3

CREATING AN EXPERT MODEL OF THE RISK

If communications are to be authoritative, they must reflect expert understanding. To that end, the first step in developing risk communications is creating influence diagrams that summarize the relevant expert knowledge. As mentioned, although it is called an "expert model," the information that it contains need not reside in the mind of any one expert, especially not in such explicit form. Indeed, the creation of an expert model can be a complex, creative act, forcing participating experts to reflect systematically on the structure of their domain.

Even when chosen for expertise about a specific risk, such as indoor radon, an expert is likely to know a lot more than most of us need to know about that risk. Some expert knowledge is likely to be arcane or simply irrelevant to the decisions that risk communication recipients face. Much expert knowledge is too detailed or peripheral to guide risk communication development. The decision or set of decisions that your communication will inform may be defined in part by the experts you consult, who have specialized knowledge about risk mitigation. But once that decision set is defined, it should guide your expert model development as well. In Section 3.2, we discuss converting scientific information about risk into a decision model, such as an influence diagram.

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3.1 Influence Diagrams

Influence diagrams were developed by decision analysts as a convenient way to summarize information about uncertain decision situations, allowing effective communication between experts and decision makers and the conduct of information-related analyses (Howard and Matheson, 1981; Shachter, 1988). We have chosen to use them in our work on risk communication because they can be applied to virtually any risk, are compatible with experts' conventional ways of thinking, are easily understood and readily subjected to peer review, and fit with a decision-making perspective. In creating an influence diagram, it is essential to follow the formalisms that we are about to describe. In communicating one, it may be adequate, at least initially, to look at its parts more heuristically – showing which factors matter and how they are interrelated.

An influence diagram is a directed graph, with arrows or "influences" connecting related "nodes." Simple influence diagrams contain nodes of two kinds: ovals, which represent uncertain circumstances or "states of the world," and rectangles, which represent choices made by a decision maker. An arrow between two nodes means that the node at the arrow's tail exerts some "influence" on the node at the arrow's head; more formally, knowing the value of the variable at the tail node helps one to predict the value of the variable at the head node. For example, an influence diagram of the weather might include an arrow from an oval representing sunshine to an oval representing air temperature, because sunshine is a factor that influences air temperature (and knowing how sunny it is helps in predicting the temperature).

The easiest way to explain influence diagrams is with an illustration. Suppose that we want to construct a model of the risk that a resident of a two-story home will trip and fall on the stairs.[1] That process involves two stages. Before they can fall, stair climbers must lose their balance by tripping. After losing their balance, they either recover their balance or fall. Thus, the diagram starts with two ovals labeled "trip on stairs" and "fall on stairs," as shown in Figure 3.1a.

[1]There are a number of other reasons, in addition to tripping, that someone may fall on the stairs. For ease of illustration, we will leave these other causes out of this example.

This two-node model is too simple to be very helpful for either estimating or communicating the risks. It does not show any of the factors influencing the likelihood that someone will trip or the likelihood that, having tripped, that person will then fall. It does show how irreversible tripping is, in the sense of how doomed one is to fall, once tripping has begun. If that conditional probability is high, then one should avoid tripping at all costs. One way to make the model more useful is by elaborating the factors influencing the likelihood of such tripping. These might include the stair climber's agility, the stairs' height and width, the floor covering, the kids' tendency to leave toys on the stairs, and the cat's preference for sleeping on the stairs. Lighting may, in turn, affect the chances of seeing the cat or toys. Figure 3.1b adds these factors. "Children's behavior" is a predictor of "toys on the stairs." Others are certainly possible.

Figure 3.1c adds two factors influencing the likelihood of not recovering one's balance after tripping. One is the person's agility, already implicated in influencing the probability of tripping; this is shown by the second arrow from "agility" to "fall on stairs." The second is whether there is a railing to grab.

Finally, there are decisions that people can make that will influence the outcome. For example, a person might decide to stop using the stairs and live just on the ground floor. Figure 3.1d shows this decision with the rectangle labeled "use the stairs," which influences the chance of tripping. The homeowner might also decide to remodel, affecting factors that influence the chance of tripping (e.g., floor covering and lighting), or the chance of falling (e.g., having a railing). Finally, while changing the cat's sleeping habits is unlikely, the family probably has some chance of persuading the children not to leave their toys on the stairs. Because the influence here is not directly on the toys but on the children, it appears as a two-step process; the decision to discipline the children influences the children's behavior, which, in turn, influences where the toys are left.

Clemen (1991) has pointed out that people often confuse influence diagrams with flowcharts, in which each node represents an event or activity in a process, such as making bread. An influence diagram can be thought of as a snapshot of all the factors that influence the state of the world, including the decisions that can trigger or shape the processes capmple to be very helpful for either esti- ks. It does not show any of the factors meone will trip or the likelihood that, hen fall. It does show how irreversible oomed one is to fall, once tripping has ity is high, then one should avoid trip- e the model more useful is by elaborat- elihood of such tripping. These might the stairs' height and width, the floor ve toys on the stairs, and the cat's pref- ghting may, in turn, affect the chances b adds these factors. "Children's behav- airs." Others are certainly possible. fluencing the likelihood of not recover- ne is the person's agility, already impli- y of tripping; this is shown by the sec- stairs." The second is whether there is

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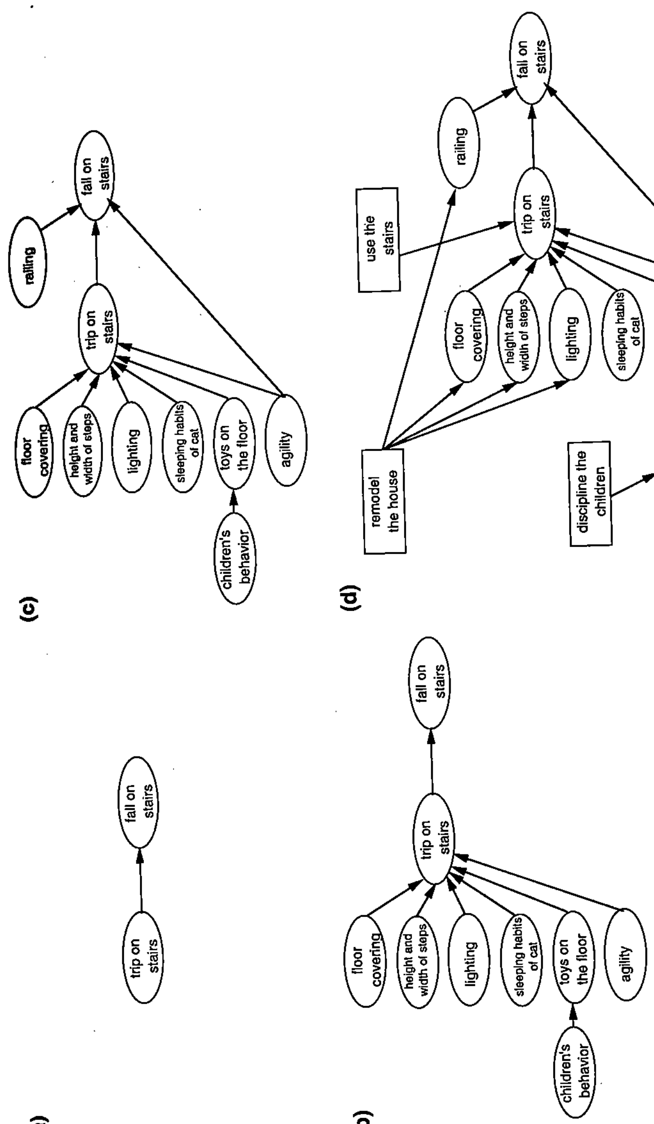

Figure 3.1. Illustration of the construction of an influence diagram for the risk of tripping and falling on the stairs: (a) shows just those two elements; (b) adds factors that could cause a person to trip; (c) adds factors that might prevent a fall after a person trips; and (d) introduces decisions that residents could make that would influence the probabilities of tripping and falling.

tured in the nodes. In contrast, a flowchart shows a deterministic process that is stepped through one box at a time. In a flowchart, the outcomes of all previous nodes are known at the time that a particular box is reached. In an influence diagram, many nodes can be involved simultaneously and involve uncertain outcomes – so that the outcome is unknown until the process has played itself out.

The formalisms underlying influence diagrams allow including both causal and noncausal (or indirectly causal) influences. For example, high levels of radon are more prevalent in certain parts of the country. If a certain ethnic group disproportionately lives in those parts, then knowing residents' ethnic background would help to predict their radon levels. However, there would be no causal relation between ethnicity and radon exposure. In some such cases, there is a common cause between the two indirectly related factors. If so, then it may be possible to model the underlying causal structure, for example, where prejudice leads members of an ethnic group both to be poor and to live in an area with high risk levels. Being able to include both causal and noncausal relationships allows influence diagrams to accommodate whatever information is available. However, because causal relations can be easier to understand, other things being equal, they might be preferred in communications.

Our descriptions of influence diagrams here are typically informal. By imposing a few structural rules, attaching actual mathematical relationships to the influences, and describing the value of the uncertain variables in terms of probability distributions, influence diagrams can be given much more precise meaning. Indeed, when properly constructed, an influence diagram can be converted into a decision tree, a standard tool in the field of decision analysis (Miller et. al, 1976). The boxed section "Influence Diagrams and Computer Models" elaborates further on the relation between influence diagrams and decision trees. Experience with our mental models method naturally leads to mastery of these procedures. For the simplest uses, though, all one needs to ask is whether the value of the variable at Node B depends on the value of the variable at Node A. If so, then draw an arrow from A to B.

The goal in constructing an expert model is achieving sufficient clarity that the influence diagram could be converted into an executable computer model. Even when that next step is not taken, formally creating an

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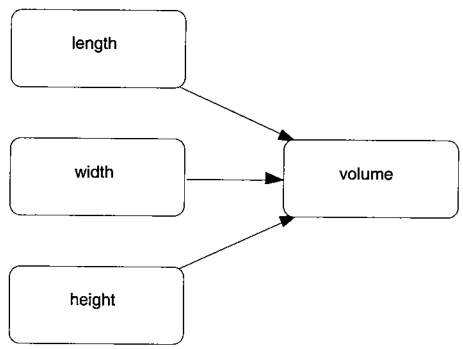
Influence Diagrams and Computer Models

The computer environment Analytica* uses influence diagrams as the interface for building computer models. Variables in these models are represented as nodes in an influence diagram, which the modeler can construct by clicking on icons, dragging them into place, and connecting them with arrows to indicate influences. Below this graphical layer, the modeler can specify the mathematical relationships indicating the nature of the influences. Importantly, Analytica allows the introduction of uncertainty regarding the values of the model variables. Suppose, for example, that we wanted to build an Analytica model to compute the volume of a rectangular building. We start by creating an influence diagram that looks like this:



If we double click on the node labeled "length," the computer gives us an opportunity to specify a mathematical definition. For example, we could define length as 10 meters, if we knew it with precision. We can do the same thing for width, or we might specify a "vector" of three values [10, 20, 30], which tells the computer to run the model once for each of the three widths: 10, 20, and 30 meters. Suppose we are uncertain about the height. If our knowledge allowed us, we could specify our uncertainty as a probability distribution, such as a lognormal distributed with a geometric mean value of 10 meters, and a geometric standard deviation value of 1.5. The computer's evaluation of the model would produce a result like this:

*Analytica is distributed by Lumina Decision Systems, Inc., 59 N. Santa Cruz Avenue, Suite Q, Los Gatos, CA 95030; info@lumina.com.

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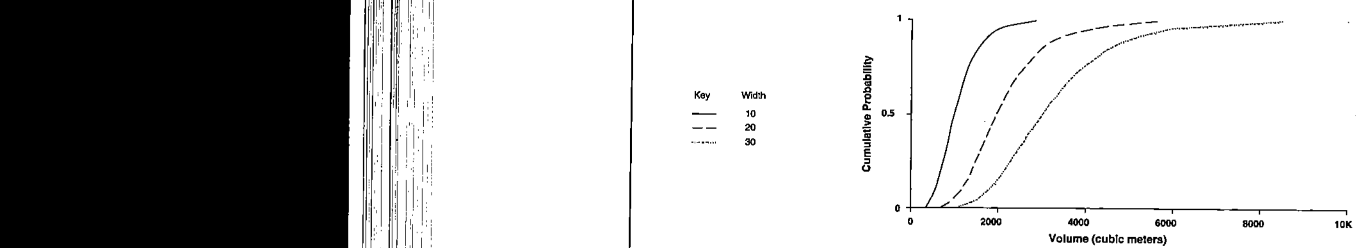
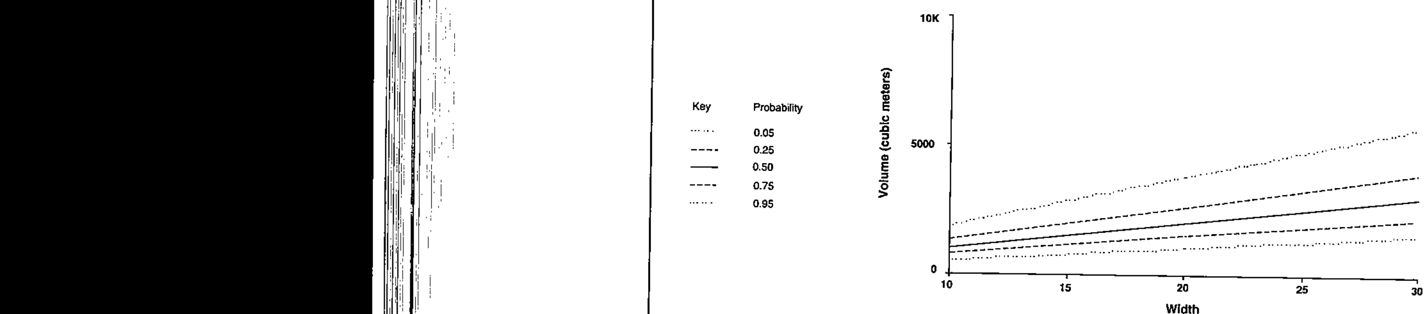


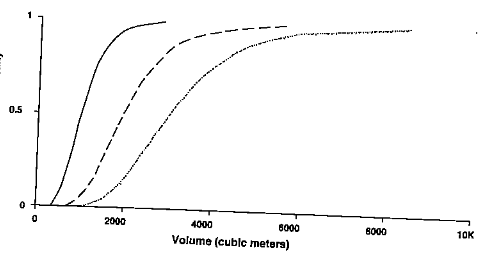
The first curve shows the cumulative probability distribution for volume when length is 10 meters, width is 10 meters, and height has the specified uncertainty distribution. The second and third curves show the distributions for volume when the width is 20 and 30 meters, respectively.

Alternatively, we could ask the computer to show us how uncertainty changes as we vary the width from 10 to 30 meters:



In this case, the five lines show a range of confidence from 5% at the bottom to 95% at the top.

In building a model of a complex system, the influence diagram can quickly become extremely complicated. In order to deal with this complexity, it is convenient to group parts of the diagram together as submodels, then organize them hierarchically. For example, models of climate change need to include physical processes (in the atmosphere and oceans), social processes (population, economic consumption and production), and biological and ecological processes (in managed and unmanaged contexts). It also should include human actions (emissions, taxes, and various forms of adaptation) that can feed back upon the system and influence its future course.



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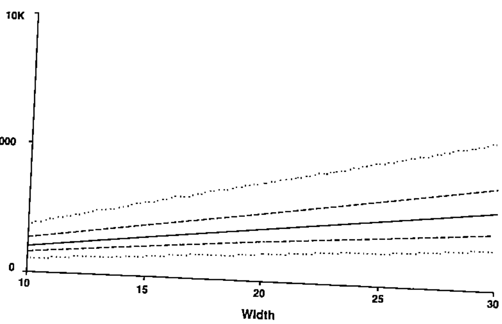

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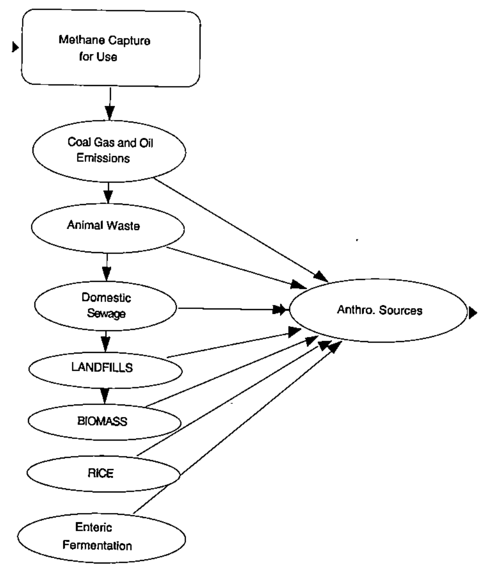
Figure 3.10 on page 59 illustrates a portion of such a hierarchically organized model, the Integrated Climate Assessment Model (ICAM) developed in Analytica by Hadi Dowlatabadi at Carnegie Mellon (http://hdgc.epp.cmu.edu). In this illustration, heavy ovals contain submodels, which are elaborated at a lower level in the hierarchy.

The upper-left corner of the illustration shows the top level of the hierarchical family of influence diagrams and associated computer models. Economic processes produce emissions to the atmosphere, which influence climate through various geophysical processes. These provide feedback to the natural world and the economy. When uses run the model, they can specify various combinations of three broad policy options (abatement, adaptation, and geoengineering). Figure 3.10 illustrates what users would see if they were to explore the submodel labeled "demographic and economic processes." If, instead, users double clicked on the node labeled "energy and emissions" in the top-level representation of ICAM, they would see a screen that displays several different kinds of emissions, such as carbon dioxide, methane, and fine particles. If they double clicked on the node for "methane," they would move one level further down in the model hierarchy and see separate nodes for natural and human (anthropogenic) sources. Double clicking on this last node would produce a screen like this:



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Here, all the principal human sources of methane release are indicated. Under each of the left-hand nodes in this diagram is a set of mathematical relations and numerical data from measurements made around the world. By choosing the methane emissions node, and asking the computer to evaluate it, the user could ask the computer model to plot a (probabilistic) projection of methane emissions for the next century.

expert model inevitably involves some (at least implicit) quantification. The experts must at least run some numbers in their heads when pruning minor influences in order to keep the diagram to a manageable size.

The scientific use of influence diagrams allows the calculation of risk levels associated with different states of nature, and with different human actions. For example, it might predict the lung cancer rate for houses with a given ground concentration of radon and the effect on that rate of various changes in ventilation. In some cases, there will be firm scientific evidence, providing the estimates needed to obtain these numerical solutions. In other cases, expert judgment will be needed. Such analyses can also help to direct and evaluate interventions. For example, an influence diagram for the risks of AIDS would include the effects of drinking on people's exposure to the virus (Fig. 8.1 on page 163). One arrow might reflect the effects of alcohol on the user's physical ability to take protective measures; a second arrow might show the effects on evaluating the risks and benefits of behaviors. A formal analysis of such an influence diagram could show the effect of, say, eliminating all drinking or creating fail-safe condoms (so that clear thinking is less necessary).

3.2 Strategies for Creating Influence Diagrams

There is no simple recipe for converting the scientific information on a risk into an influence diagram. Even among the most experienced risk analysts, the process is an iterative one, as specialists from the relevant disciplines review one another's work and reflect on their own. The construction of each new diagram poses different, and often interesting, challenges. Section 3.3 provides some examples of influence diagrams, along with discussions of their properties. Before turning to them, we sketch several generic strategies in this section. These can be used in isolation or in combination, as a way of providing converging approaches to a common problem.

A full influence diagram, developed through repeated iterations with multiple experts, can be a daunting place to begin the study of a problem. Indeed, looking at some of the worked examples in this volume might lead some readers to conclude that this is all too complicated for those without a staff having deep analytical experience. However, we encourage readers to stay the course. The complete diagrams here all began as simple ideas. Moreover, even a rough approximation will provide much of the guidance needed for creating effective risk communications. These diagrams do not require the detail and precision required for performing formal quantitative analyses. Nonetheless, pushing the analyses as far as possible helps to refine thinking about a risk (see the boxed section "Influence Diagrams and Computer Models").

Technical experts are often happy to assist risk communicators to develop diagrams that capture the key elements of their knowledge. Directed graphs, such as influence diagrams, are common devices in many technical fields. Once the particular formalism has been explained to them, experts often demonstrate considerable facility in using it. Jointly creating the diagram also provides a structured and mutually respectful way for communicators and technical experts to ensure that they understand one another.[2] It is also a good way to communicate with technical specialists, by listening to them first. It can make communication with laypeople seem more tractable to skeptical experts, by decomposing the task into more manageable pieces.

[2]There are also several computer programs that can be used for mounting influence diagrams. Some just make it easier to create the physical representation than with conventional drawing programs (by treating arrows as relationships, and not just lines). Others, like Analytica and DPL (Decision Programming Language), allow the user to build a full computer model underneath the diagrams and provide help, such,as consistency checks.

The assembly method In one sense, an influence diagram is just a set of linked factors. As a result, it can, in principle, be assembled by listing all relevant factors and then figuring out how they are related. The listing step might be done alone or as a group brainstorming effort. Members of the team might even conduct mental models interviews with one another. The factors that emerge could then be sorted into related categories, keeping an eye out for functionally equivalent ones. If an overall structure does not emerge spontaneously, then it might reveal itself by making pair-wise comparisons among factors. One strategy that we have sometimes used is to write the factors on Post-it notes and then put them on a blackboard, so that they can be moved around easily, with chalk arrows being drawn and erased until an appropriate structure has been found.

The materials/energy balance method Many risks involve physical processes. The laws of physics say that under normal circumstances both energy and materials are conserved – that is, the same amount goes in and comes out. Thus the total mass of all the raw materials flowing into a manufacturing plant must equal the mass of the products and wastes flowing out of it and permanently stored there. The same sort of calculation can be done with energy (although the form of the energy may change, as when mechanical or electric energy ends up as heat). Technical experts often rely on such physical conservation laws when they analyze risks.

For example, many risks are created by exposure to particular materials, such as lead. Tracking that (fixed) quantity allows an expert to set an upper limit on possible exposures. The influence diagram then becomes a summary of the factors affecting the amount of the material available for human contact. Those factors might include natural processes, concentrating or dispersing the material, and deliberate human interventions. Once the exposure has occurred, an effects model is needed to show which health effects are possible and how their progress depends on medical treatment, self-care, and so on (Morgan and McMichael, 1981; Morgan, 1993).

The scenario method Most risks can be described in terms of a causal chain of events. The risk literature contains several discussions of such chains (Morgan, 1981; Hohenemser, Kates, and Slovic, 1983; Hohenemser,

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Kasperson, and Kates, 1985; Earle and Cvetkovich, 1983; Kammen and Hassenzahl, 1999). Something happens (e.g., people get exposed to pollution), then another thing happens (e.g., they ingest the pollution), and, eventually, someone gets hurt. The occurrence of each event affects the probability of the next, thereby meriting a link in the influence diagram. Branches leading into each event can then capture the other factors that increase or decrease its probability of occurrence. The chain might be traced forward and backward, hoping that these complementary perspectives reveal a more complete picture. That is, a situation may look different when worrying about how one thing can lead to another and when worrying about where specific problems might come from. Scenarios can be used to test models created by other methods for completeness, by tracing them through the diagram.

The template method When risk processes have similar structures, each need not be analyzed separately, based on first principles. Rather, one can create modules capturing recurrent exposure and effects processes. For example, as Figure 3.2 illustrates, exposure processes typically precede effects processes. How each operates may be influenced by similar environmental, physiological, and behavioral factors – and, in turn, by the choices made by risk managers or others.

Figure 3.3 applies this general template to the specific risk of infection by Lyme disease. The portion of the diagram to the left of the vertical dashed line describes the processes influencing a person's chances of being bitten by a disease-infected tick. The portion of the diagram to the right of the vertical line describes the processes that influence whether a bitten person becomes infected and, if so, how serious the resulting disease is.

Lyme disease is carried by deer ticks. Adult ticks live and feed on a variety of animals, including white-tailed deer. After mating in the fall, the ticks drop off to lay eggs. Deer tick eggs hatch and develop into larvae, which feed on small animals, such as white-footed mice. If the mouse happens to be infected by Lyme disease, the tick nymphs also become infected and may go on to infect other mice. From mid- to late summer, tick nymphs lie in grass and on bushes, waiting to attach themselves to a passing animal, such as a deer, pet, or person.

The rectangles show control strategies. Habitat influences the popula-

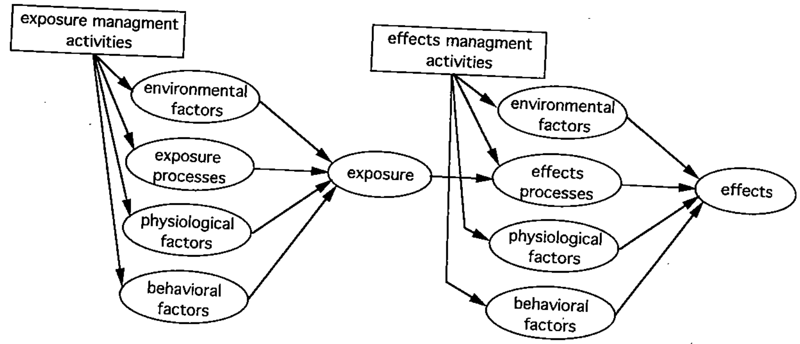
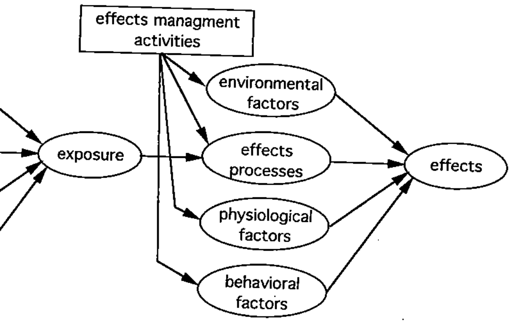


Figure 3.2. Example of a basic template for an influence diagram of risk processes. The left side shows the factors that influence exposure. The right side shows the factors that determine whether and how exposure results in effects.

tion and distribution of deer and mice; controlling either species will reduce risks. Distributing containers of insecticide-impregnated cotton, which mice find attractive as bedding for their nests, can reduce the populations of tick nymphs and ticks among mice. The probability that people will be bitten (exposed) depends on where they go, how they behave, what they wear, and whether they frequently inspect exposed skin for ticks. These behaviors might be affected by educational efforts. When a person is bitten by an infected tick, it takes some time before the infection is passed. Hence, how quickly people discover ticks and how effectively they remove them can affect their risk of infection. Once infection occurs, how quickly it is diagnosed and how effectively it is treated affect the progression of the disease and the severity of its symptoms. If untreated, patients may develop heart problems, headaches, stiff neck, and facial paralysis after a few months. The organization of medical services can affect these processes.

Although the specifics will vary from one risk to the next, many have an underlying structure like that in Figure 3.2.

At first glance, the examples in the next section may seem dauntingly complicated. However, they typically yield to a few minutes of patient study. Start somewhere and go forward or backward, asking the reason for each connection. Then, see what other things are connected to each node.



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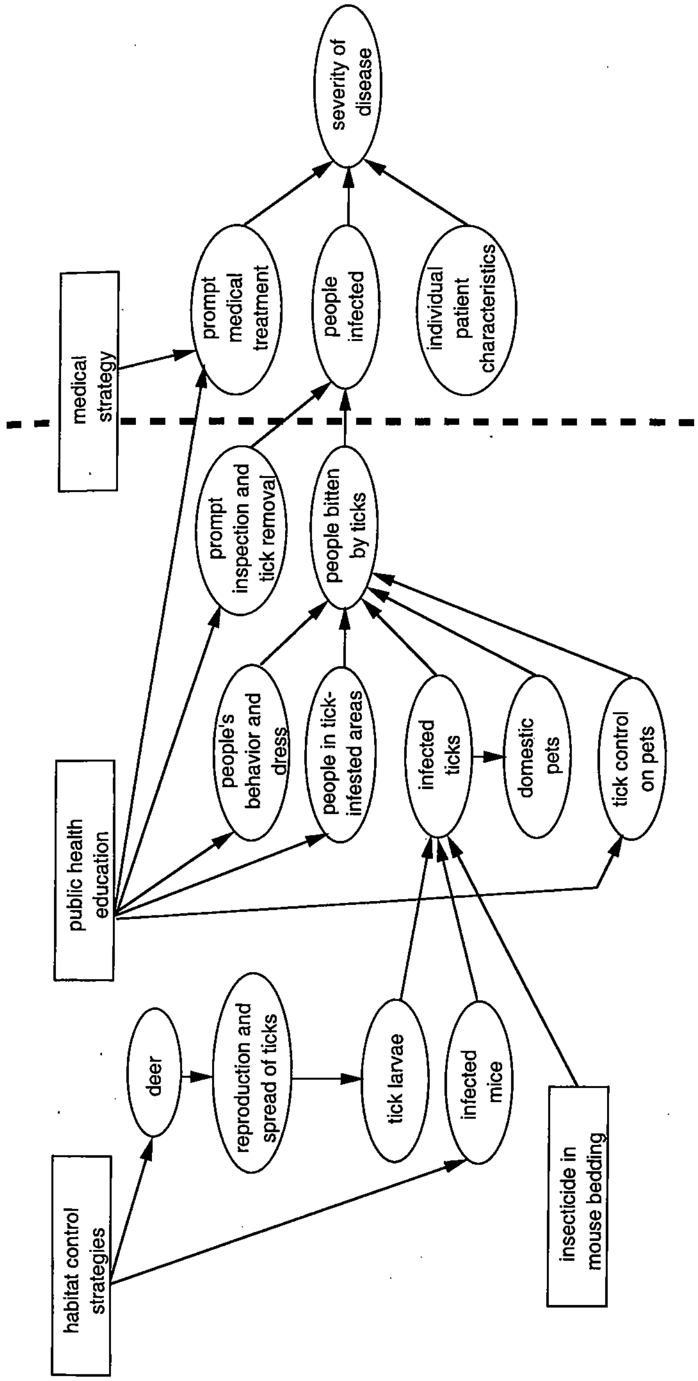

Figure 3.3. Illustration of applying the basic template of Figure 3.2 to the specific risk of infection by Lyme disease. The portion of the diagram to the left of the vertical dashed line deals with exposure processes. The portion to the right of the dashed line deals with effects processes. The diagram has been simplified for illustrative purposes.

Gradually, the overall structure will emerge. In some cases, a simple story ties it all together. In other cases, the reality is just complicated, and the diagram reflects that.

3.3 Examples of Influence Diagrams

This section presents several of the influence diagrams that we have used in developing risk communications.

Indoor air pollution Figure 3.4 describes radon exposure in homes. It was developed primarily by Keith Florig, an engineer with a background in nuclear and environmental topics, in consultation with members of our research group and external reviewers. To make it easier to follow the diagram, large boxes bracket the major processes, showing the hierarchical structure of the model.

The diagram is for a home with a crawl space. Four different sources of radon are included. Usually, the most important is the soil under the building, labeled "radon from soil gas" (in the lower-left corner of Figure 3.4). Second, radon can diffuse out of building materials containing naturally occurring radium. Third, radon dissolved in water can be released when the water is used in the home (e.g., in showering). Because radon is short-lived, it is seldom found in municipal water systems, but it is not uncommon in well water in locations with high radon concentrations. Finally, radon is sometimes found in natural gas. Although it is uncommon in commercially supplied gas, it can be significant in rural homes with small private gas wells.

The diagram shows the variables that influence the intensity of the source. These factors lead to a node that represents the flow rate, or "flux," of radon from each source into the home.

After radon flows into a home, things happen to it. The gas undergoes radioactive decay into very small particles (called radon "daughters" or "progeny"). Some of these decay products can be harmlessly lost by attaching to or "plating out" on surfaces in the home; others are inhaled and attach to people's lungs. These processes, by which radon and its decay products leave the air, are described in the lower-right corner of the

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l of the influence diagrams that we have used
cations.

3.4 describes radon exposure in homes. It was
ith Florig, an engineer with a background in
topics, in consultation with members of our
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the major processes, showing the hierarchical

ome with a crawl space. Four different sources
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om soil gas" (in the lower-left corner of Figure
use out of building materials containing natu-
ird, radon dissolved in water can be released
he home (e.g., in showering). Because radon is
und in municipal water systems, but it is not
in locations with high radon concentrations.
found in natural gas. Although it is uncom-
lied gas, it can be significant in rural homes
.
e variables that influence the intensity of the
a node that represents the flow rate, or "flux,"
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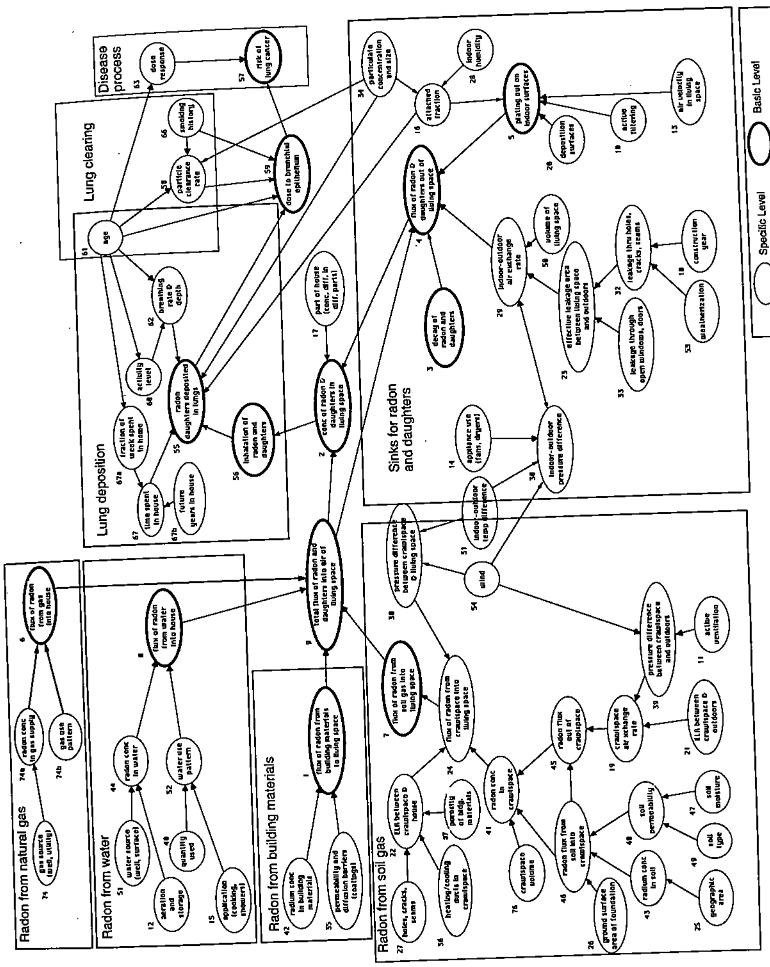

Figure 3.4. Influence diagram for risks produced by radon in a house built over a crawl space. Basic high-level concepts are represented with bolder ovals. *Source:* Bostrom, Fischhoff, and Morgan (1992).

decay products leave the air, are described in the lower-right corner of the diagram, labeled "sinks for radon and daughters."

The concentration of radon and its by-products in the living space depends on both the sources (the four boxes along the left side of the diagram) and the sinks (the box in the lower right).

The three overlapping boxes in the upper-right portion of the diagram contain elements that determine what gets into people's lungs, how much stays there and for how long, and whether the resulting exposure of lung tissue to ionizing radiation ultimately produces lung cancer many years later.

Throughout the diagram, the most important determinants of risk level and, hence, topics for communication are represented by heavy ovals.

Although the causal relations in the diagram are straightforward, it is easy to imagine laypeople not thinking of them spontaneously. Even specialists with technical expertise in one part of the diagram might overlook factors in another.

Our construction of this influence diagram used a combination of the scenario method, the materials-balance approach, and the exposure-to-effects template. In order for health effects to occur, people need to be exposed to radon. For that to happen, radon needs to come from somewhere and then reach them, without being removed by any intervening processes. Thus, we asked ourselves and our experts where the radon comes from and where it goes, what determines the rates of these processes, and, finally, what damage it can do while in contact with people. Given the limited success of medical treatment for lung cancer, we did not elaborate on the disease processes. Because the source of lung cancer has no effect on its progress, a standard disease module could be used here and in related applications. Facts like radon being a gas and radioactive do not appear directly in the influence diagram. Rather, they are background concepts, knowledge of which is essential to interpreting the links that are shown.

In a diagram that we developed for another indoor air pollutant, perchlorethylene, used as dry-cleaning fluid, we had to elaborate the health impacts portion of the diagram in much greater detail. Perchlorethylene differs from radon in having several possible health effects (i.e., it may be

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In developing an influence diagram for other indoor or outdoor air pollutants, one would follow a similar process. The diagram would need to describe where the material comes from; the processes (e.g., loss, chemical reaction) that determine its concentration; the behavioral, physiological, and other factors that determine the amount of exposure; and various health, environmental, or other consequences that such exposure can produce. In some cases, air may not be the only route of exposure. For example, water can be a secondary source of exposure to the perchlorethylene used in dry cleaning. When more than one "medium" (air, water, soil) is involved, it may be necessary to construct parallel diagrams for each.

Problems that involve water pollution can be diagrammed in much the same way. The specific details of the sources, transport, conversion, loss, and exposure processes may all be different, but the basic structure applies.

Catastrophic failure of an engineered system Figure 3.5 shows an influence diagram for the risks created by nuclear energy sources on spacecraft. Sometimes, these sources are used as a matter of engineering convenience. More typically, they are a necessity, providing the only way to deliver large amounts of power or to support missions far from the sun, where photocells are impractical. This example provides a mixture of technologies that, for many people, evoke feelings that are good (spacecraft) and bad (nuclear power). The risks arise from the breakdown in an engineered system. As a result, the influence diagram follows the scenarios initiated by various possible breakdowns. The probability of each path depends on how the system is engineered (affecting the kind of breakdown and attempted containment), where the breakdown happens (affecting its proximity to people and its dispersal properties), and how various people respond to it (either issuing warnings or taking indicated precautions).

The diagram was primarily developed by Michael Maharik, an engineer with a background in aerospace systems (Maharik, 1992; Mahařik et al., 1993). Figure 3.5 reproduces a simplified version. Figure 3.6 shows the

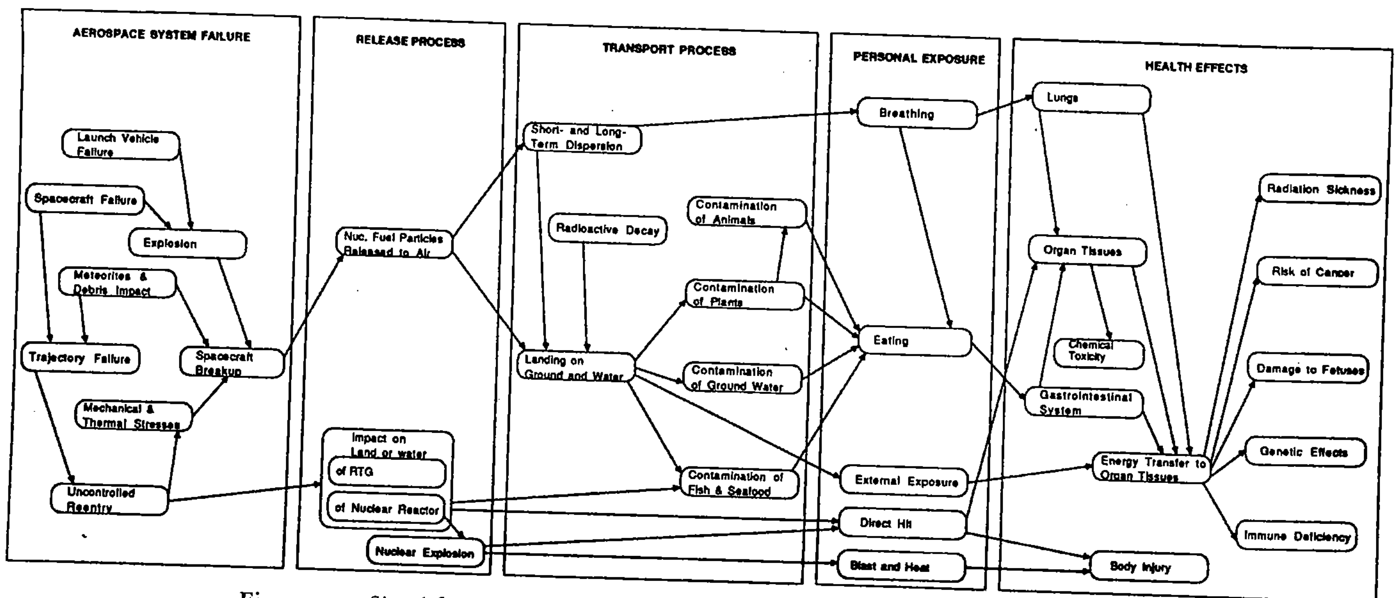


Figure 3.5. Simplified influence diagram of risks from nuclear energy sources on spacecraft. *Source:* Maharik and Fischhoff (1992).

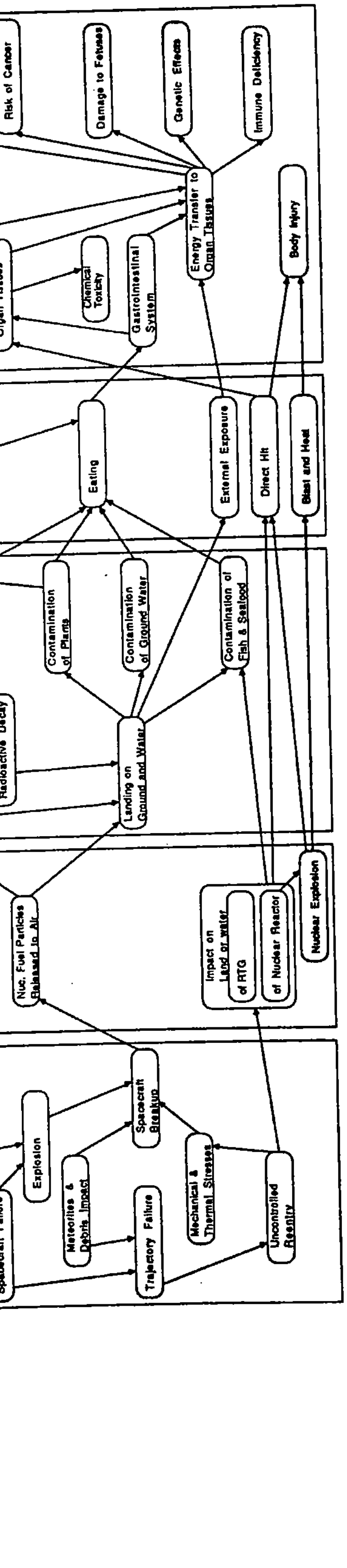


Figure 3.5. Simplified influence diagram of risks from nuclear energy sources on spacecraft. *Source:* Maharik and Fischhoff (1992).

full diagram. As with radon, boxes have been added to help the viewer follow the overall structure. Moving from left to right, the first box displays influences that can result in the failure of the system (e.g., the launch vehicle may blow up and destroy the spacecraft or the spacecraft may crash to earth through other failures). The second box shows processes that can result in the release of radioactive materials into the environment. The third box shows how released materials might be transported to other locations and expose people. The final box, on the right-hand end of the diagram, shows how exposures can produce adverse health consequences.

This structure is fairly typical for failures resulting in environmental releases from engineered systems. The first section of the diagram involves processes that are unique to the particular system (oil tanker, chemical plant, waste storage facility). The subsequent exposure and effects processes develop in the same general way as with other forms of pollution.

Failures of engineered systems often can immediately affect people and property (by impact, fire, or explosion), as seen in the bottom of Figure 3.6. With some engineered systems, such as transportation, physical injury is often the principal source of health risk.

Infectious disease Infectious diseases, transmitted through either direct person-to-person contact or various intermediaries (or "vectors"), such as insects or contaminated needles, are an important class of risks. Figure 3.3 showed a simplified influence diagram for Lyme disease, with the movements of deer, mice, ticks, and people combining to create exposures.

Figure 3.7 provides a more elaborated diagram, describing the risks associated with AIDS. There are several parallel transmission processes for this disease, requiring either several separate diagrams or a single one formulated in general terms. This diagram adopts the latter strategy. As a result, it has the "clutter" of factors that are irrelevant for some modes of transmission. For example, alcohol consumption is very important for sexual exposures but irrelevant to transfusion exposures. Because human behavior is involved, some of the factors conceal extraordinarily complicated processes under a single label. For example, "motivation" appears as a single factor. Although it may be analytically efficient to reduce the variety of underlying processes affecting motivation to an aggregate measure, doing so provides little insight into how motivation might be antici-

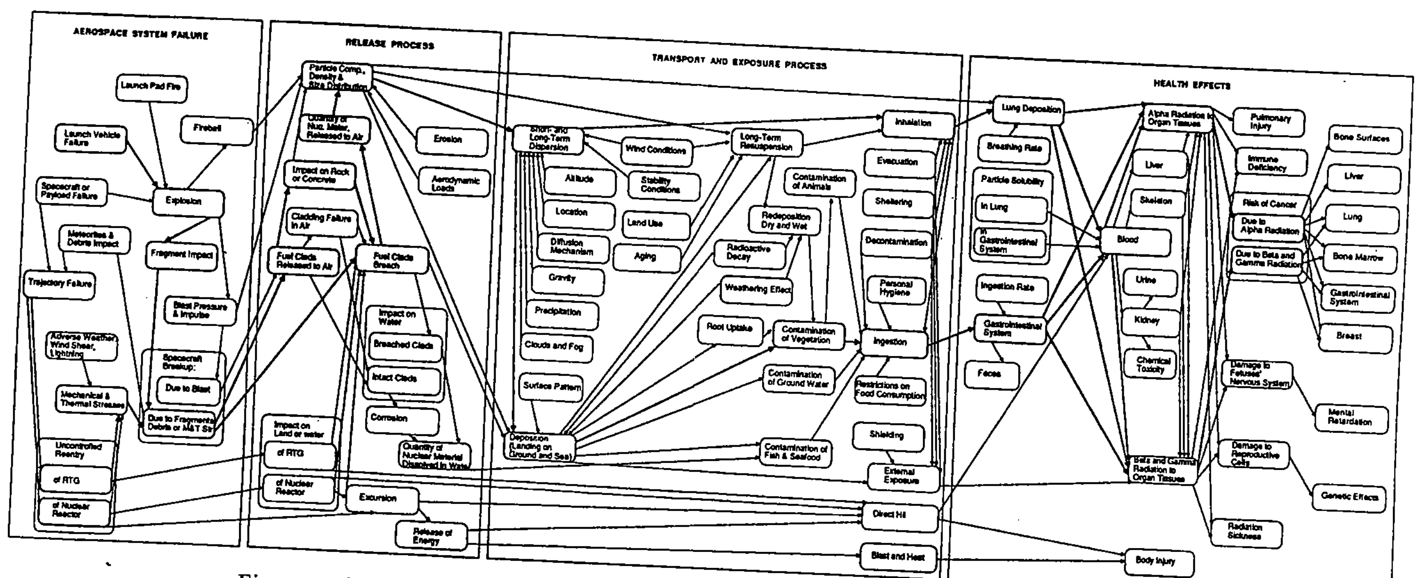


Figure 3.6. Full influence diagram of risks from nuclear energy sources on spacecraft.
Source: Maharik (1992).

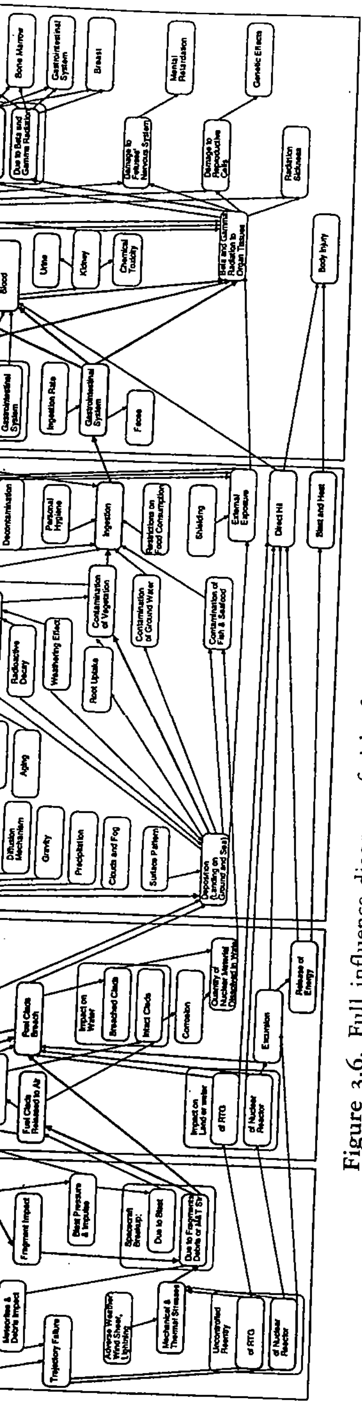


Figure 3.6. Full influence diagram of risks from nuclear energy sources on spacecraft. *Source:* Maharik (1992).

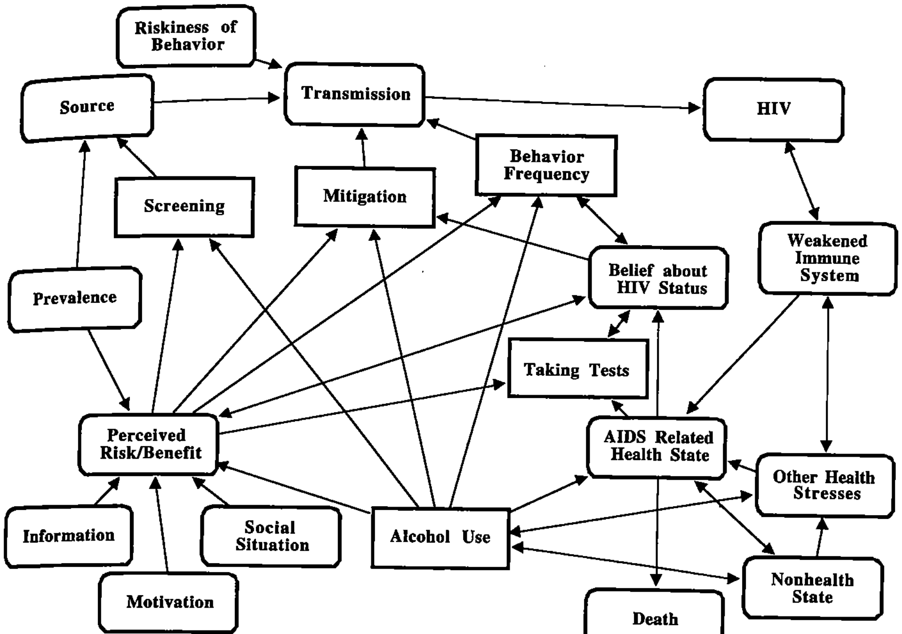


Figure 3.7. Influence diagram for the risks associated with HIV and the resulting disease, AIDS. *Source:* Fischhoff and Downs (1997).

pated or controlled. This node is, in effect, a placeholder for these contributing factors.[3]

The AIDS diagram differs from the others presented so far in having significant feedback. People who have, or fear that they have, HIV may change their behavior in ways that affect others' risk. The extent of their fears should be affected by test results or, more specifically, by their interpretation of those results. Analogous distinctions between perceived and actual risks can be found elsewhere in the diagram. For example, the actual prevalence of HIV affects the probability that an individual will come into contact with a source of the virus (e.g., a sex or drug partner). That individual's perception of that prevalence will affect how potential

[3]In a project on other sexually transmitted diseases, we expand this section of the AIDS influence diagram (Fischhoff, Downs, and Bruine de Bruin, 1998).

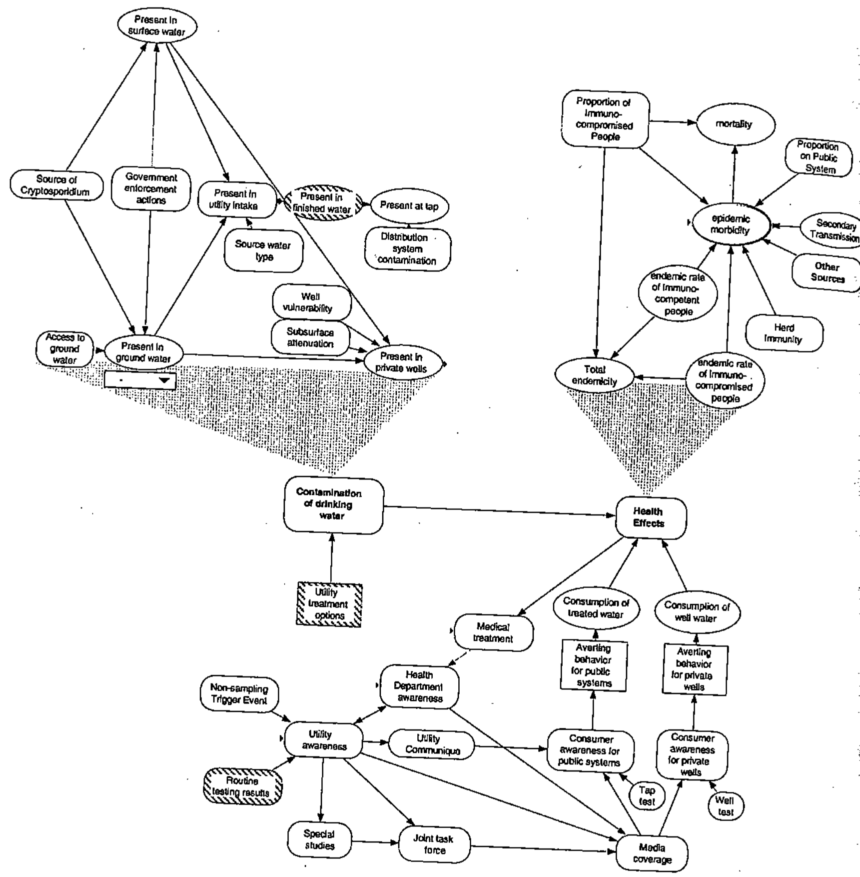
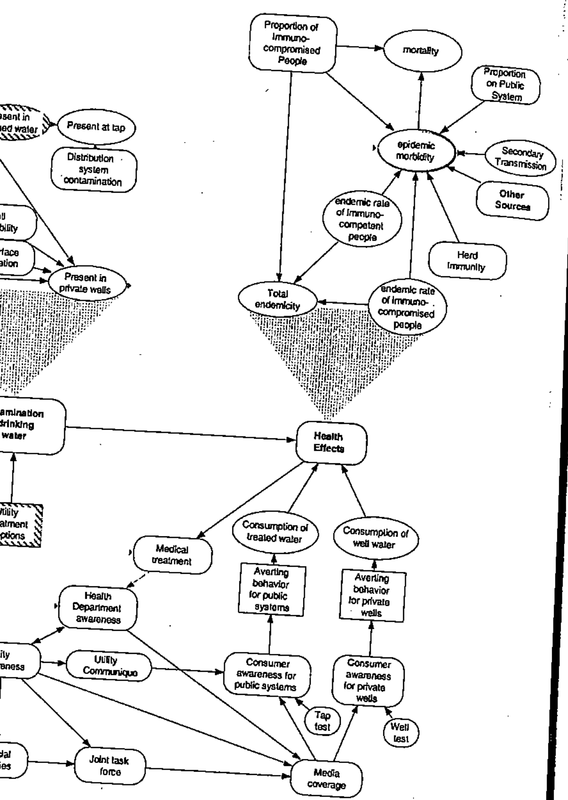


Figure 3.8. Influence diagram using Analytica to depict the risks associated with the contamination of drinking water by cryptosporidium. In this case, a full computable model has been developed. See Figure 3.9 for details of the structure that underlies the node "present in surface water." *Source:* Casman et al. (2000).

sources are screened, if at all; the effectiveness of that screening will determine the ultimate probability of exposure to a source having the virus.

Another quite different infectious disease is cryptosporidiosis. This disease is primarily transmitted to people in runoff from agricultural land that has become contaminated with cryptosporidium oocysts from infected cattle. The oocysts are so small and robust that once they contaminate water, it is quite difficult to filter or kill them with standard methods, such as chlorina-



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Variable Present_in_surface **Units:** binary (yes/no)

Title: Present in surface water

Description: Cryptosporidia are present in a surface drinking water source if sufficient amounts of contaminated waste are delivered to the body of water.

Contamination of surface water can lead to contamination of ground water. Also contaminated surface water can enter wells via breached casings and/or well head flooding.

reference
Rose, JB 1997 Environmental ecology of Cryptosporidium and public health implications. Annual Review of Public Health, 18:135-161.

0 indicates no contamination
1 indicates contamination

Definition: if source - regulation <= 0 then 0
else 1

Inputs: Regulation EPA environmental actions
Source Source of Cryptosporidium

Outputs: Present_in... Present in utility intake
Present_in... Present in private wells

Figure 3.9. If a user were to "double click" on any variable in the Analytica model represented by the influence diagram in Figure 3.8, a "dialogue box" would open up, explaining the variable, the mathematical definition of the variable, and a list of the variables that feed into this variable (inputs) and are fed out from it (outputs). See Chapter 10 of the 1998 printing of Morgan and Henrion (1990) for more details on Analytica, or go to info@lumina.com.

tion. Our work has focused on the water treatment and public warning portions of the problem. Figure 3.8 displays the influence diagram, developed in Analytica with an executable computer model underlying the diagram. Figure 3.9 illustrates the details associated with the node labeled "present in surface water." A user can display this information by "double clicking" on that node in Figure 3.8. Even when actual calculations are not anticipated, creating such work sheets helps to ensure that each node has been clearly and consensually defined – not to mention documenting what was intended.

Global change We have created expert models of several complex environmental problems, including acid rain (Rubin et al., 1992) and climate change (Morgan and Dowlatabadi, 1996). In these cases, our influence diagrams are so complicated that they would look like a plate of spaghetti if condensed to a single sheet of paper. Like the cryptosporidium example, such diagrams must be organized hierarchically, displaying just a few key pieces at the top level and adding detail as one moves down the hierarchy. Programs like Analytica have features to facilitate keeping everything organized in such a hierarchy. Figure 3.10 provides an illustration of how this particular one works. Although the full influence diagram is material for a course rather than a risk communication, some portions might be more appropriately sized.

When we undertook the development of risk communications on climate change and nuclear energy sources on spacecraft, we based our work on a simplified diagram. However, in contrast to the spacecraft example, the climate change diagram adopted a somewhat different organization than the one in the computer model, so as to emphasize the issues that were most central for general public understanding – which has different foci than some policy making and climate science. Figure 3.11 shows that diagram (Bostrom et al., 1994; Read et al., 1994). Thus, there is no single correct influence diagram for a given risk. The structure should be chosen to represent important expert knowledge in a form that addresses the audience's informational needs.

3.4 Summary

Influence diagrams provide a convenient way to summarize the expert knowledge upon which a risk communication will be built. The influence diagrams use a language that experts often find easy to understand and use. Because a well-designed influence diagram is compatible with more detailed decision or risk analyses, its rigor can build expert support for the communication process. However, a qualitative description is all that is needed for many communications. The discipline involved in constructing an influence diagram can help the risk communicator to ensure that nothing important is overlooked, that only decision-relevant information is included, and that a framework is created for obtaining systematic assistance from experts, as well as documenting the assumptions underlying the communication.

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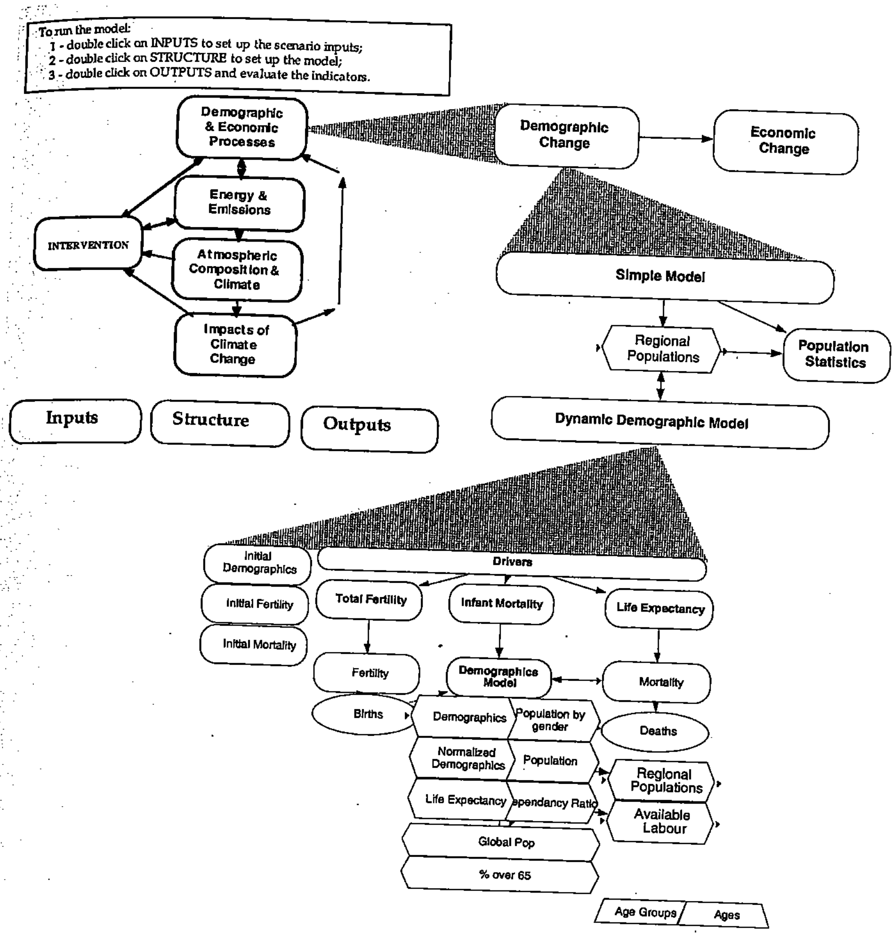

Figure 3.10. Illustration of a portion of the hierarchically organized influence diagram for the Carnegie Mellon Integrated Climate Assessment Model implemented in Analytica. Heavy boxes indicate submodels. Here we illustrate what users would see if they first double clicked on the submodel labeled "demographic and economic processes," then on the submodel labeled "demographic change," and finally on the submodel labeled "dynamic demographic model." Overall, the influence diagram that describes the ICAM computer model contains >1,800 objects, making a hierarchical organization absolutely essential. Note that in the first screen (upper-left portion of figure) there are three disconnected boxes across the bottom. They are *dialogue boxes* in which the user chooses inputs, outputs, and alternative model structures (such as a simple or dynamic demographic model).

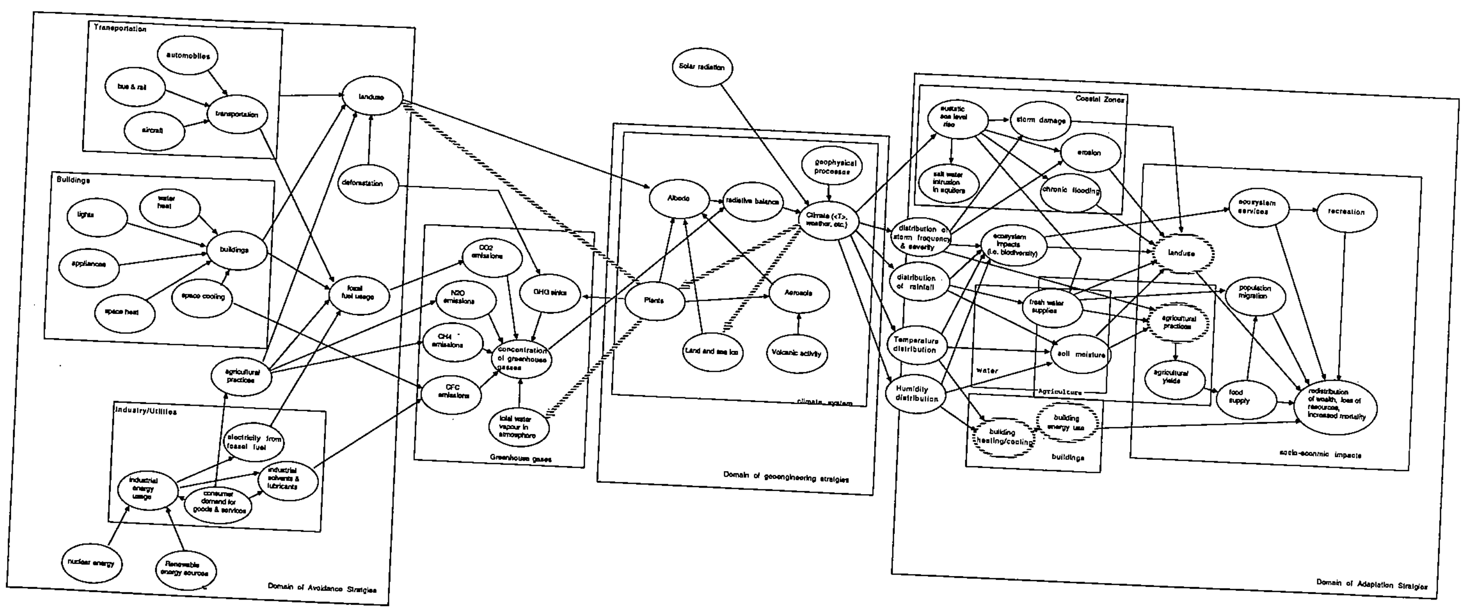

Figure 3.11. Simplified influence diagram of climate change, developed and used in mental models studies.

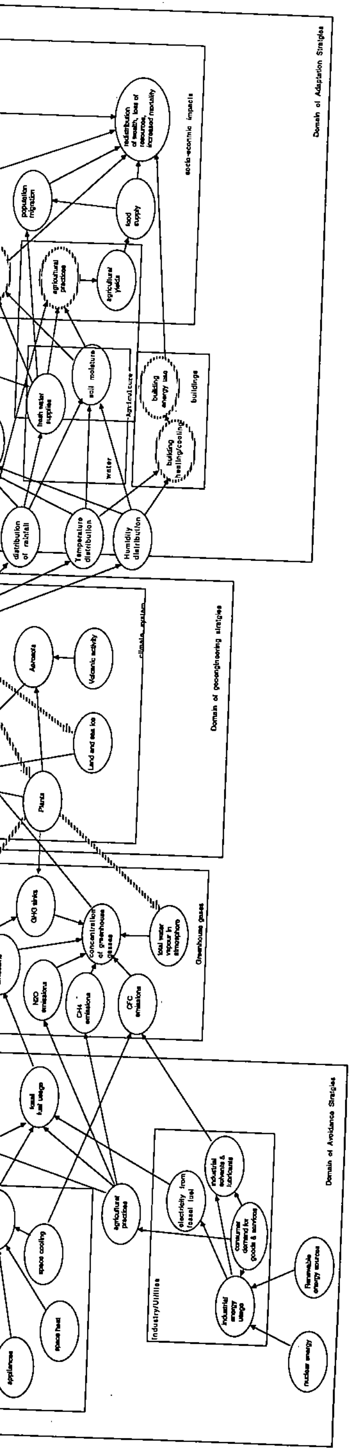

Figure 3.11. Simplified influence diagram of climate change, developed and used in mental models studies.

References

Bostrom, A., Atman, C. J., Fischoff, B., and Morgan, M. G. (1994). "Evaluating Risk Communications: Completing and Correcting Mental Models of Hazardous Processes, Part 2, *Risk Analysis,* 14:789–798.

Bostrom, A., Fischhoff, B., and Morgan, M. G. (1992). "Characterizing Mental Models of Hazardous Processes: A Methodology and an Application to Radon," *Journal of Social Issues,* 48(4):85–100.

Casman, E. A., Fischhoff, B., Palmgren, C., Small, M. J., and Wu, F. (2000). "An Integrated Risk Model of a Drinking-Water-Borne Cryptosporidiosis Outbreak." *Risk Analysis,* 20:495–511.

Clemen, R. T. (1991). *Making Hard Decisions: An Introduction to Decision Analysis,* 2nd ed. PWS-Kent Publishing, Boston, Mass.

Earle, T. C., and Cvetkovich, G. (1983). *Risk Judgment and the Communication of Hazard Information: Toward a New Look in the Study of Risk Perception.* Battelle Human Affairs Research Center, Seattle, Wash.

Fischhoff, B., and Downs, J. (1997). "Accentuate the Relevant," *Psychological Science,* 8(3):1–5.

Fischhoff, B., Downs, J., and Bruine de Bruin, W. (1998). "Adolescent Vulnerability: A Framework for Behavioral Interventions," *Applied and Preventive Psychology,* 7:77–94.

Fischhoff, B., Riley, D., Kovacs, D., and Small, M. (1998). "What Information Belongs in a Warning? A Mental Models Approach," *Psychology and Marketing,* 15(7):663–686.

Hohenemser, C., Kasperson, R. E., and Kates, R. W. (1985). "Causal Structure," in R. W. Kates, C. Hohenemser, and J. X. Kasperson, eds., *Perilous Progress.* Westview Press, Boulder, Colo., pp. 25–42.

Hohenemser, C., Kates, R. W., and Slovic, P. (1983). "The Nature of Technological Hazard," *Science,* 220:378–384.

Howard, R. A., and Matheson, J. (1981). "Influence Diagrams," in *The Principles and Applications of Decision Analysis,* Vol. II. Strategic Decisions Group, Menlo Park, Calif.

Kammen, D., and Hassenzahl, D. (1999). *Shall We Risk It?* Princeton University Press, Princeton, N.J.

Maharik, M. (1992). "Public Perception of the Risks of an Unfamiliar Technology: The Case of Using Nuclear Energy Sources for Space Missions." Ph.D. dissertation, Department of Engineering and Public Policy, Carnegie Mellon University.

Maharik, M., and Fischhoff, B. (1992). "The Risks of Nuclear Energy Sources in Space: Some Activists' Perceptions," *Risk Analysis,* 12:383–392.

Maharik, M., Fischhoff, B., and Morgan, M. G. (1993). "Risk Knowledge and Risk Attitudes Regarding Nuclear Energy Sources in Space," *Risk Analysis,* 13:345–353.

Miller, A. C., Merkhofer, M. W., Howard, R. A., Matheson, J. E., and Rice, T. R. (1976). *Development of Automated Aids for Decision Analysis.* Stanford Research Institute, Menlo Park, Calif.

Morgan, M. G. (1981). "Probing the Question of Technological Risk" and "Choosing and Managing Technology-Induced Risk," *IEEE Spectrum,* 18(11):58–64 and 18(12):53–60.

(1993). "Risk Analysis and Management," *Scientific American,* (July):32–41.

Morgan, M. G., and Dowlatabadi, H. (1996). "Learning from Integrated Assessment of Climate Change," *Climatic Change,* 34:337–368.

Morgan, M. G., and Henrion, M., with a chapter by Small, M. (1990). *Uncertainty: A Guide to Dealing with Uncertainty in Quantitative Risk and Policy Analysis.* Cambridge University Press, New York.

Morgan, M. G., and McMichael, F. M. (1981). "A Characterization and Critical Discussion of Models and Their Use in Environmental Policy," *Policy Sciences,* 14:345–370.

Read, D., Bostrom, A., Morgan, M. G., Fischhoff, B., and Smuts, T. (1994). "What Do People Know about Global Climate Change? Part 2. Survey Studies of Educated Laypeople," *Risk Analysis,* 14:971–982.

Rubin, E. S., Small, M. J., Bloyd, C. N., and Henrion, M. (1992). "Integrated Assessment of Acid Deposition Effects on Lake Acidification," *Journal of Environmental Engineering,* 118(1):120–134.

Shachter, R. D. (1988). "Probabilistic Inference and Influence Diagrams," *Operations Research,* 36(4):589–604.

Risk Communication

A Mental Models Approach

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