INFLUENCE DIAGRAM MODEL OF PUMP ROOM GAS LEAK AND FIRE SCENARIO

by
William H. Moore
Department of Naval Architecture & Offshore Engineering
University of California, Berkeley

Ship Pump Room Gas Detector - A shipping company has operated its vessels with 25 crew members since 1955. In 1982, the first engineer and a pumpman were seriously injured in an accident in the pump room when a gas leak ignited. The company managers, decide to place gas detection and emergency shutdown systems in the pump room which can be operated from the bridge. In addition, to cut costs and the chances of injury to crew members, the vessels are to be operated with a single dayshift engineer (instead of 3 or 4 engineers) and no pumpman since the new detection and shutdown system is totally automated and operational from the bridge. The company also believes the new technology is attractive since pump and engine room maintenance crews can be brought aboard at ports of call and need not ride with the ships thus reducing operating costs (as well as ship maintenance).

No major problems developed with gas leaks aboard the vessel until 1991, when a leak occured in the pump room again. The bridge operators, having not had a problem with this system in the past nine years, paid little attention to the gas detection gauge on the bridge consol (early warning signal), and did not shut down the system before an explosion and fire occurred. In addition, over the last 8 years, the company decided to employ a day engineer whose specialties are not mechanical systems, but electrical systems to keep pace with the new automated technologies implemented over the years. The day engineer, having little experience with these types of problems (he hasn't seen these problems since he left maritime school 15 years ago), cannot control the fire automatically nor is there the manpower to effectively fight the fire since the size of the crew had been reduced. The ensuing fire escalated and reached the engine room. The result was a power plant failure while the ship was being driven through an area with many navigational hazards. The ship sent a "mayday" for assistance since it was drifting towards a hazardous reef. Assistance did not arrive in time and the ship ran aground spilling 200,000 barrels of oil in an environmentally sensitive area.

The point of this example is that new technological systems also carry their own set of risks. This scenario demonstrates human errors (improper bridge monitoring, inadequate training), organizational errors (ship managers cutting back on manpower), and system errors (inadequate system to prevent, detect, control and fight the fire). In addition, it exemplifies the overconfident trust placed upon a technological system (gas detection, emergency shutdown systems, and automatic control from the bridge) without paying attention to the potential risks associated with it. The monitoring system had been changed from an active system (engineers and pumpmen working around the clock) to a passive system (gas detection and bridge control). Technological "fixes" did not control the problem but only created new failure scenarios. This type of problem can be addressed through probabilistic risk analysis to construct failure modes and their potential consequences.

Simple modeling of pump room scenario: manual vs. automated system

Let us now return to the pump room example described previously. Using the influence diagram shown in Figure 9, we can consider two alternatives for emergency gas detection and shutdown in a tanker pump room: Alternative 1 - manual monitoring of pump room by an engineer and pumpman on duty around the clock and Alternative 2 - installing an emergency gas detection and shutdown system which is operated from the bridge. These alternatives are examined to determine the eventual failure probabilities of the power plant resulting from fires initiated by pump room gas leaks. Each single border oval or circular node shown in Figure 9 describes probabilistic nodes while double border nodes describe deterministic values in the model. Table VII shows the probabilities of a gas leak in the pump room.

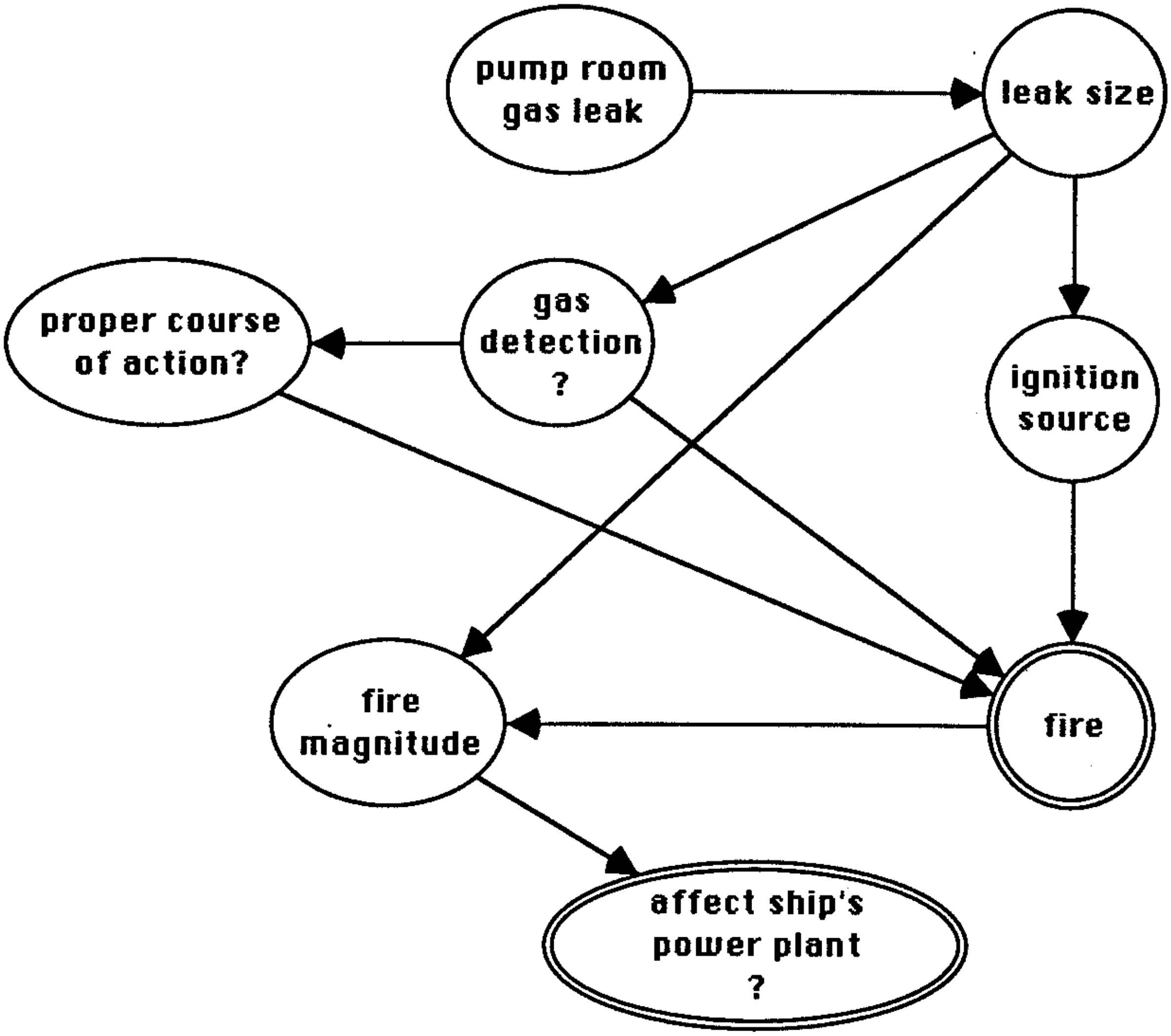

Figure 9: Influence diagram of effects of gas leak in tanker pump room

Table VII: Probability of a pump room gas leak

Gas leak (GL)	.005
No gas leak (NGL)	.995

A probability distribution is established for the magnitude of the leak and is represented by the "leak size" node. Table VIII shows this probability distribution for leak sizes. The leak size will influence three factors: (1) the detection of gas, (2) the magnitude of the fire, and (3) location of an ignition source. Gas detection is assumed to be dependent upon its concentration in the ambient atmosphere around either the pump room operators (detection by smell, sound, or gaging) or the automatic gas detection system (GDS). Gas detection is a step process for both manual and automatic operations: a warning signal followed by the problem recognition, identification, and execution of a plan (see Figure 4). The larger the leak, the greater the chance of detection. Table IX displays the conditional probability distribution for gas detection dependent upon the initiation of the leak and its size. In addition, the gas must locate an ignition source for a fire to be initiated. The model assumes the greater the magnitude of the gas leak, the greater the probability it finds an ignition source as shown in Table X.

Table VIII: Probabilities of pump room gas leak sizes

Small leak (SL)	.7
Moderate leak (ML)	.25
Large leak (LL)	.05

Table IX: Probability distribution of a pump room gas leak detection before ignition

Pump room gas leak	Leak size	Gas detection	Probability of detection (GDS)	Probability of detection (operators)
Leak	Small	Yes	.90	.75
		No	.10	.25
	Medium	Yes	.99	.85
		No	.01	.15
	Large	Yes	.999	.95
		No	.001	.05
No leak	No leak	Yes	0.0	0.0
		No	1.0	1.0

Table X: Probabilities of gas leaks finding ignition sources

Leak size	Ignition source	Probability of ignition source being located
Small	Found	.4
	Not found	.6
Medium	Found	.7
	Not found	.3
Large	Found	.95
	Not found	.05
No leak	Found	0.0
	Not found	1.0

The "proper course of action?" node models whether operators were able to return the system to a normal state by intervening to prevent the fire from occurring. The distributions shown in Table XI demonstrate two factors: (1) the probability of manual control of a leak or fire is greater than that of automatic control since both manpower and mechanical expertise are available to extirpate the problem, and (2) passive monitoring from the ship's bridge can lead to a limited alert time before escalation to a state which is impossible to control (see Figure 5).

Table XI: Probabilities of controlling gas leak

Gas detection	Leak controlled	Probability using manual operation	Probability using GDS system
Yes	Yes	.90	.60
Yes	No	.10	.40
No	No	1.0	1.0

As shown in Figure 9 fire initiation, presented by the deterministic node "fire", is dependent upon three factors: (1) if the gas was detected, (2) whether a proper course of action was carried out to control the leak if detected, and (3) if the gas located an ignition source. Table XII shows the conditions in which a fire event occurs.

Table XII: Conditions to initiate fire event

Ignition source located	Leak controlled	Gas detected	Fire event
Yes	Yes	Yes	No fire
Yes	No	Yes	Fire
Yes	No	No	Fire
No	Yes	Yes	No fire
No	No	Yes	No fire
No	No	No	No fire

As represented in Figure 9, "fire magnitude" is dependent upon both the size of the leak and fire occurrence. The larger the gas leak, the greater the chance of a larger magnitude fire. These assumptions are represented by the probabilistic distributions shown in Table XIII.

Finally, due to the proximity of the pump room to the main engine room, the magnitude of the fire will have an affect on the probability of failure of the the ship's power plant. The fire events represented by the fire magnitudes will determine whether the power plant is operational. It is assumed that if the fire events are small, they can be effectively controlled and do not pose a threat to the integrity of the power plant. If the fire is moderate or large, the integrity of the power plant is affected and the plant fails (this may be due to heat, smoke, or flame moving from the pump room to the engine room).

Based upon the assumptions of the probabilistic and deterministic variables discussed above, Table XIV summarizes both the failure probabilities of the power plants and the conditional failures of the power plants dependent upon fire events. Though the automatic GDS is better at detecting gas leaks than human operators, the probabilities of fires for the manual system are approximately half those of the GDS system. This is primarily the result of the limited ability to control a fire due to limited manpower. Similarly, the probabilities of plant failures for the automated system are approximately twice that of the manual system.

Table XIII: Probability distributions of fire magnitudes

Leak size	Fire event	Fire magnitude	Probability of fire magnitude
No leak	Fire	No fire	1.0
	No fire	No fire	1.0
Small	Fire	Small	.75
	Fire	Moderate	.175
	Fire	Large	.075
	No fire	No fire	1.0
Medium	Fire	Small	.25
	Fire	Moderate	.5
	Fire	Large	.25
	No fire	No fire	1.0
Large	Fire	Small	.2
	Fire	Moderate	.4
	Fire	Large	.4
	No fire	No fire	1.0

Table XIV: Probabilities of plant failures for operational alternatives

Manual operated system	Probabilities of failure
Fire	7.58×10^{-4}
Plant failure	3.11×10^{-4}
Automatic GDS	
Fire	1.33×10^{-3}
Plant failure	6.19×10^{-4}