Chapter 3
Event Tree Analysis

Marvin Rausand
marvin.rausand@ntnu.no

RAMS Group
Department of Production and Quality Engineering
NTNU

(Version 0.1)

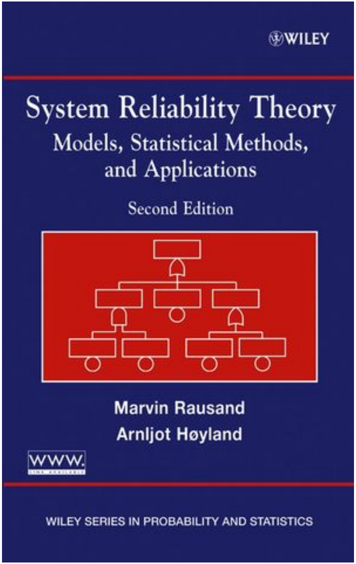
NTNU – Trondheim
Norwegian University of
Science and Technology

Slides related to the book

System Reliability Theory
Models, Statistical Methods,
and Applications

Wiley, 2004

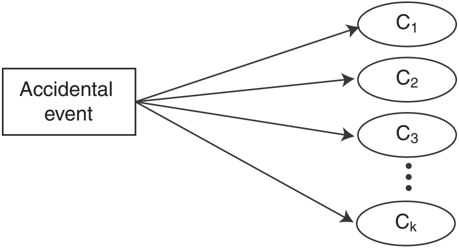
Homepage of the book:
http://www.ntnu.edu/ross/books/srt



Consequence spectrum

An *accidental event* is defined as the first significant deviation from a normal situation that may lead to unwanted consequences (e.g., gas leak, falling object, start of fire)

An accidental event may lead to many different consequences. The potential consequences may be illustrated by a *consequence spectrum*



Barriers

Most well designed systems have one or more barriers that are implemented to stop or reduce the consequences of potential accidental events. The probability that an accidental event will lead to unwanted consequences will therefore depend on whether these barriers are functioning or not.

The consequences may also depend on additional events and factors. Examples include:

- Whether a gas release is ignited or not
- Whether or not there are people present when the accidental event occurs
- The wind direction when the accidental event occurs

Barriers are also called *safety functions* or *protection layers*, and may be technical and/or administrative (organizational). We will, however, use the term *barrier* in the rest of this presentation.

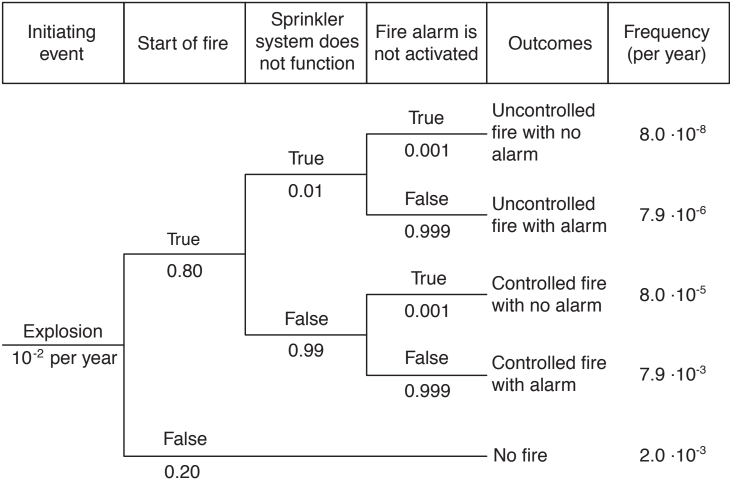
What is event tree analysis?

An event tree analysis (ETA) is an *inductive* procedure that shows all possible outcomes resulting from an accidental (initiating) event, taking into account whether installed safety barriers are functioning or not, and additional events and factors.

By studying all relevant accidental events (that have been identified by a preliminary hazard analysis, a HAZOP, or some other technique), the ETA can be used to identify all potential *accident scenarios* and sequences in a complex system.

Design and procedural weaknesses can be identified, and probabilities of the various outcomes from an accidental event can be determined.

Example



– Adapted from IEC 60300-3-9

Applications

- Risk analysis of technological systems
- Identification of improvements in protection systems and other safety functions

Main Steps

1. Identify (and define) a relevant accidental (initial) event that may give rise to unwanted consequences
2. Identify the barriers that are designed to deal with the accidental event
3. Construct the event tree
4. Describe the (potential) resulting accident sequences
5. Determine the frequency of the accidental event and the (conditional) probabilities of the branches in the event tree
6. Calculate the probabilities/frequencies for the identified consequences (outcomes)
7. Compile and present the results from the analysis

Accidental event

When defining an accident event, we should answer the following questions:

- What type of event is it? (e.g., leak, fire)
- Where does the event take place? (e.g., in the control room)
- When does the event occur? (e.g., during normal operation, during maintenance)

In practical applications there are sometimes discussions about what should be considered an accidental event (e.g., should we start with a gas leak, the resulting fire or an explosion). Whenever feasible, we should always start with the *first significant deviation* that may lead to unwanted consequences.

Accidental event

An accidental event may be caused by:

- System or equipment failure
- Human error
- Process upset

The accidental event is normally *"anticipated"*. The system designers have put in barriers that are designed to respond to the event by terminating the accident sequence or by mitigating the consequences of the accident.

Accidental event

For each accidental event we should identify:

- The potential accident progression(s)
- System dependencies
- Conditional system responses

Barriers

The barriers that are relevant for a specific accidental event should be listed in the sequence they will be activated.

Examples include:

- Automatic detection systems (e.g., fire detection)
- Automatic safety systems (e.g., fire extinguishing)
- Alarms warning personnel/operators
- Procedures and operator actions
- Mitigating barriers

Additional events/factors

Additional events and/or factors should be listed together with the barriers, as far as possible in the sequence when they may take place.

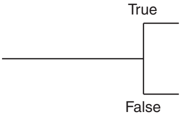
Some examples of additional events/factors were given on a previous frame.

Event sequence

Each barrier should be described by a (negative) statement, e.g., “Barrier X does not function” (This means that barrier X is not able to performs its required function(s) when the specified accidental event occurs in the specified context).

Additional events and factors should also be described by (worst case) statements, e.g., gas is ignited, wind blows toward dwelling area.

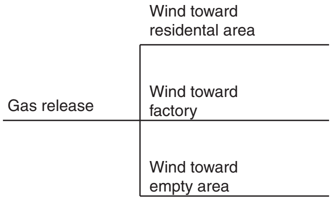
	B_1	B_2	B_3	B_4	B_5	
Accidental event	Additional event I occurs	Barrier I does not function	Barrier II does not function	Barrier III does not function	Additional event II occurs	Outcome / consequence



By this way the most severe consequences will come first

Outcome alternatives

In most applications only two alternatives (“true” and “false”) are considered. It is, however, possible to have three or more alternatives, as shown in the example below:



End outcomes

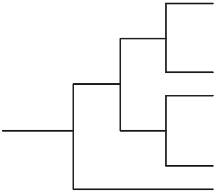
- In practice, many event trees are ended before the “final” consequences are reached
- Including these “final” consequences may give very large event trees that are impractical for visualization
- This is solved by establishing a consequence distribution for each end event and the probability of each consequence is determined for each end event
- In effect, this is an extension of the event tree, but it gives a more elegant and simpler presentation and also eases the summary of the end results

Results in decision-making

The results from the event tree analysis may be used to:

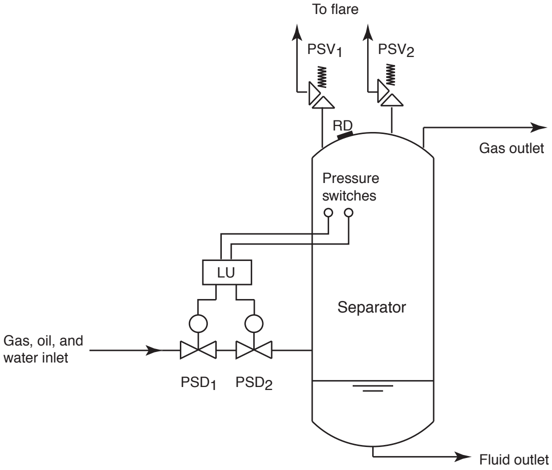
- Judge the acceptability of the system
- Identify improvement opportunities
- Make recommendations for improvements
- Justify allocation of resources for improvements

End events

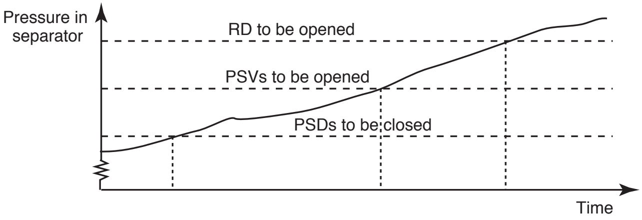


Out-come descr.	Freq-uency	Loss of lives					Material damage				Environmental damage			
		0	1-2	3-5	6 - 20	> 20	N	L	M	H	N	L	M	H

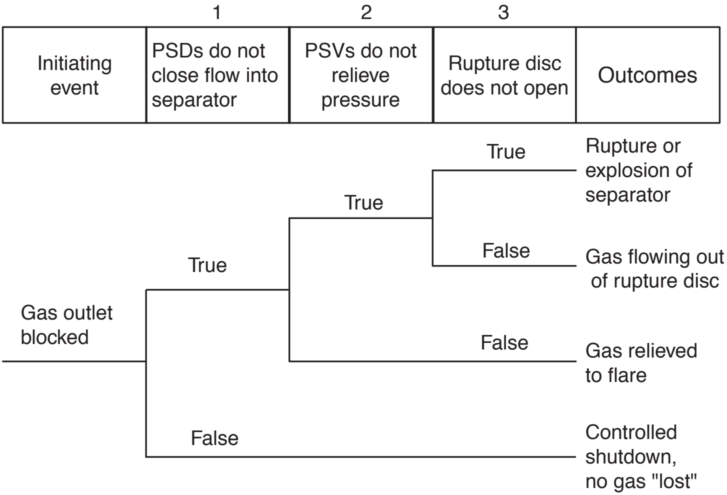
Offshore separator



Activation Pressures



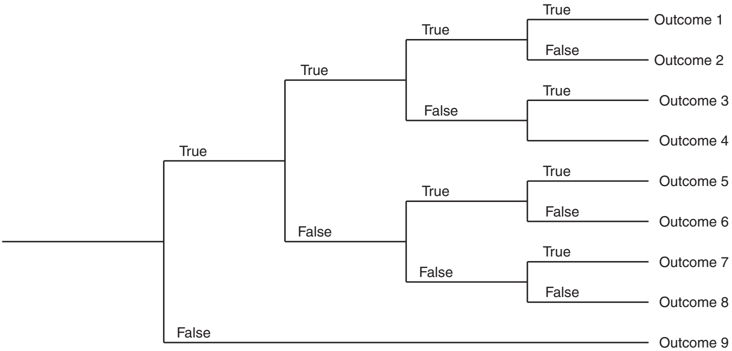
Event tree


1
2
3
Initiating event
PSDs do not close flow into separator
PSVs do not relieve pressure
Rupture disc does not open
Outcomes
Gas outlet blocked
True
False
True
False
True
False
Rupture or explosion of separator
Gas flowing out of rupture disc
Gas relieved to flare
Controlled shutdown, no gas "lost"

Example

Consider the generic example:

	B_1	B_2	B_3	B_4	
Accidental event	Additional event I occurs	Barrier I does not function	Barrier II does not function	Additional event II occurs	Outcome / consequence



Frequencies of outcomes

Let λ denote the frequency of the accidental (initiating) event. Let $\Pr(B_i)$ denote the probability of event $B(i)$.

When we know that the accidental even has occurred, the probability of "Outcome 1" is:

$$\begin{aligned}\Pr(\text{Outcome 1}\ |\text{Accidental event}) &= \Pr(B_1 \cap B_2 \cap B_3 \cap B_4) \\ &= \Pr(B_1) \cdot \Pr(B_2 \mid B_1) \cdot \Pr(B_3 \mid B_1 \cap B_2) \cdot \Pr(B_4 \mid B_1 \cap B_2 \cap B_3)\end{aligned}$$

Note that all the probabilities are conditional given the result of the process until "barrier" i is reached.

The frequency of "Outcome 1" is:

$$\lambda \cdot \Pr(B_1 \cap B_2 \cap B_3 \cap B_4)$$

The frequencies of the other outcomes are determined in a similar way.

Pros and cons

Positive

- Visualize event chains following an accidental event
- Visualize barriers and sequence of activation
- Good basis for evaluating the need for new / improved procedures and safety functions

Negative

- No standard for the graphical representation of the event tree
- Only one initiating event can be studied in each analysis
- Easy to overlook subtle system dependencies
- Not well suited for handling common cause failures in the quantitative analyses
- The event tree does not show acts of omission