Lecture 04

Event Trees & Fault Trees

Learning Objectives

1.Be able to formulate, manipulate and evaluate:

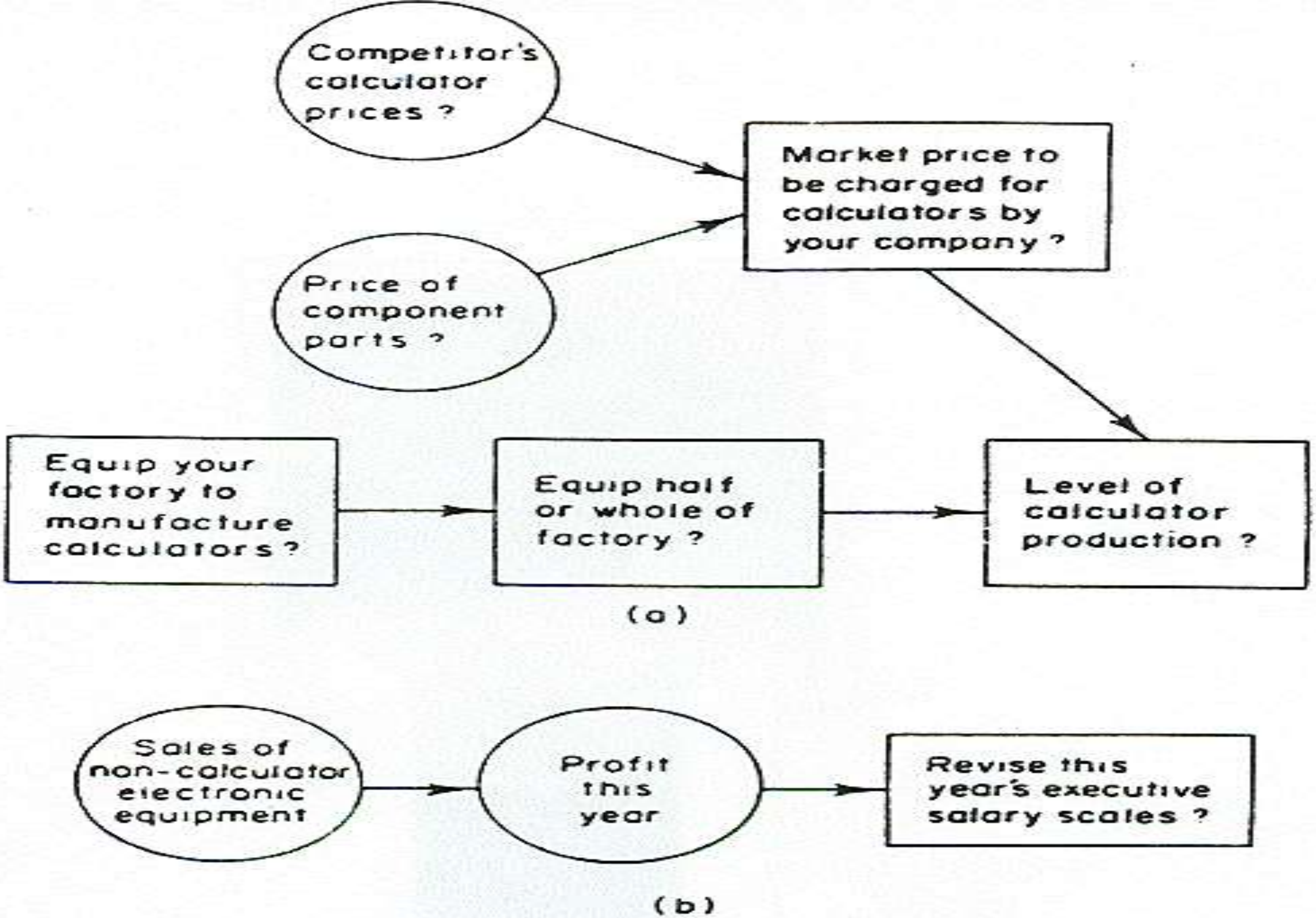
Influence Diagrams
Event Trees
Decision Trees
Fault Trees

2. Be able to construct fault trees, event trees and risk profiles for realistic problems and to compute the resulting estimates of failure probabilities.

Influence Diagrams

Show relationships among information and decisions.

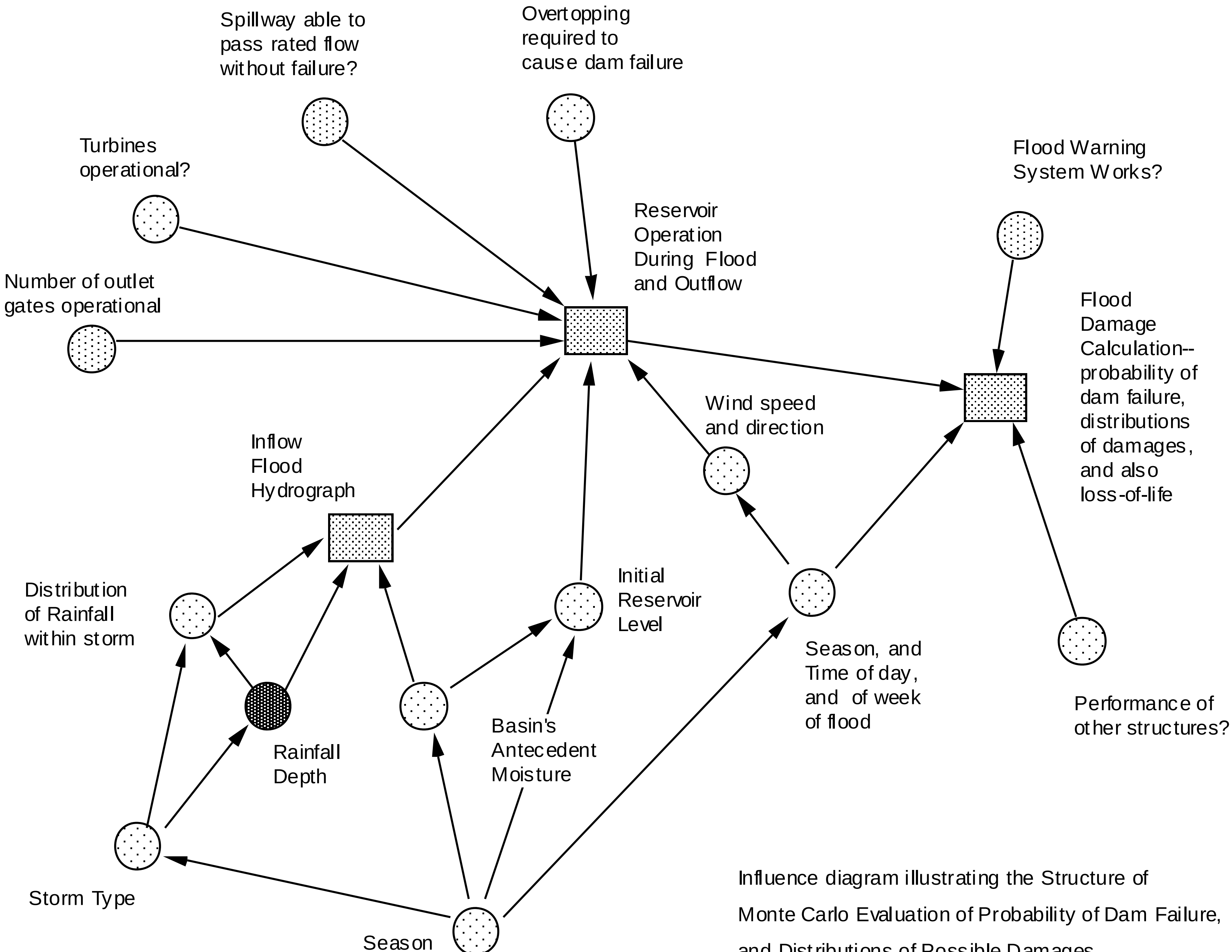
Good for organizing ideas and describing problems.



Influence Diagrams

Show relationships among information and decisions

Good for organizing ideas and describing problems



Influence diagram illustrating the Structure of Monte Carlo Evaluation of Probability of Dam Failure, and Distributions of Possible Damages and Loss-of-Life.

Event and Decision Trees

Event Trees

For standby/safety systems, begins with an initiating event

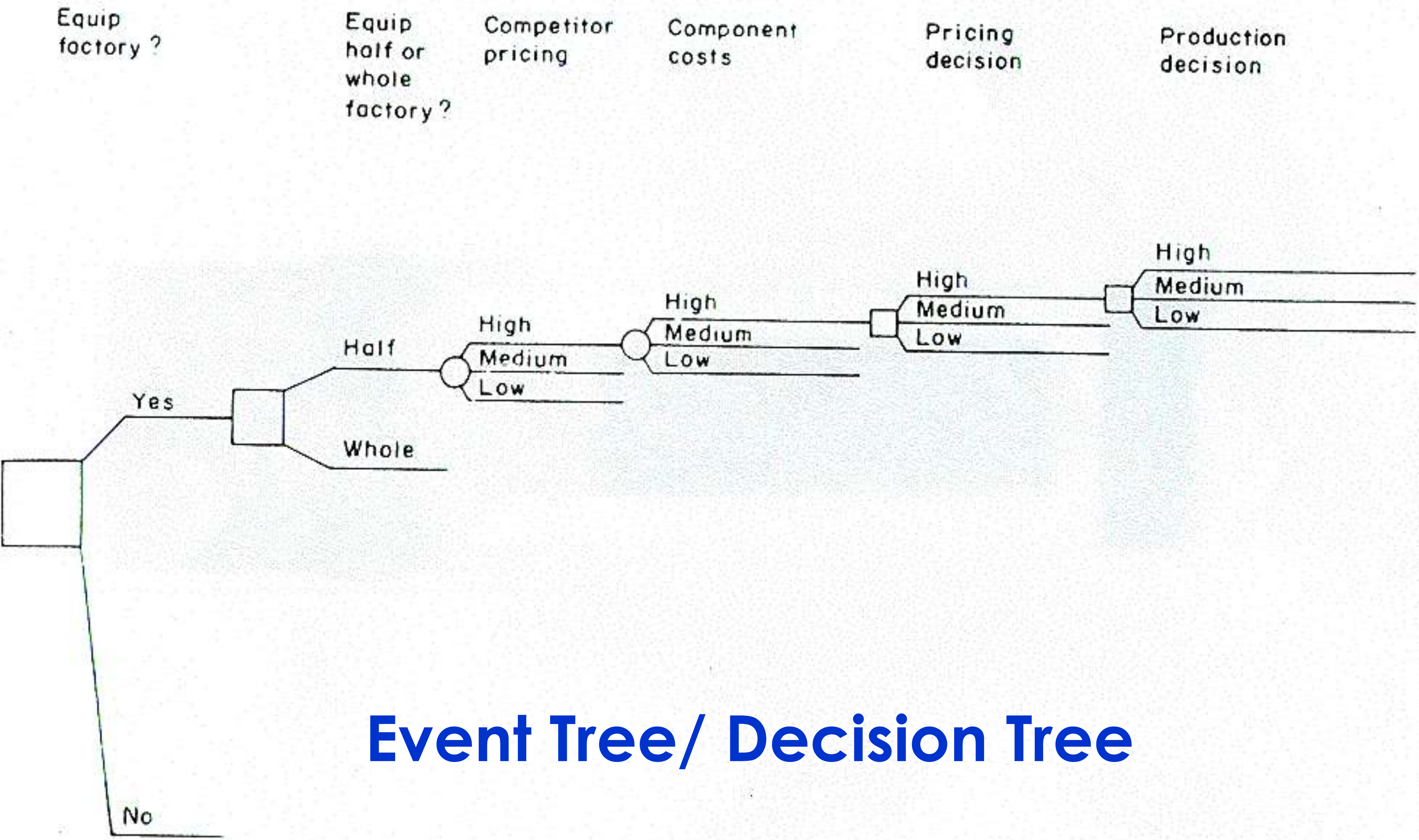
Describes (graphically) alternative event sequences, or accident sequences

Employs conditional probabilities of alternative events given preceding events

Employs induction (reasoning from part to the whole) or FORWARD LOGIC Can identify failure sequences and their probability

Decision Trees

Event trees with decision nodes, where a decision can be made among several alternatives based upon results at that point.



Event Tree/ Decision Tree

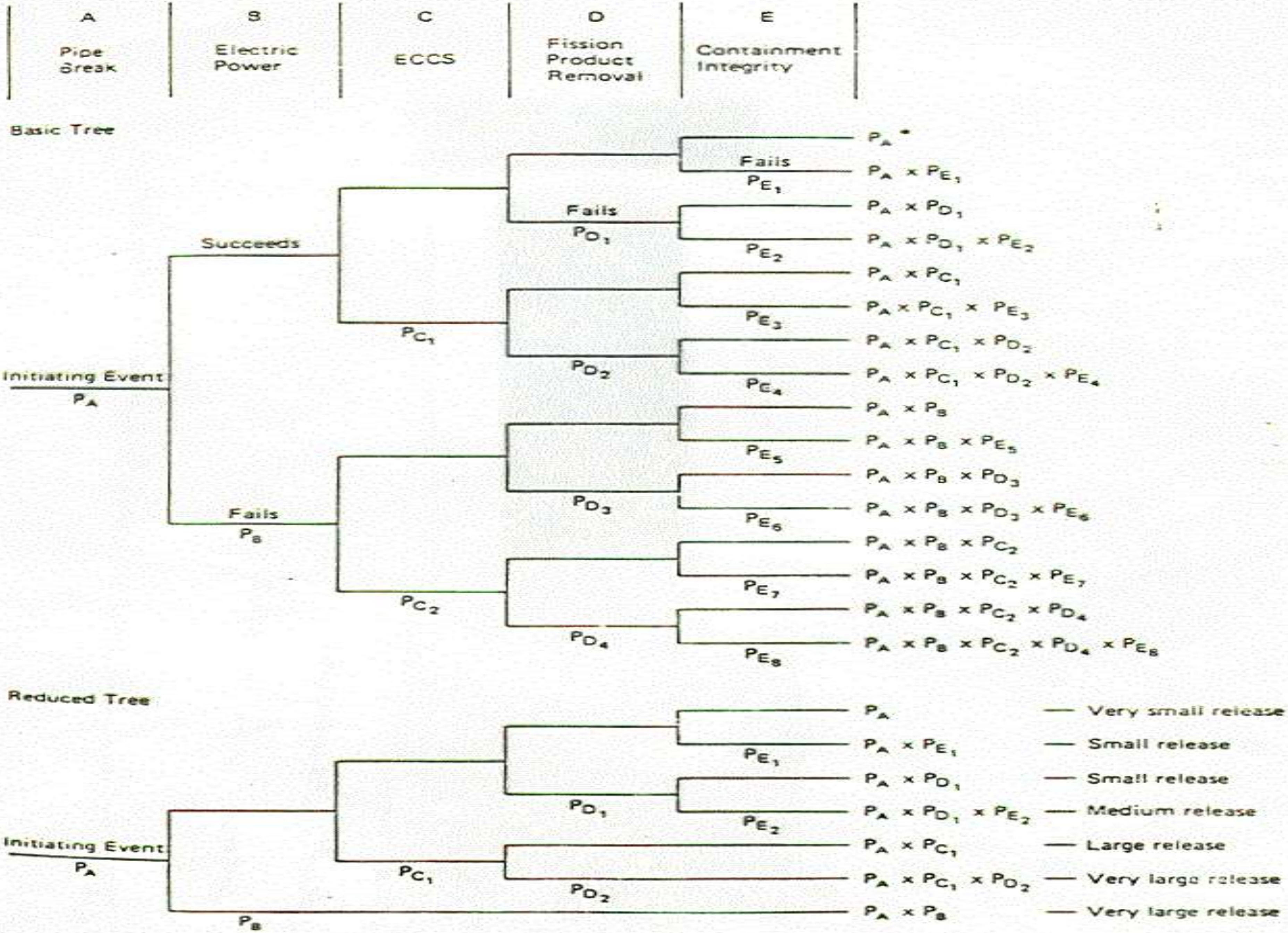


Figure 1.9. Pruning an event tree.

Decision Tree Example (Real Option Analysis)

Decision tree

Decision node

3 options

Invest & Operation (I&O), Delay,

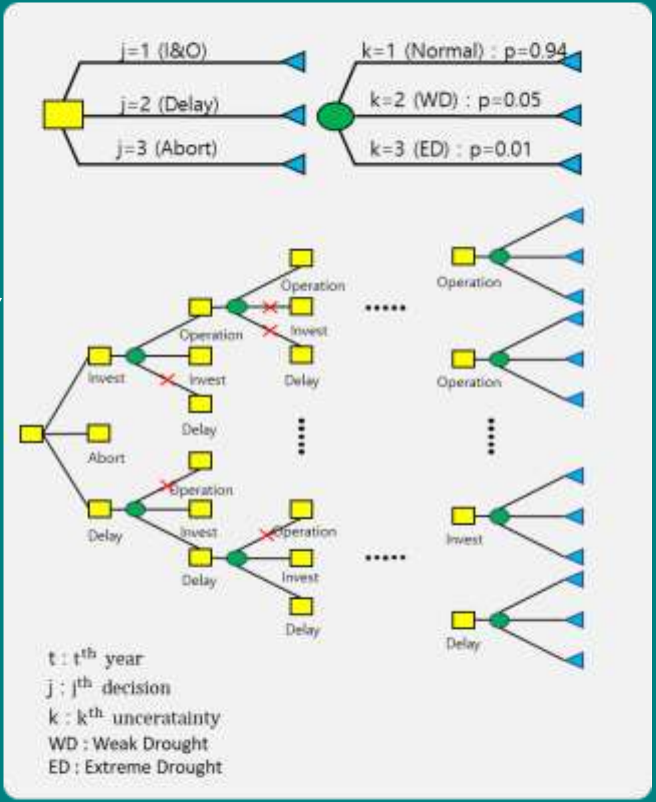
Chance node

3 probabilities

Normal,

Weak Drought (WD),

Extreme Drought (ED)



Decision Tree Example (Real Option Analysis)

2016	2017	2018	2019	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030	2031	2032	2033	2034	2035	2036	2037	2038	2039	2040	2041	2042	2043	2044	2045
I	I	I	I	I	I	I	I	I	I	I	I	I	I	I	I	I	I	I	I	I	I	I	I	I	I	I	I	I	I
	D	I	I	I	I	I	I	I	I	I	I	I	I	I	I	I	I	I	I	I	I	I	I	I	I	I	I	I	I
		D	D	D	I	I	I	I	I	I	I	I	I	I	I	I	I	I	I	I	I	I	I	I	I	I	I	I	I
			D	D	D	D	D	I	I	I	I	I	I	I	I	I	I	I	I	I	I	I	I	I	I	I	I	I	I
				D	D	D	D	D	D	I	I	I	I	I	I	I	I	I	I	I	I	I	I	I	I	I	I	I	I
					D	D	D	D	D	D	D	D	I	I	I	I	I	I	I	I	I	I	I	I	I	I	I	I	I
						D	D	D	D	D	D	D	D	D	D	I	I	I	I	I	I	I	I	I	I	I	I	I	I
							D	D	D	D	D	D	D	D	D	D	D	I	I	I	I	I	I	I	I	I	I	I	I
								D	D	D	D	D	D	D	D	D	D	D	D	D	I	I	I	I	I	I	I	I	I
									D	D	D	D	D	D	D	D	D	D	D	D	D	D	I	I	I	I	I	I	I
										D	D	D	D	D	D	D	D	D	D	D	D	D	D	D	D	I	I	I	I
											D	D	D	D	D	D	D	D	D	D	D	D	D	D	D	D	D	I	I
												D	D	D	D	D	D	D	D	D	D	D	D	D	D	D	D	D	I
													A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A
														A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A
															A	A	A	A	A	A	A	A	A	A	A	A	A	A	A
																A	A	A	A	A	A	A	A	A	A	A	A	A	A
																	A	A	A	A	A	A	A	A	A	A	A	A	A
																		A	A	A	A	A	A	A	A	A	A	A	A
																			A	A	A	A	A	A	A	A	A	A	A
																				A	A	A	A	A	A	A	A	A	A
																					A	A	A	A	A	A	A	A	A
																						A	A	A	A	A	A	A	A
																							A	A	A	A	A	A	A
																								A	A	A	A	A	A
																									A	A	A	A	A
																										A	A	A	A
																											A	A	A
																												A	A
																													A

Alt. 1

I: Invest now

D: Delay

A: Abandon

Underlying asset (V_0): 42,365

Cost (X): 1,213,026

Upward(u): 1.031

Downward(d): 0.949

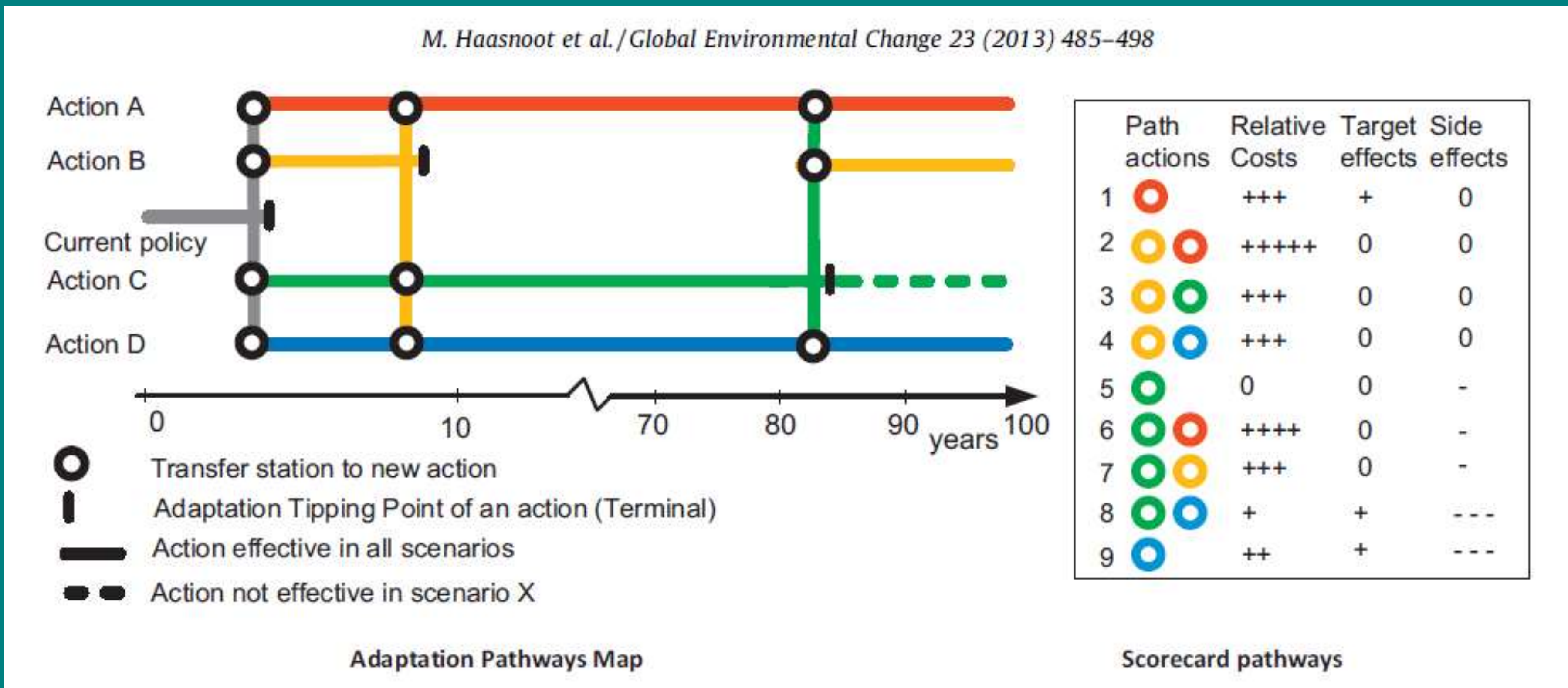
Investment opportunity (T): 30 yrs

Time step(dt): 1yr

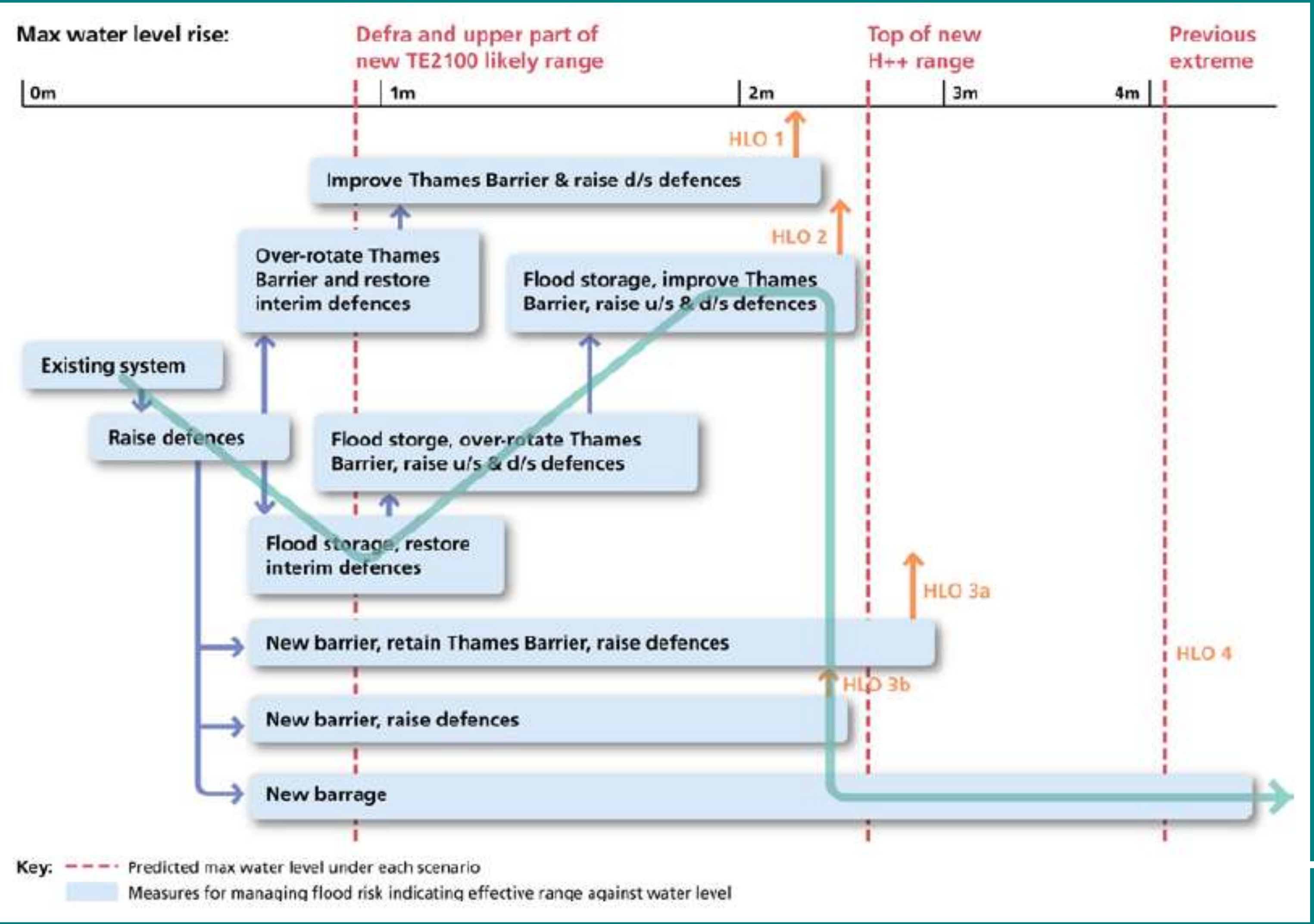
Risk free interest rate(r): 6 %

Durable years(n): 50 yrs

Decision Tree Example
(Dynamic Adaptive Policy Pathways)



Decision Tree Example (Route Map Approach)



Classroom Example: Communication with a Radio in an Emergency

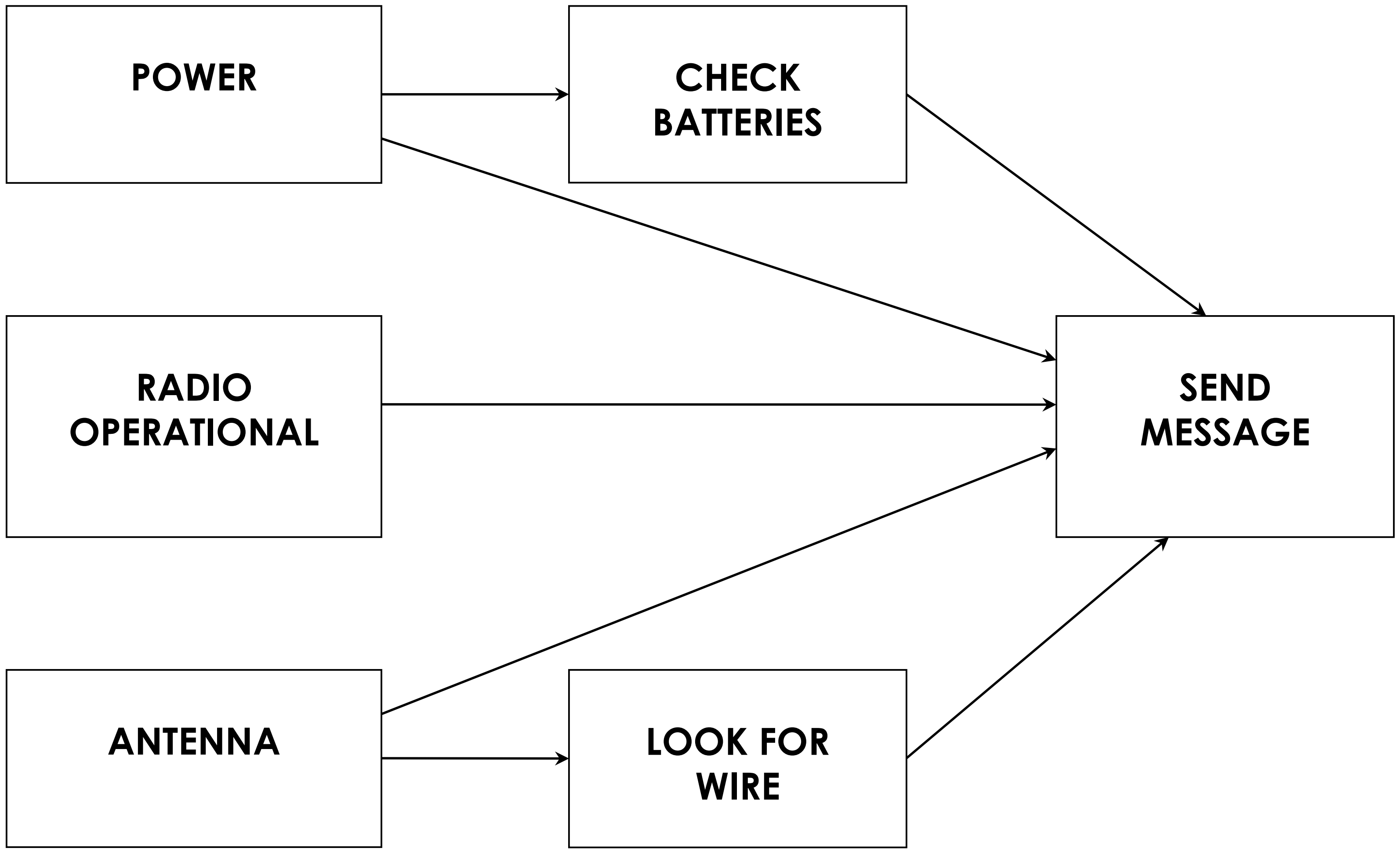
One needs

either power or batteries

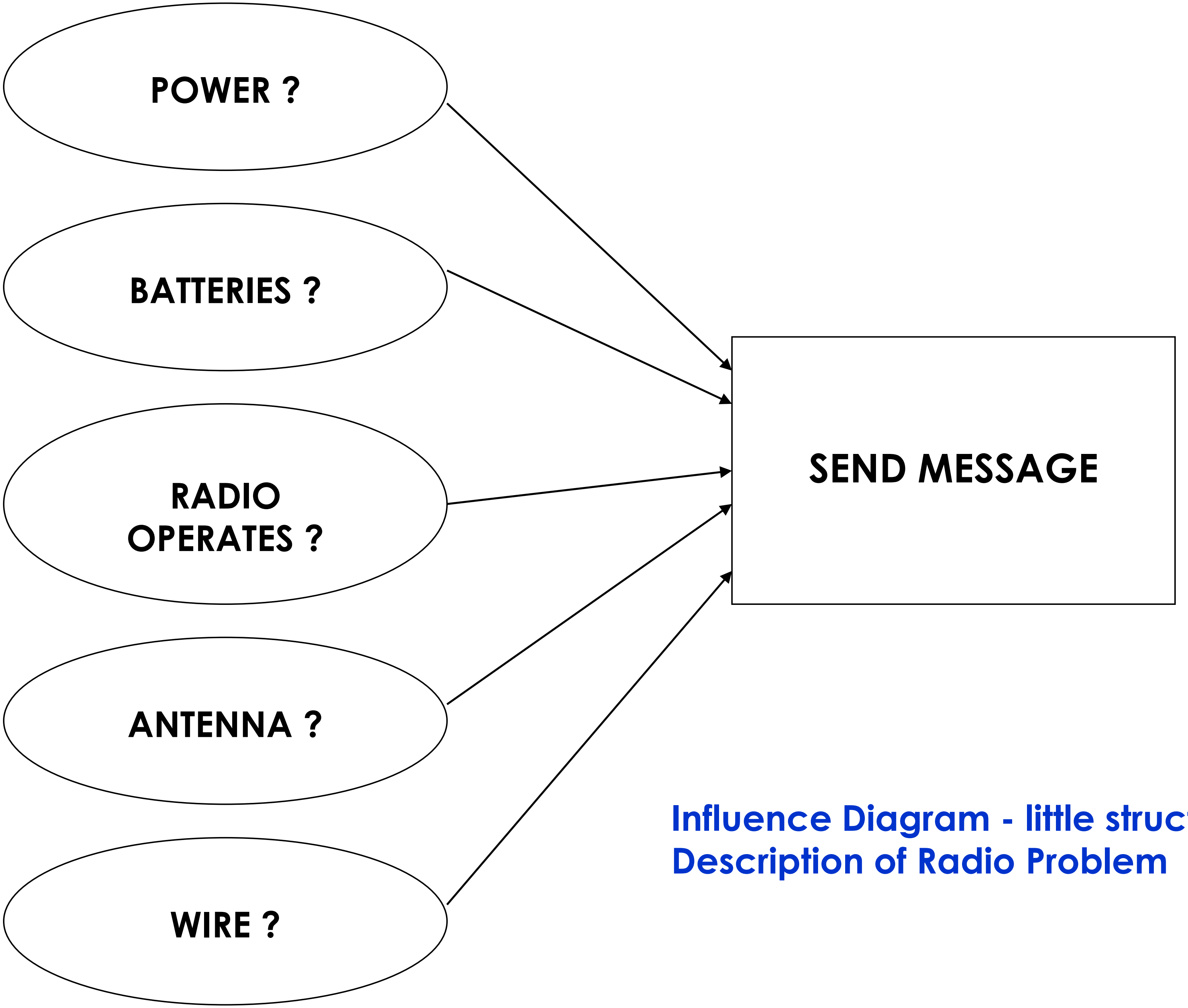
to supply electrical energy to a radio, and

requires either the built-in antenna or else

wire to rig an antenna to send the signal.



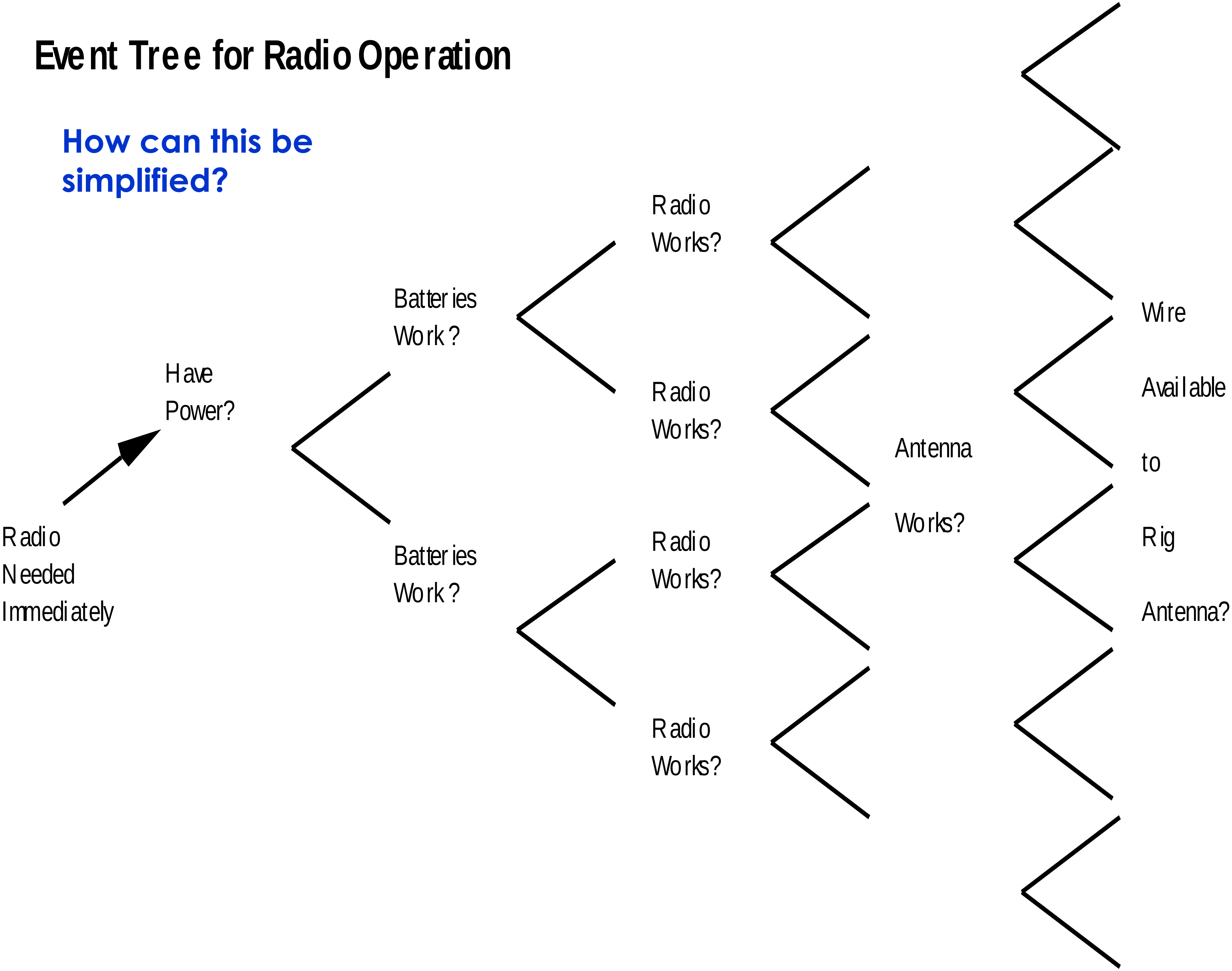
Influence Diagram Describing Actions In Radio Problem



Influence Diagram - little structure - Description of Radio Problem

Event Tree for Radio Operation

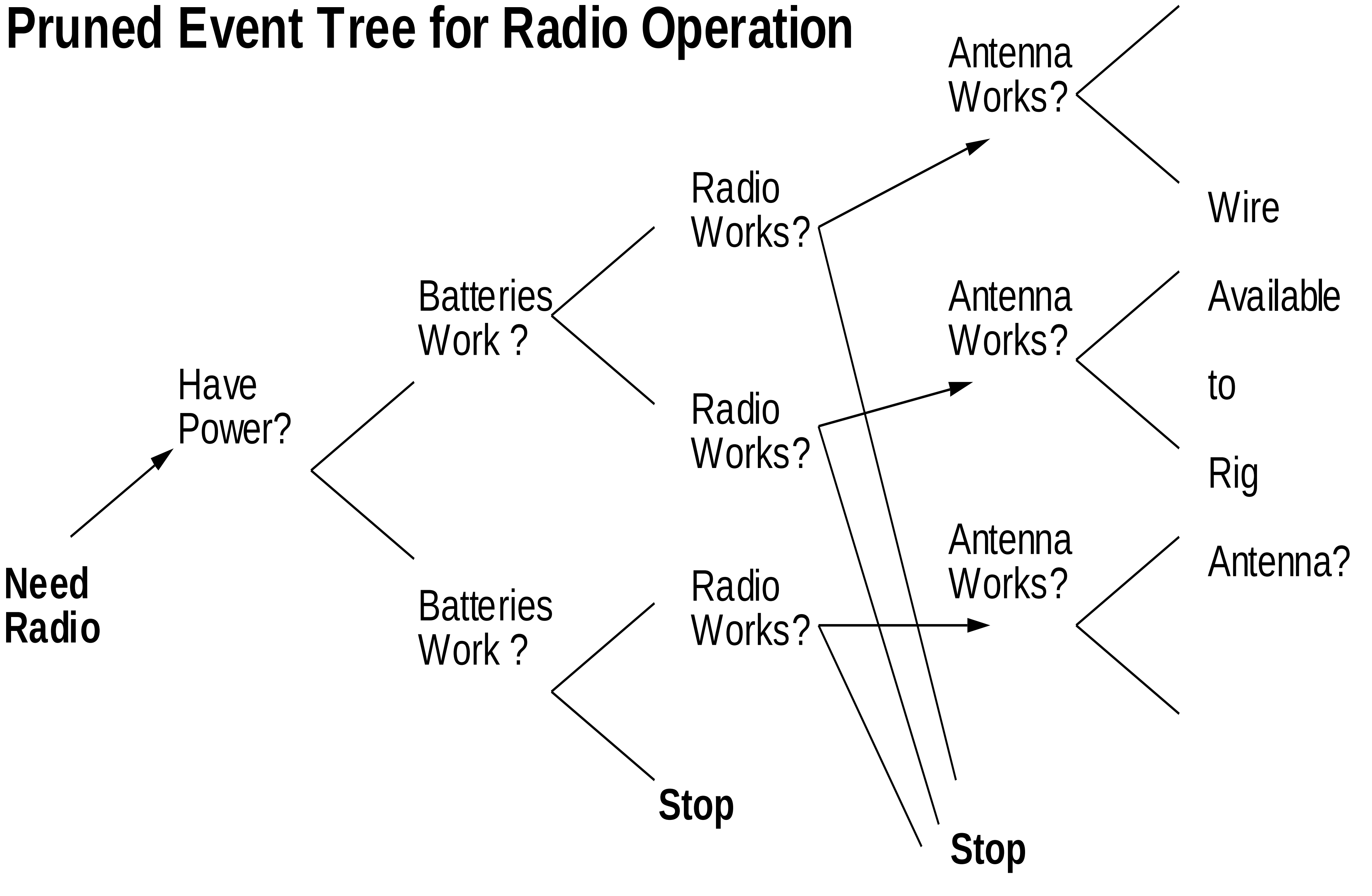
How can this be simplified?



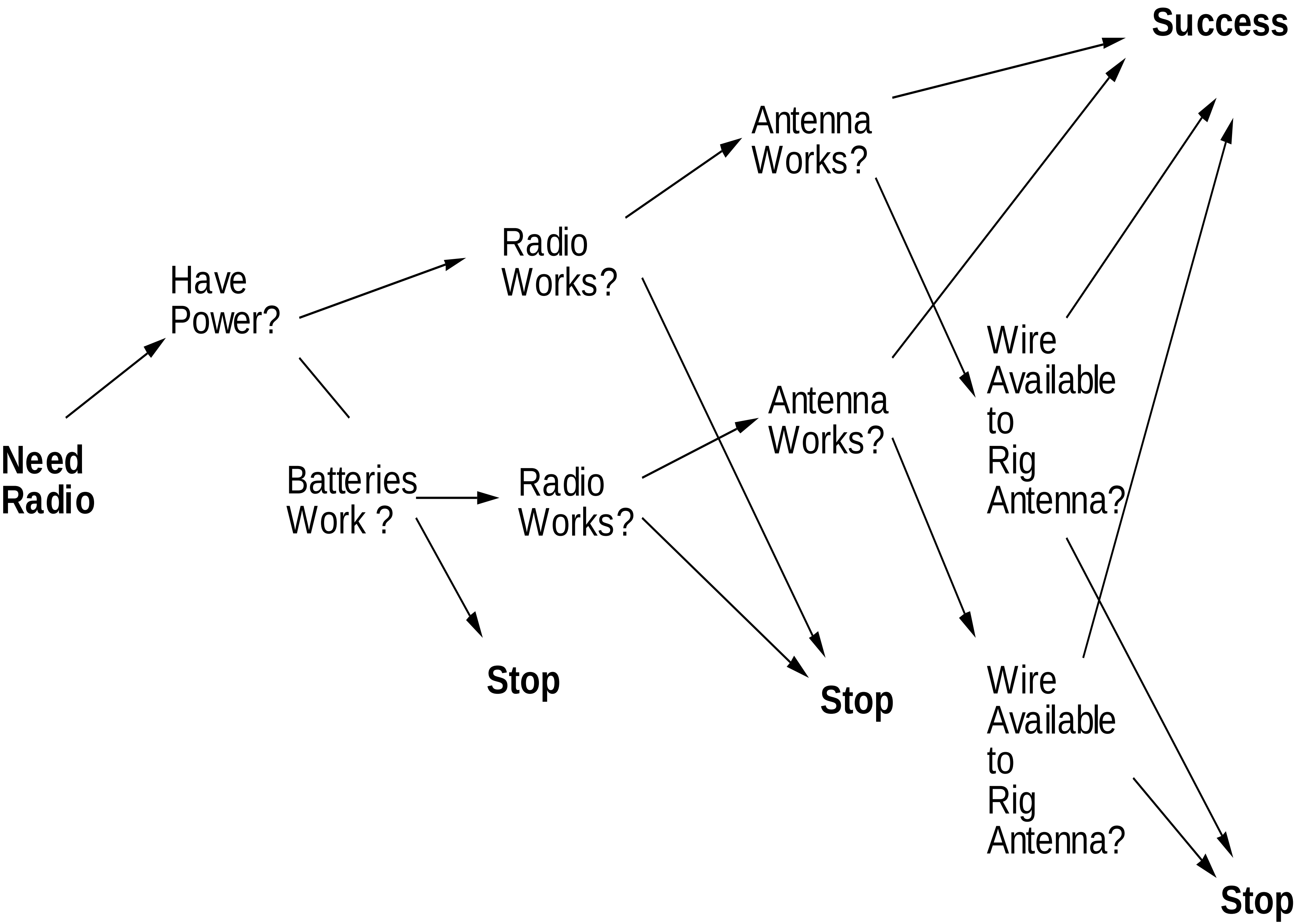
Tips for Event Tree Constuction/Pruning

- end tree where failure occurs
- tree gives probability of success
- each branch/path is mutually exclusive (think OR)
- along path, events must all result in success in order for the end result to be a success (think AND)
- each successive event is conditional on the previous event being successful
- multiply probabilities along a path for overall probability of success from that series of events
- add probabilities of successful paths to get overall probability of success

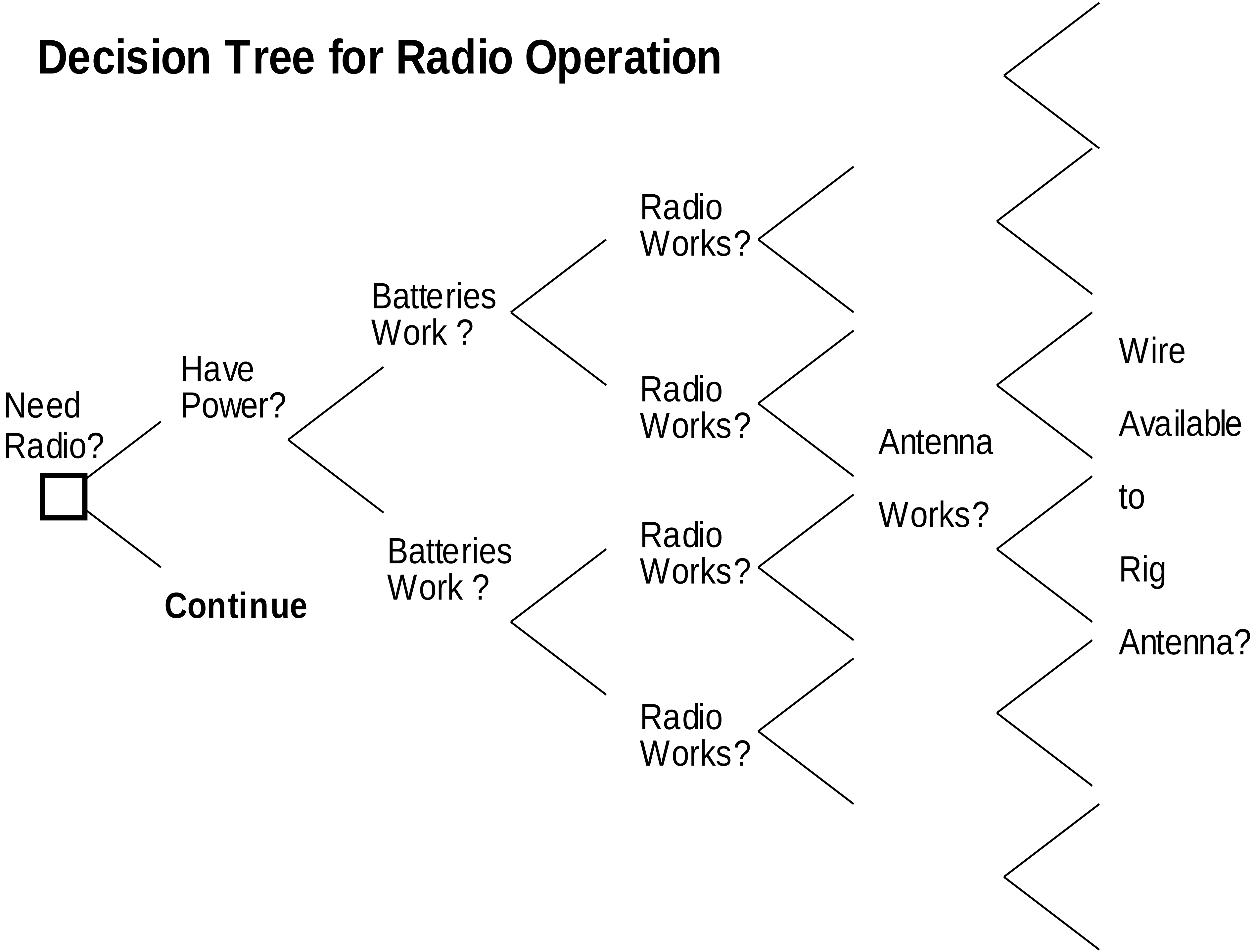
Pruned Event Tree for Radio Operation



Pruned Event Tree for Radio Operation



Decision Tree for Radio Operation



Revisit: Communication with a Radio in an Emergency

Calculate the probability you will be able to communicate using the radio when we have the following probabilities:

Pr[Have power] = 0.80

Pr[Batteries fail] = 0.10

Pr[Radio Works!] = 0.92

Pr[wire available] = 0.75

Pr[Antenna inoperable] = 0.30

Fault Trees

Starts with failure condition of interest.

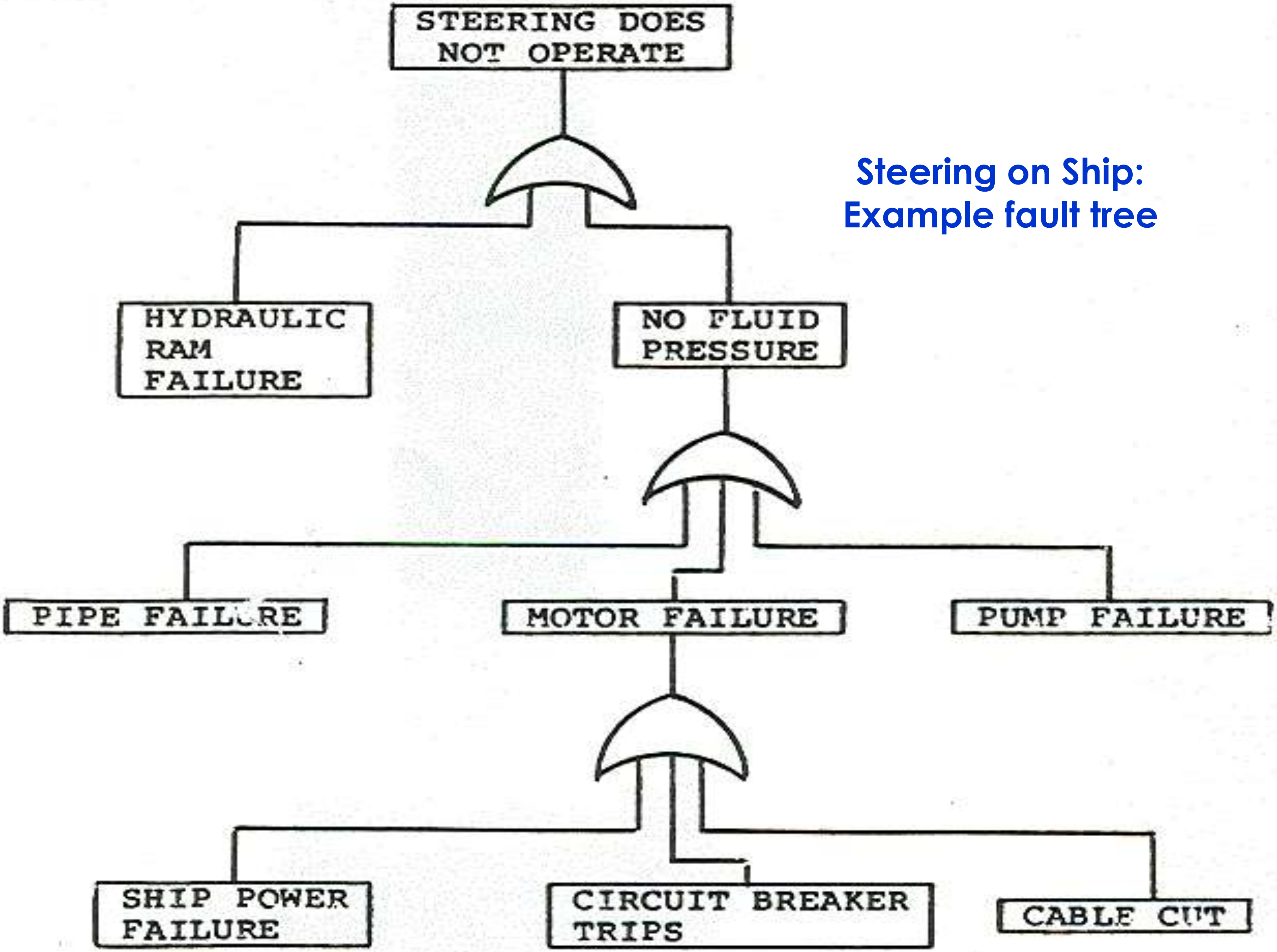
Derives the combinations of individual events what would result in that failure.

Accepted as a methodology of examining in detail the different ways in which the operation of independent binary components can lead to failure.

Uses Boolean logic to delineate all ways failure can occur in discrete state systems; relationships for probabilities of different independent outcomes allows computation of probability of failure condition.

Employs deduction (conclusion by reasoning) with BACKWARD LOGIC.

Steering on Ship: Example fault tree



Culvert Flooding Failure

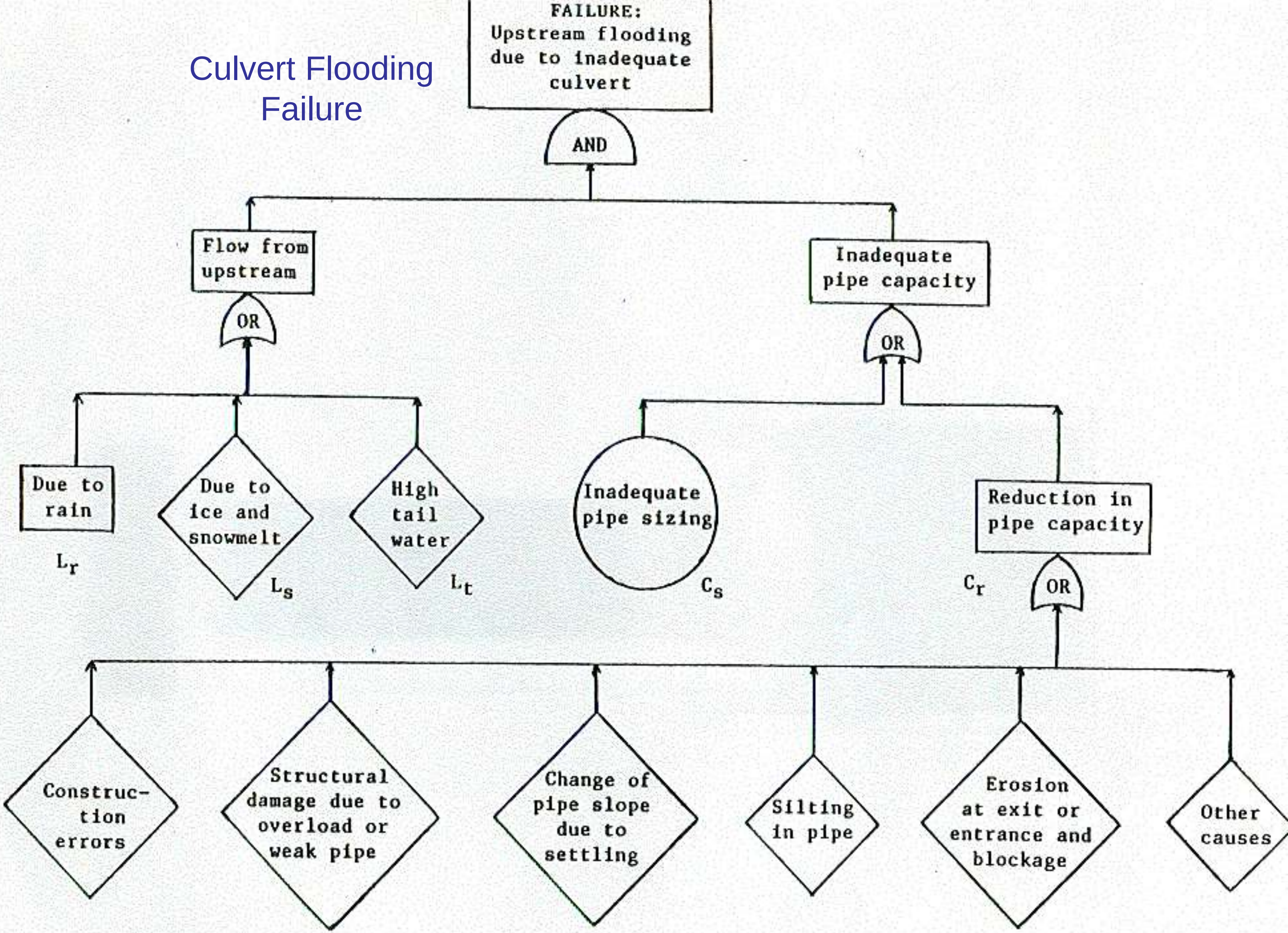
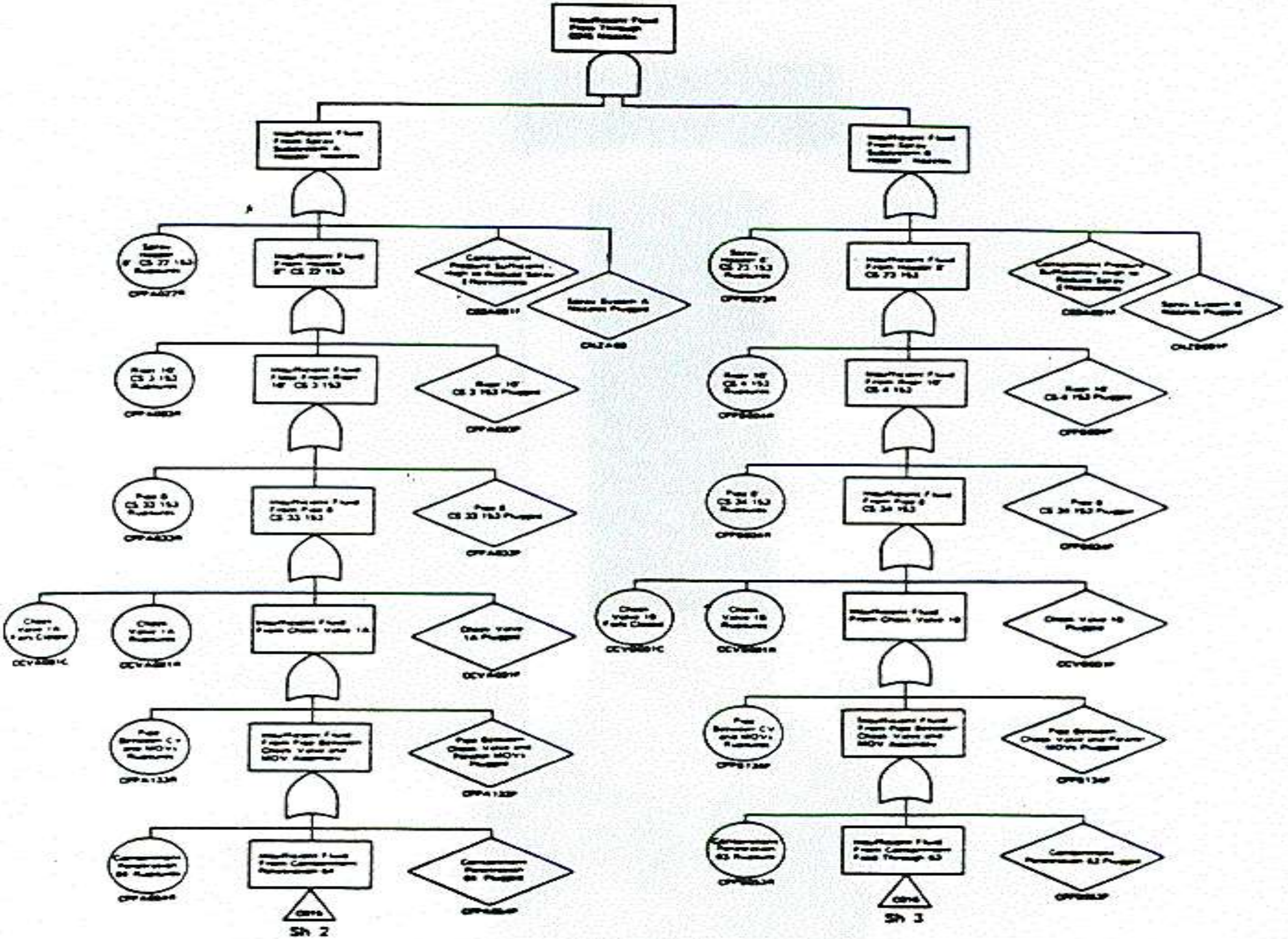
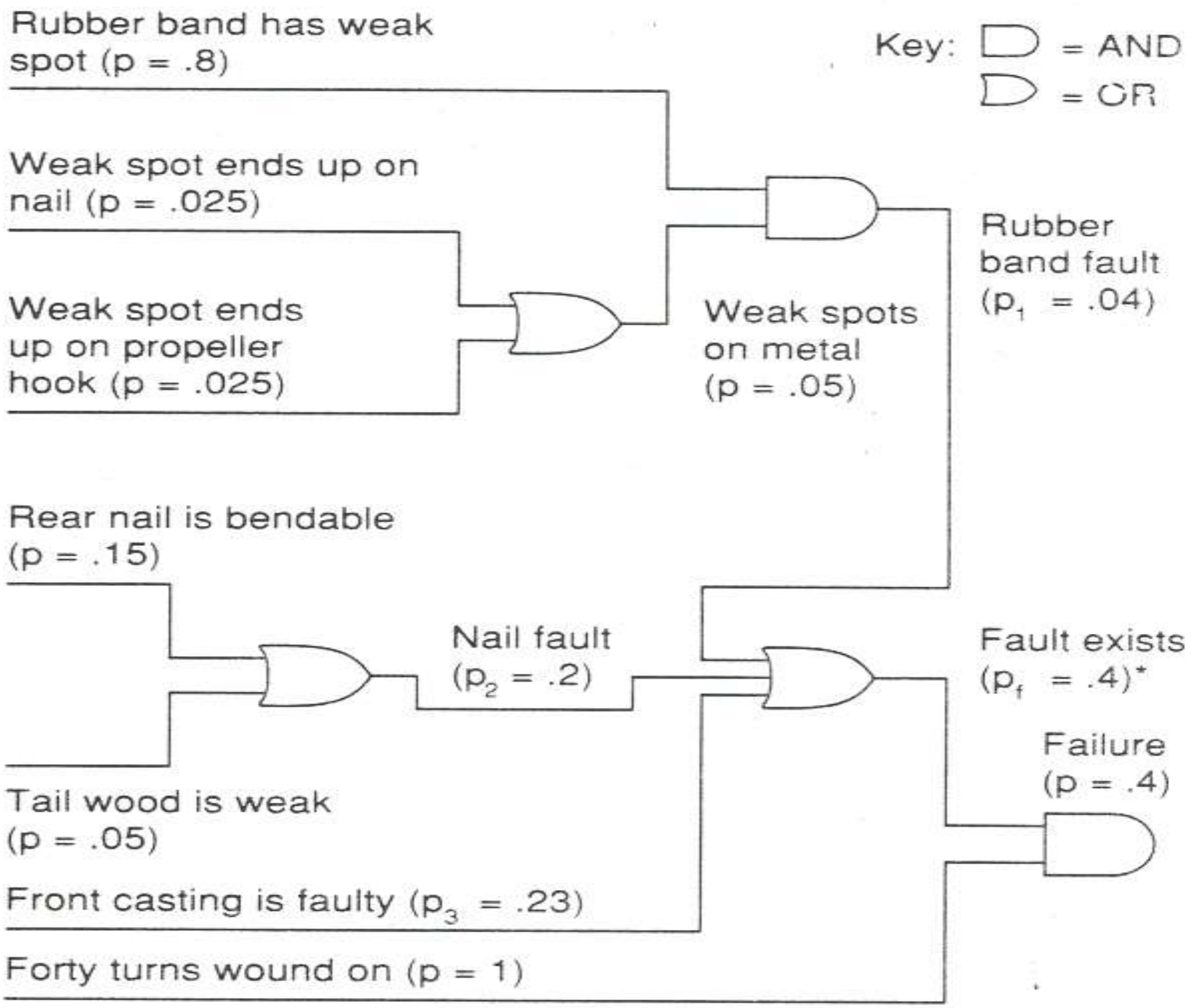


Figure 2. Example Fault Tree for Culvert Flooding Failure


Sh 2
Sh 3



* Since all three faults can occur together, $p_f = 1 - (1 - p_1)(1 - p_2)(1 - p_3) = .4$

Figure A. Fault tree with associated probabilities (p) for failure of a rubber-band airplane if 40 turns are wound onto the rubber band.

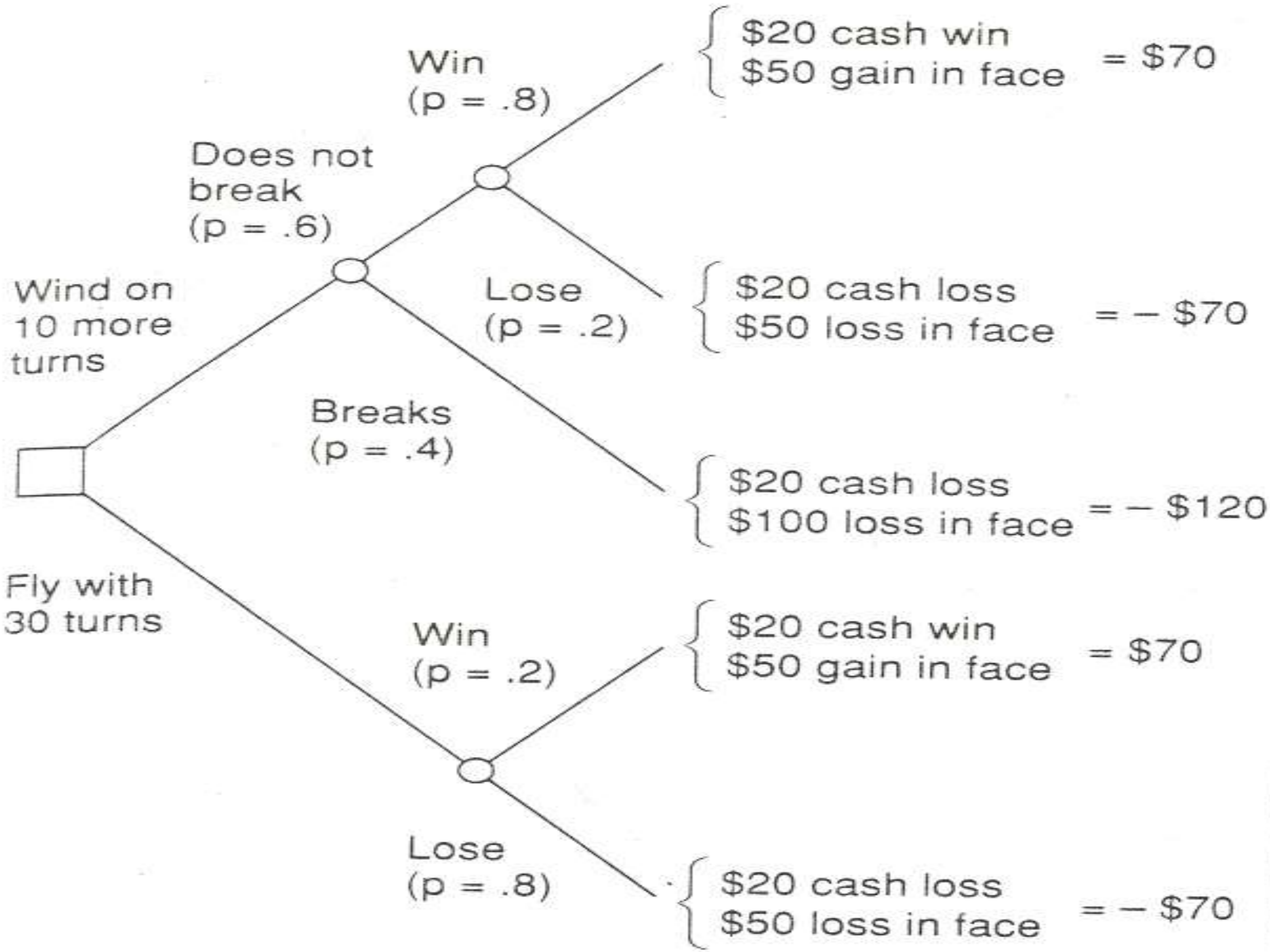
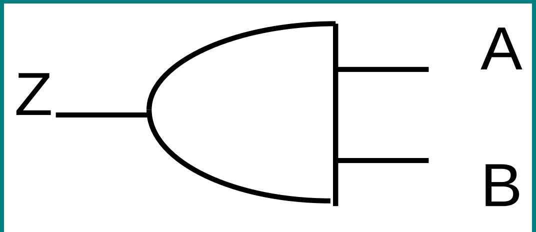


Figure B. Decision tree with associated probabilities (p) and monetary gains or losses in rubber-band airplane bet.

Negative Viewpoint

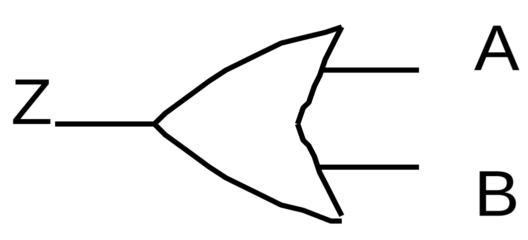
AND



Both A and B must fail for Z to be in faiiure state

P(Z) = $P(A \cap B) = P(A)\,P(B)$ for independent events A & B.

OR



If either A or B fail, then Z is in failure state.

P(Z) = $P(A \cup B) = P(A) + P(B) - P(A)\,P(B)$, independent events A & B.

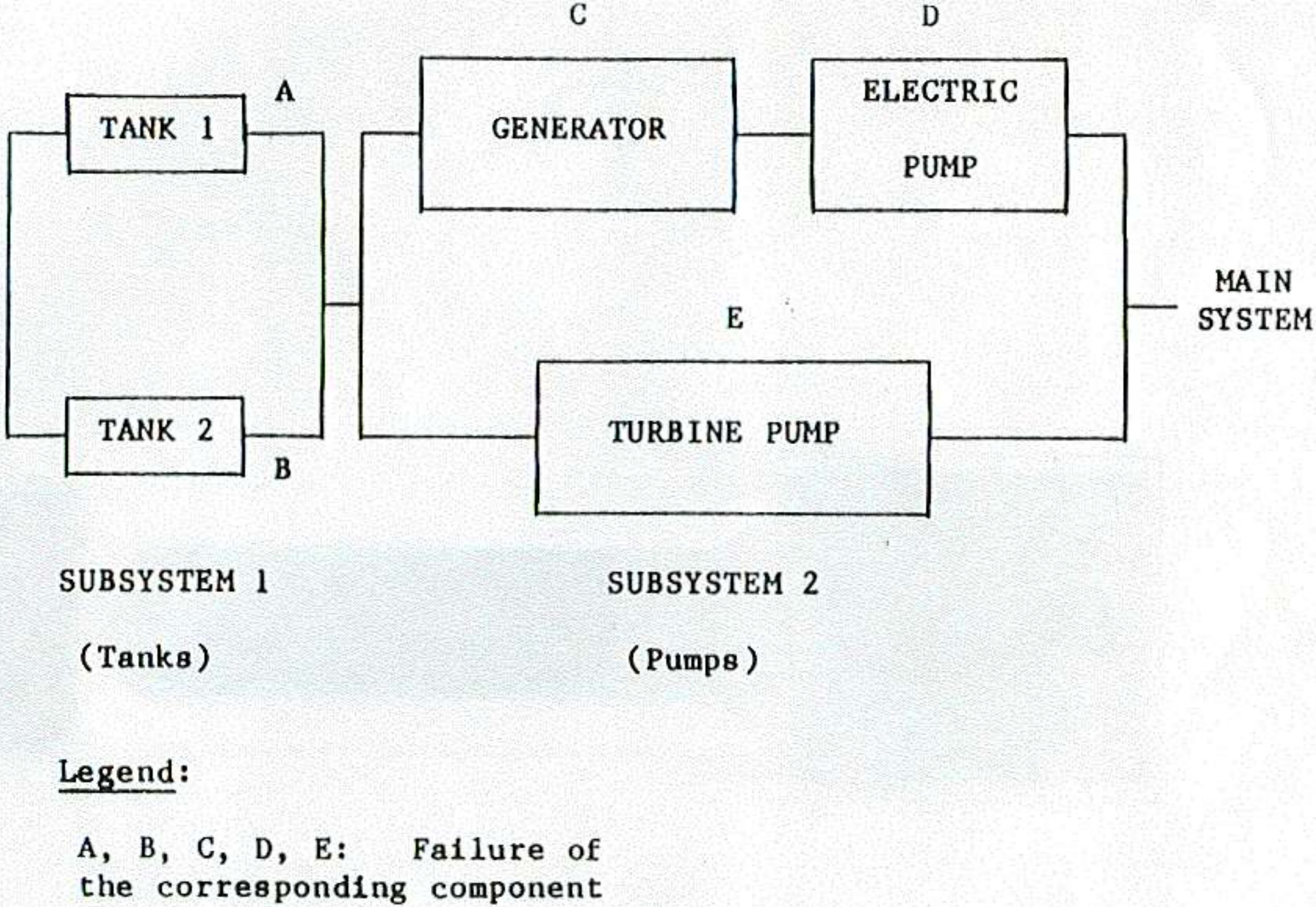


Fig. 1. Auxiliary feed water system: Block diagram.

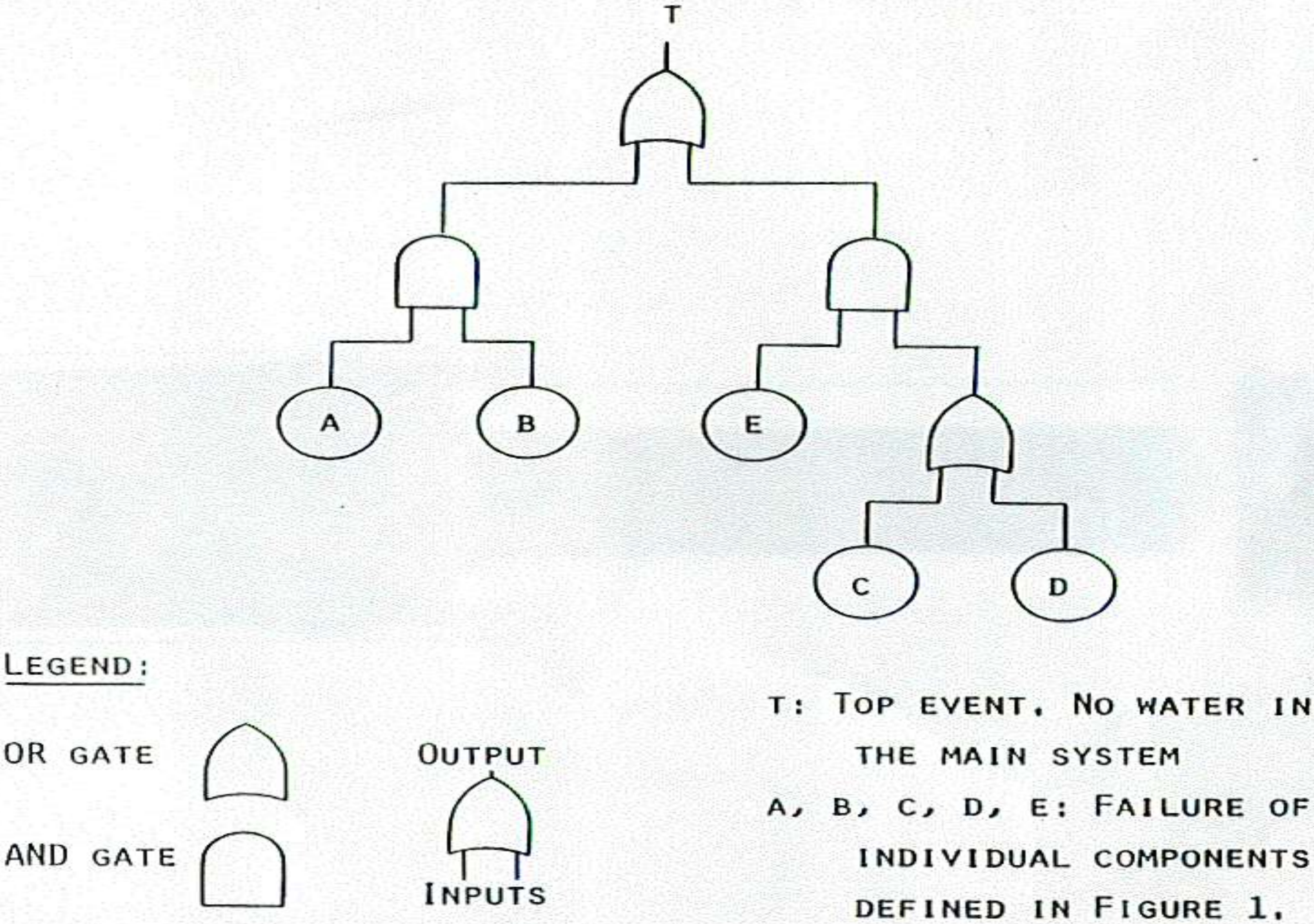


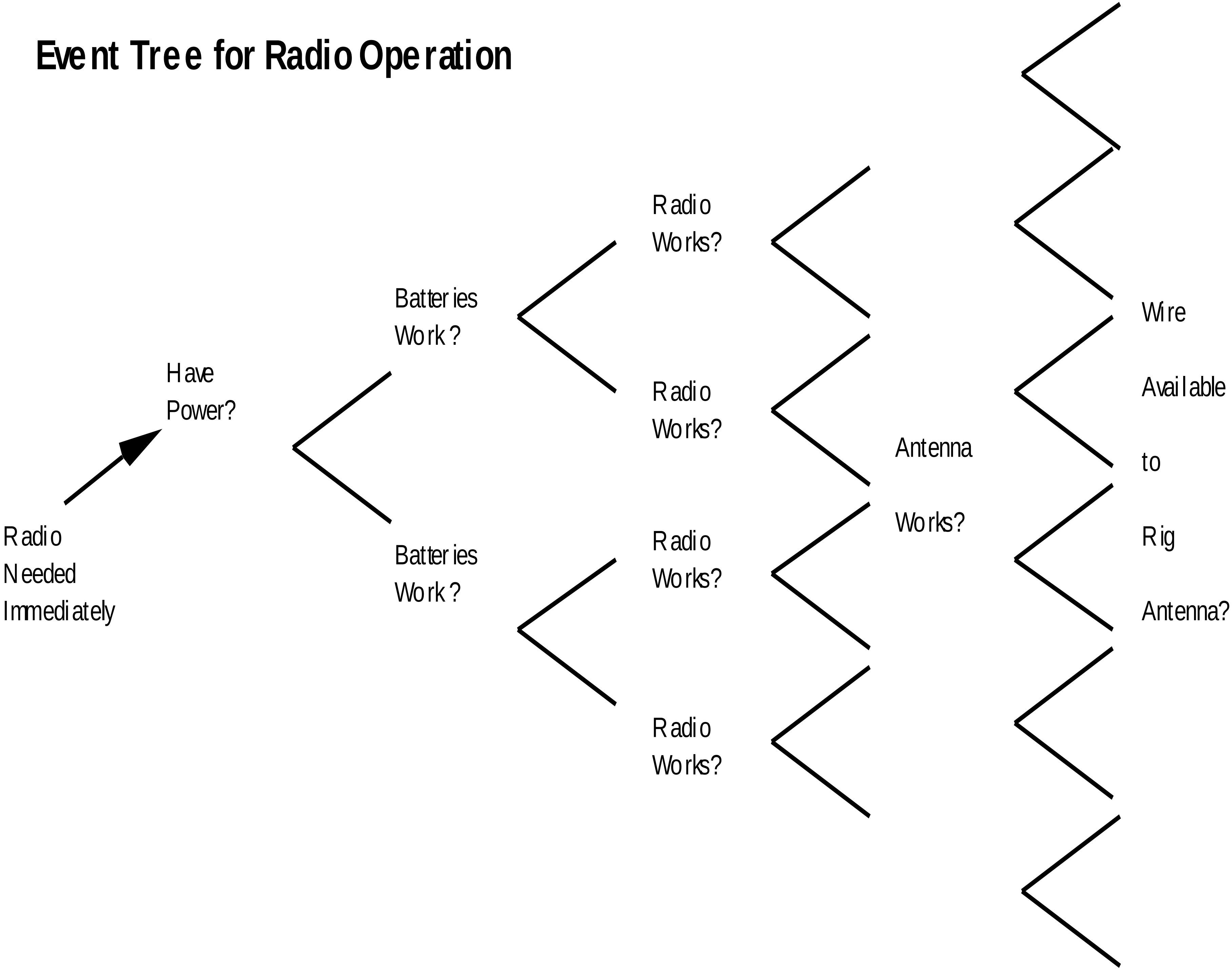
Fig. 2. Fault tree corresponding to the failure of the AFWS.

Revisit Again: Communication with a Radio in an Emergency

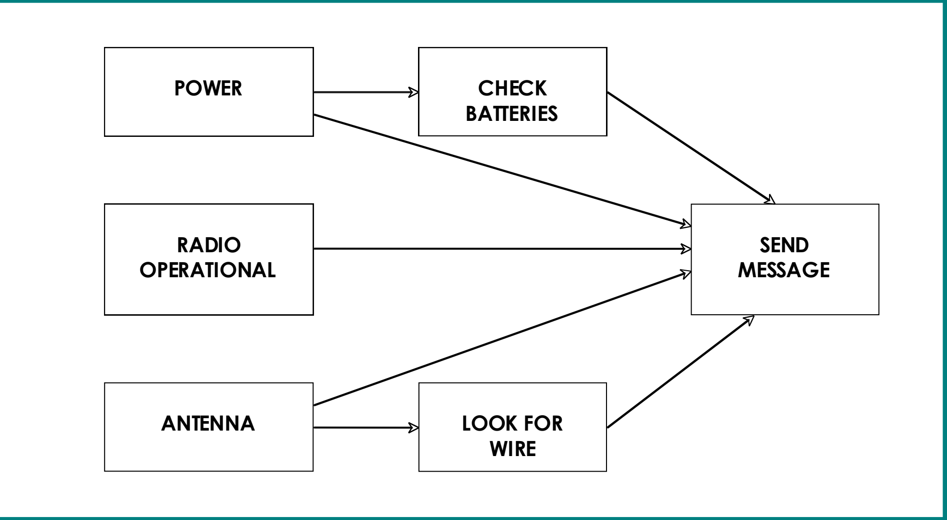
Can we draw a fault tree for this problem?

Evaluate the system's reliability using your fault tree.

Event Tree for Radio Operation



INFLUENCE DIAGRAMS



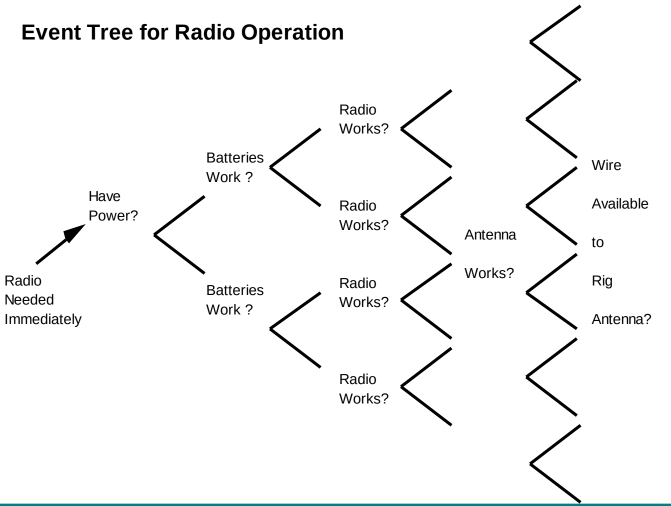
Advantage

Good for formulating important activities and their relationships. Outcome can be multidimensional with many values

Disadvantage

Insufficient structure to immediately provide quantitative results

EVENT TREES



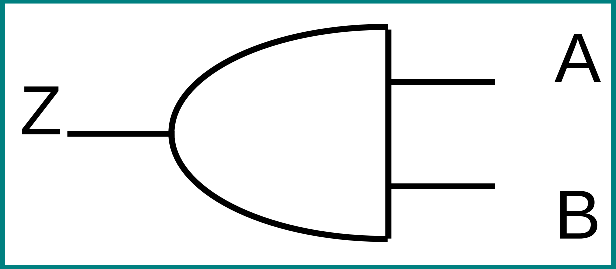
Advantage

Shows time evolution of system.
Employs conditional probabilities.
Outcome can be multidimensional with many values.
Some events can be modeled by fault trees or other methods.

Disadvantage

Easily become BIG and contain many uninteresting branches.
Fails in case of parallel sequences started with different initiating events.

FAULT TREES



Advantages

Well accepted.

Able to handle larger systems in efficient
way to find fault conditions
and their probability for independent binary components.

Conditional fault trees can be used to condition entire system's operation on a common component's status, then combine results.

Disadvantages

Actual character and sequential nature of failure events lost.

Outcome is restricted to success or failure.

Hard to understand.

Logic can become complex.

Binary components

EVENT & FAULT TREES

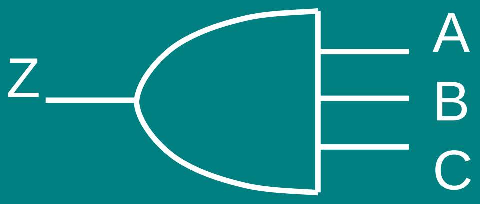
This ends the beginning of our exploration of mathematical models used to describe reliability and performance of systems of components.

We will go on and further explore methods for analyzing more complex systems, systems with various levels of failure, and the impact of time on reliability.

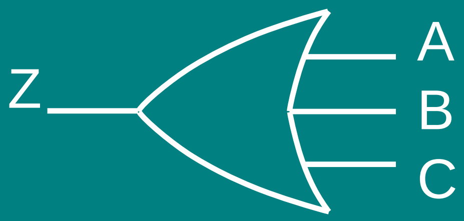
The fun has just begun.

In-class Assignment

Consider the use of fault tree for three 0-1 events denoted A, B, and C.



Means that A, B and C must all fail for Z to be inoperable



Means that if either A, B or C fails, then Z is inoperable

(a) For statistically independent events A, B, and C corresponding to failures with probabilities P[A], P[B], and P[C], what is the probability P[Z] that Z is inoperable in each case?

(b) What value do you get for failure probabilities P[A] = P[B] = 0.5, P[C] = 0.3?

(c) Write the triple input logic units above as combination of AND/OR's which have only two inputs.

Homework for the Next Class

Study the Poisson Process and Distribution!