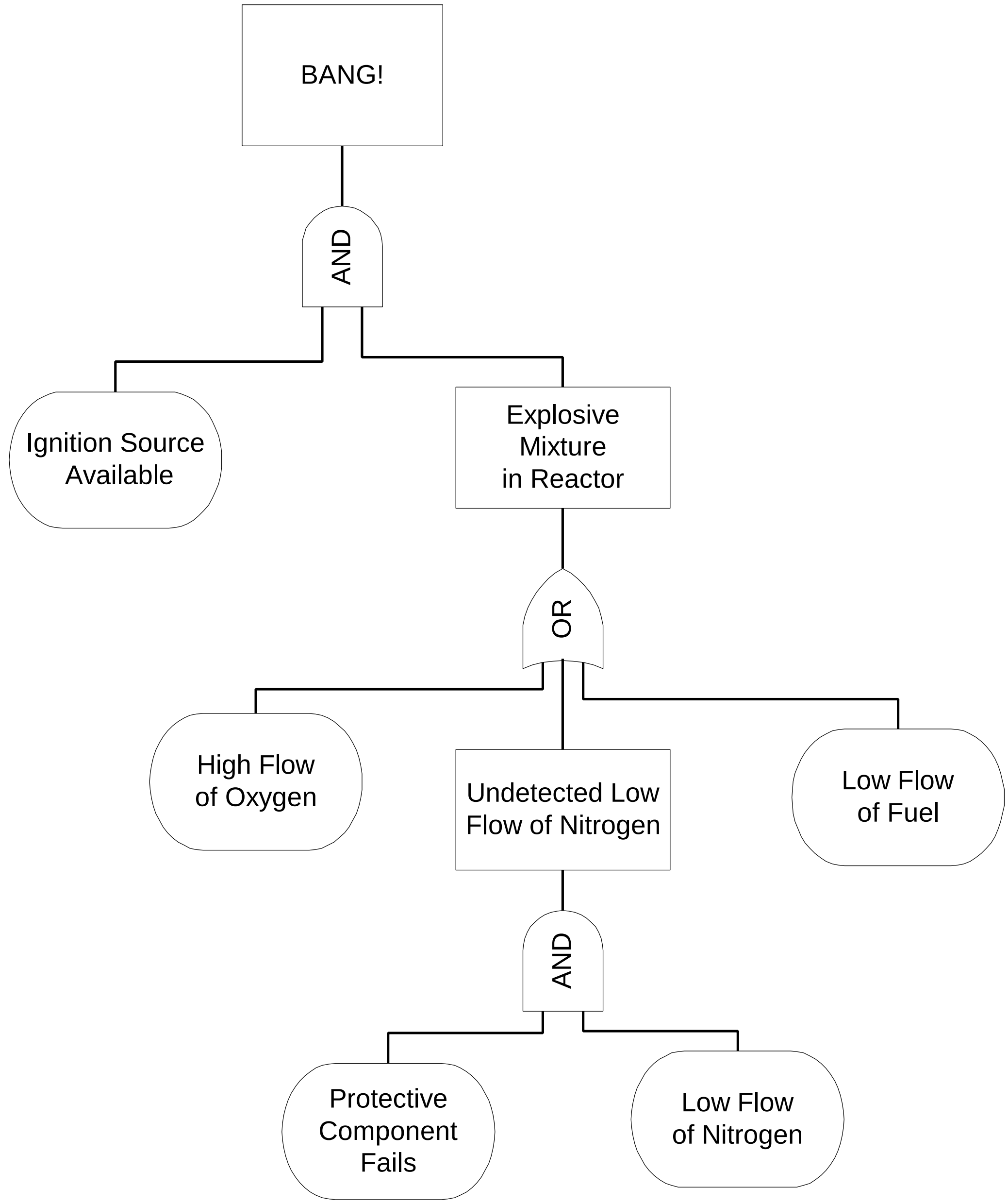

**Simplified Example from WASH 1400 Study**

# Fault Tree Analysis

An analytical technique, whereby an undesired state (e.g. an oil spill) of a system (e.g. Prince William Sound System) is specified and the system is then analyzed (deductive) to find all credible (or incredible) ways in which the undesired event can occur.

## EXAMPLE:






Ignition Source Available = I
Low Flow of Nitrogen =N
Low Flow of Fuel = F
High Flow of Oxygen = O
Protective Component Fails = P

## Representation of Fault Tree in terms of Boolean Algebra

$$BANG! = I \cap \left(O \cup (P \cap N) \cup F\right)$$

## Quantification of Fault Tree in terms of Frequencies (Occurrences per year)

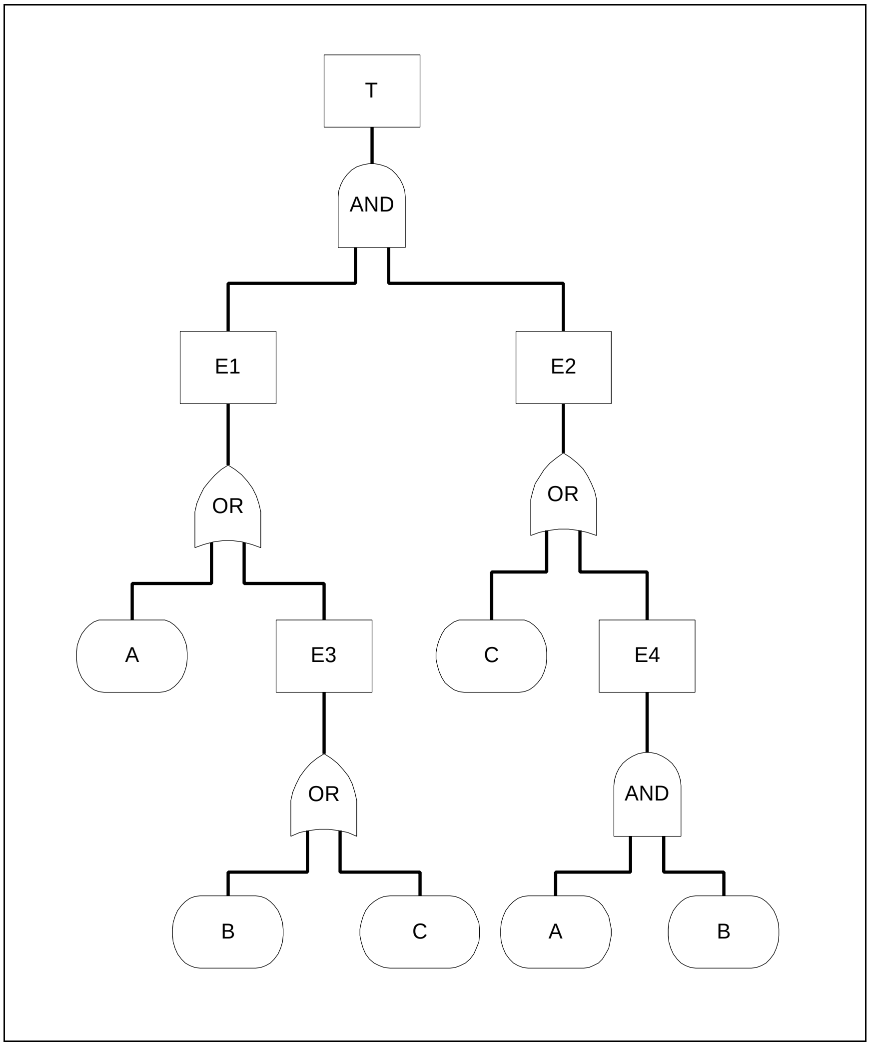
$$Fr(BANG) = \Pr(I) * \left\{Fr(O) + \left\{\Pr(P) * Fr(N)\right\} + Fr(F)\right\}$$

The above observation leads to a popular quantification method of Fault Trees by :

- Equating intersections between events with multiplication of (1) frequencies and probabilities or (2) probabilities and probabilities
- Equation unions between events with additions of (1) frequencies or (2) probabilities.

**The above quantification method is wrong as it misses the most fundamental step of Fault Tree Analysis!**

# EXAMPLE



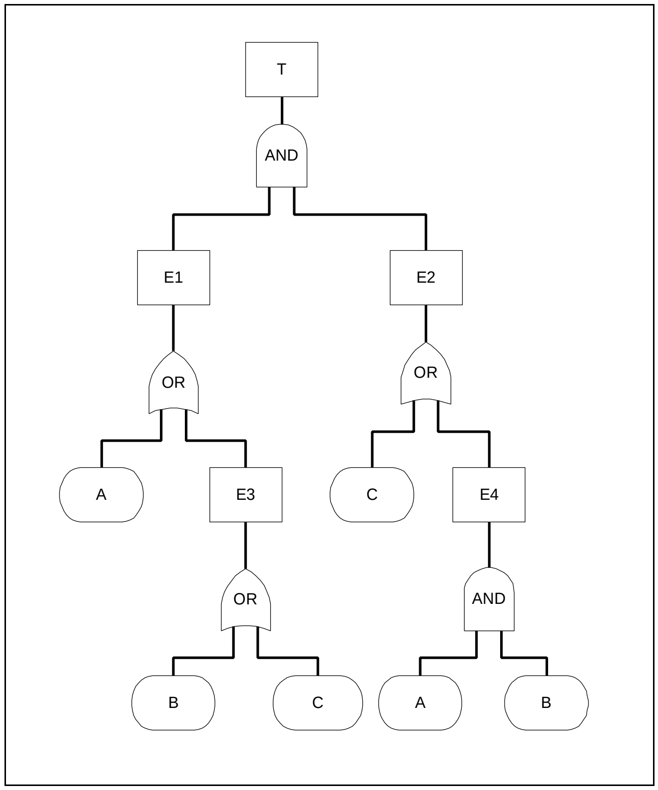

$$\begin{cases} T = E1 \cap E2 \\ E1 = A \cup E3 \\ E3 = B \cup C \\ E2 = C \cup E4 \\ E4 = A \cap B \end{cases}$$

# RULES OF BOOLEAN ALGEBRA

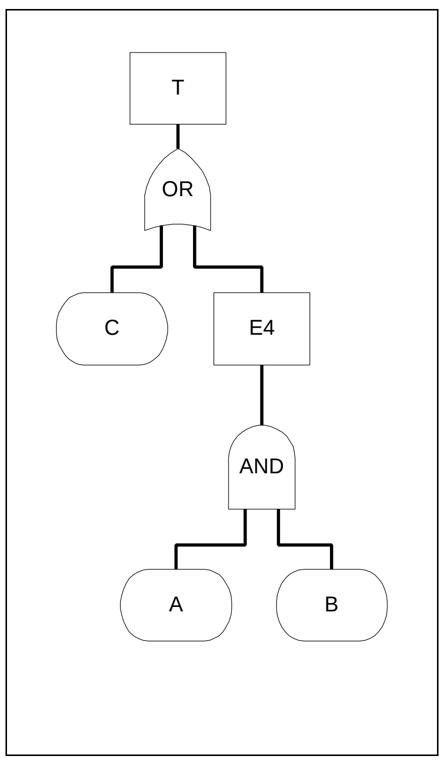
| Number | Mathematical Symbolism | Designation |
|---|---|---|
| 1A | $A \cap B = B \cap A$ | Commutative Law |
| 1B | $A \cup B = B \cup A$ | |
| 2A | $A \cap (B \cap C) = (A \cap B) \cap C$ | Associative Law |
| 2B | $A \cup (B \cup C) = (A \cup B) \cup C$ | |
| 3A | $A \cap (B \cup C) = (A \cap B) \cup (A \cap C)$ | Distributive Law |
| 3B | $A \cup (B \cap C) = (A \cup B) \cap (A \cup C)$ | |
| 4A | $A \cap A = A$ | Idempotent Law |
| 4B | $A \cup A = A$ | |
| 5A | $A \cap (B \cup A) = A$ | Absorption Law |
| 5B | $A \cup (B \cap A) = A$ | |

$$\begin{cases} T = E1 \cap E2 \\ E1 = A \cup E3 \\ E3 = B \cup C \\ E2 = C \cup E4 \\ E4 = A \cap B \end{cases} \Rightarrow T = C \cup (A \cap B)$$

# FAULT TREE EXAMPLE CONTINUED




## MINIMAL CUT SET REPRESENTATION



# MINIMAL CUT SET REPRESENTATION

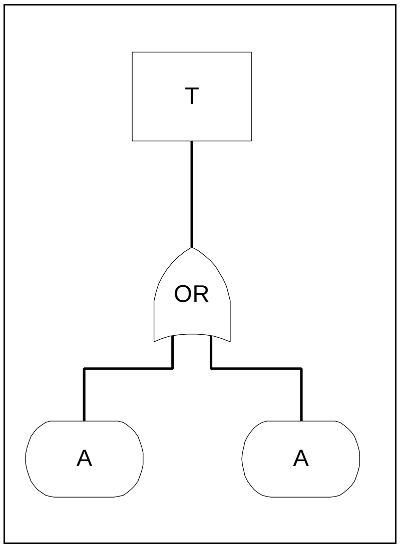
$$T = \bigcup_{i=1}^{k} M_i$$

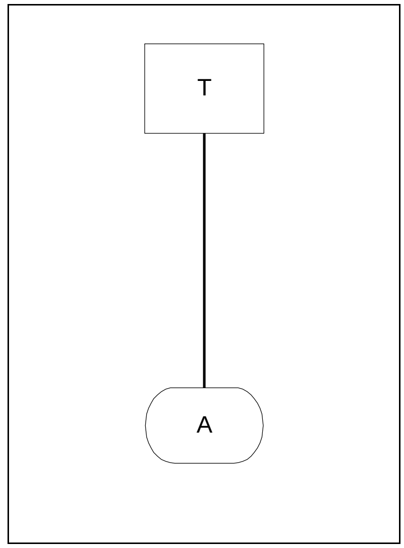
**Minimal Cut Set =**
"Smallest" combination of basic events which, if all occur, will cause the top event to occur.

- Different Fault Trees may represent the same top event correctly.
- Each Tree has a finite number of Minimal Cut Sets
- The Minimal Cut Sets are the failure modes (=different ways in which the failure can occur) leading to the top event
- The Minimal Cut Set Representation is UNIQUE and the SIMPLEST.
- The Minimal Cut Set Representation must be determined PRIOR to quantification
- Quantification of the fault tree involves: 1. Specification of the probabilities of the basic events & 2. Use of LAWS OF PROBABILITY in determining the probability or frequency of the top event.
- Sensitivity Analysis of top event probability to basic event probabilities should be analyzed at a minimum
- Uncertainty Analysis of top event in terms of uncertainty distribution of basic events should be considered.
- Risk Reduction Measures can be modeled by their effect on basic event probabilities. Thus, Risk Reduction Measure Evaluation = Sensitivity Analysis.

# WHY MINIMAL CUT SET REPRESENTATION PRIOR TO QUANTIFICATION?

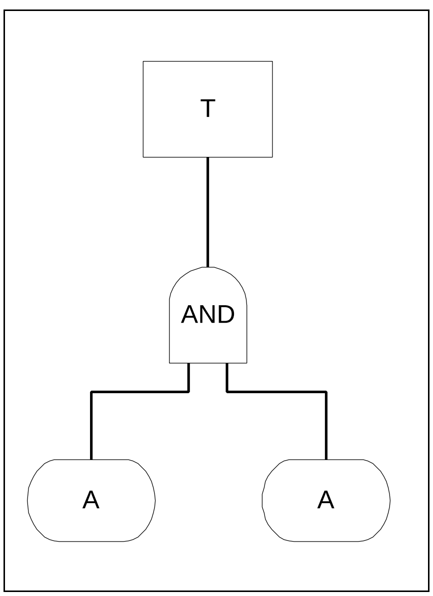
MINIMAL CUT SET REPRESENTATION

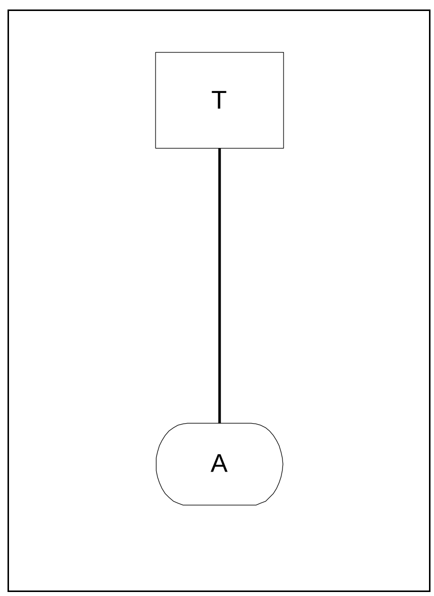



**$Pr(T) = Pr(A)+Pr(A)$** **$Pr(T)=Pr(A)$**

MINIMAL CUT SET REPRESENTATION

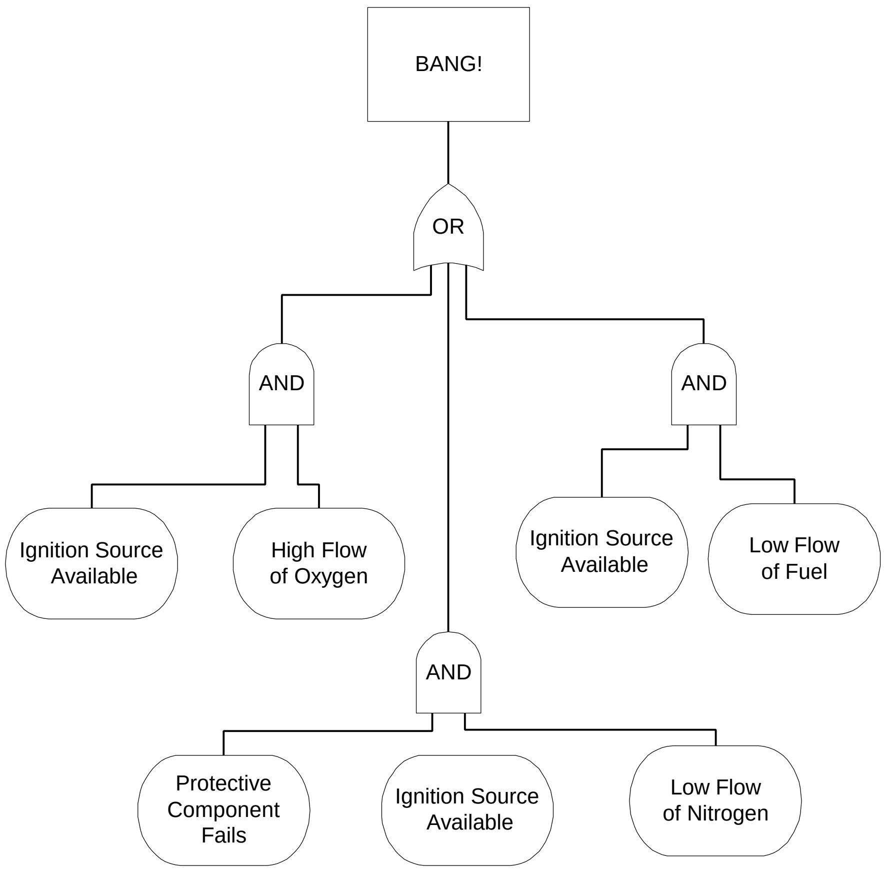



**$Pr(T) = Pr(A)*Pr(A)$** **$Pr(T)=Pr(A)$**

$$BANG! = I \cap \left(O \cup (P \cap N) \cup F\right)$$

**MINIMAL CUT SET REPRESENTATION:**




**QUANTIFICATION:**

$$Fr(BANG!) =$$

$$\Pr(I) * Fr(O) + \Pr(I) * \Pr(P) * Fr(N) + \Pr(I) * Fr(F)$$

**AS IT TURNS OUT QUANTIFICATION RESULT IS THE SAME**