Oceans Risk and Criteria Analysis

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Given scarce resources and a continuing emphasis on a business approach, the Canadian Coast Guard (CCG) is striving to better allocate resources among waterways, programs, and users in order to achieve the best possible level of marine safety. In this regard, the CCG has used, and is continuing to use, risk analysis and risk management tools on a project and program basis. However, to better match resources to risk (both geographically and by program) the CCG still would like an estimate of overall marine risk by program and waterway.

Technically, such an estimate of risk would be given by the expected annual dollar losses by geographic area for all those hazards and associated impacts addressed by CCG programs (the annual dollar value of marine fatalities and injuries, environmental damages, clean-up effort, vessel damages and losses, cargo losses, fishery impacts, and so forth, given that no CCG services existed). Knowing the expected dollar losses by geographic area and hazard type, the CCG could then attempt to allocate available resources to each geographic area and program in a way that would optimize the reduction of these losses (i.e., maximize risk-reduction results).

Although the above risk-based approach is theoretically the method of choice, many practical problems exist. To derive a geographic distribution of expected dollar losses requires a multitude of activity, probability, and value estimates for vessels, cargoes, human life, birds, mammals, and so forth. Furthermore, the past and current risk-reduction effectiveness of every existing program is needed if residual or observed risk is to be blown up into total annual risk.

If applying values to life, birds, mammals, ecosystems, and so forth is too problematic, counting expected physical losses is the next desirable level of analysis. Even here, however, the analysis is time-consuming and not without controversy (e.g., each program's historical risk-reduction effectiveness still must be estimated in order to convert observed physical losses into total estimated losses). The CCG and Consulting and Audit Canada (CAC) have conducted a number of traditional risk-based analyses on a project and program basis in the past [e.g., the Confederation Bridge Risk Analysis, the Port of Hong Kong Risk Study, and various Vessel Traffic Services (VTS) Risk Studies across Canada]. However, these types of studies are relatively expensive and take considerable time to complete.

The next level of analysis involves creating an index from those factors or criteria that the marine community now uses, both explicitly and implicitly, to rank risk and to allocate resources across waterways and by program [the explicit form of this approach, called *Multi-Criteria Decision Analysis (MCDA)*, is commonly used to order complex requests for proposals, alternative policies, options, and strategies]. CAC created a display and risk index computer system with about 150 columns of risk-related data covering 100+ waterways/ports. The data were subdivided into four categories:

- Frequency (e.g., number of cargo vessel movements, number of ferry movements);
- Impact (e.g., metric tons of petroleum transported, number of passenger trips);
- Modifiers (e.g., visibility, windspeed); and
- History (e.g., vessel collisions, loss of life).

The computer system (called ORCA—Oceans Risk and Criteria Analysis) allows a user to automatically display data in bar chart, map, or scattergram format and to weigh and combine criteria data in a risk index. Data can be modified to conduct "what if" analyses. Study area risk index values for a given safety program can be compared with study area expenditures or other activity measures for the program and potential anomalies can be identified. However, detailed analysis of any apparent anomalies is necessary before any resources can be reallocated. Furthermore, a minimum level of waterway service may be required for some programs regardless of the measured level of a program risk index. Finally, it should be noted that considerable resources must be dedicated to ensuring that risk criteria data are kept up-to-date and that costs are properly allocated to programs and waterways.

Examples of ORCA displays are presented in Figures 1 through 6.

Demonstration Risk Index for VTS and Other Programs

Oil spills and the threat of oil spills were the major impetus for creation of Canadian VTS systems starting in the 1960s. Today, 12 high-level VTS centers are in operation covering 14 distinct zones [Vancouver, Tofino, Prince Rupert, Sarnia, Montreal, Quebec, Les Escoumins, Saint John (with remote coverage of Northumberland Strait), Halifax (with remote coverage of Canso), Placentia Bay, Port-aux-Basques, and St. John's]. The following VTS index was developed in an effort to reflect, as much as possible, the current distribution of VTS centers:

$$\text{VTS Index} = \Big\{0.9 \times (D8 \times 0.6 + E8 \times 0.1 + F8 \times 0.3) + 0.1 \times \Big[(I8 + J8) + (G8 + H8 + K8 + L8 + Q8)^{1/2} + (M8 + N8 + O8 + P8 + R8)^{1/3}\Big]\Big\} \times \text{if}\Big[S8/2 + T8/2) < 1, 1, (S8/2 + T8/2)^{1/2}\Big] \times U8 \times V8$$

where

D = metric tons of petroleum cargo arriving, departing, and transiting;

E = metric tons of chemical cargo arriving, departing, and transiting;

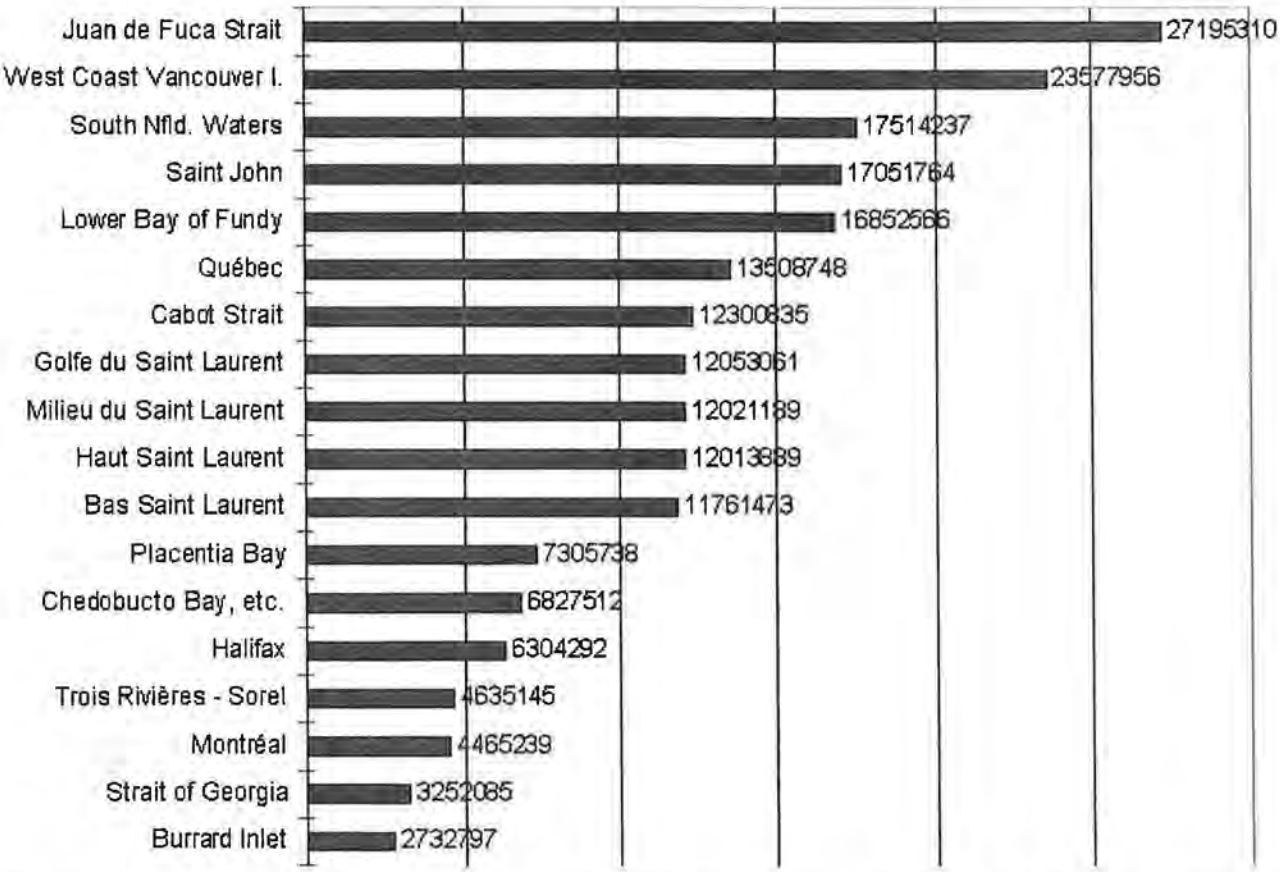

FIGURE 1 Metric tons of petroleum transported by vessel in 1996 (Source: Statistics Canada and U.S. Waterborne Commerce).

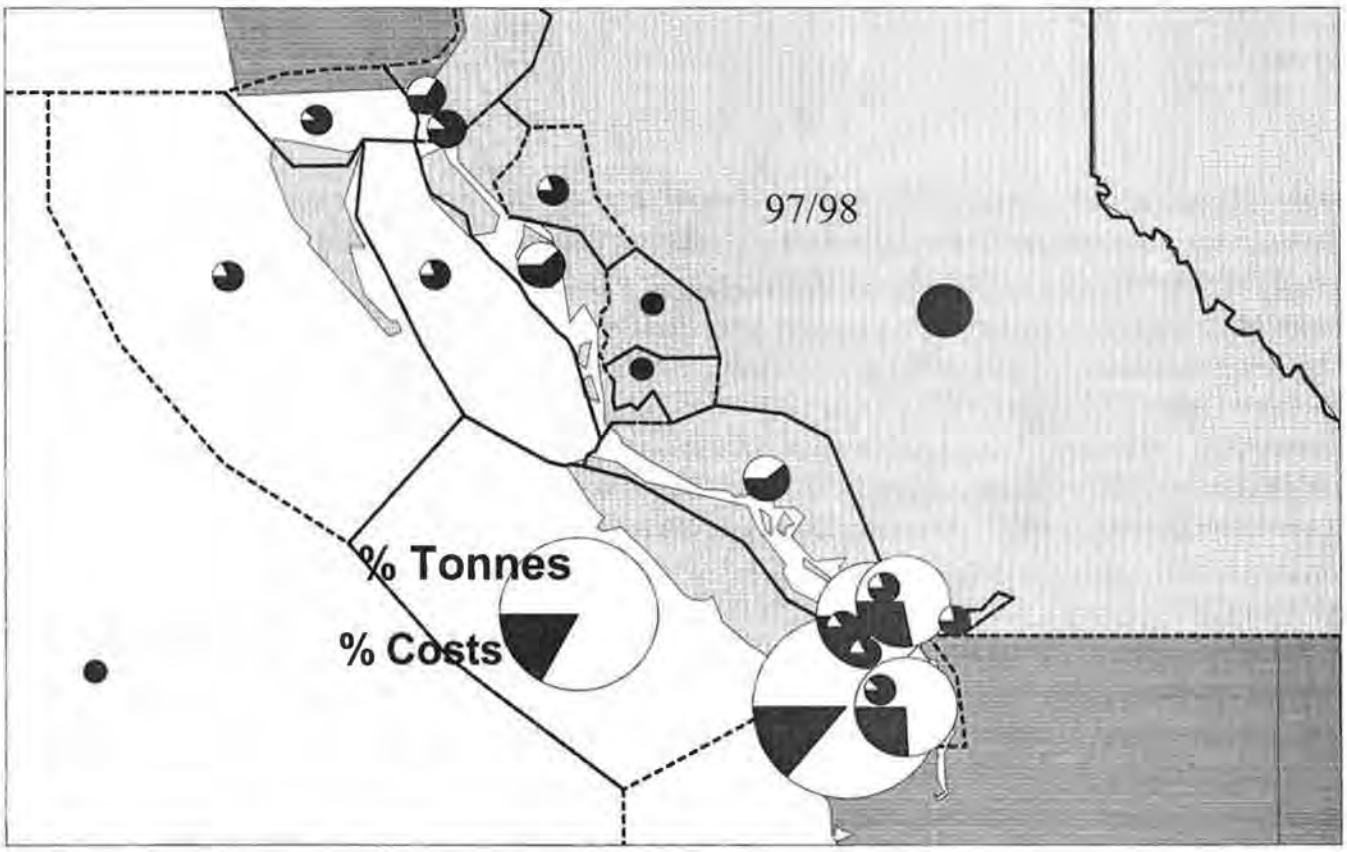

FIGURE 2 Total polluting cargoes versus rescue safety and environmental response costs (example only).

F = metric tons of onboard bunker fuel arriving, departing, and transiting;
G = crews arriving/departing on tugs and tows;
H = crews transiting on tugs and tows;
I = crews arriving/departing on tankers, lakers, and other cargo vessels;
J = crews transiting on tankers, lakers, and other cargo vessels;
K = crews arriving/departing on cruise and passenger vessels;
L = crews transiting on cruise and passenger vessels;
M = crews arriving/departing on large ferries;
N = crews transiting on large ferries;
O = crews arriving/departing on small ferries;
P = crews transiting on small ferries;
Q = passengers arriving/departing/transiting on cruise and passenger vessels;
R = passengers arriving/departing/transiting on all ferries;
S = percent of time in January visibility <0.5 nautical mile (NM);
T = percent of time in July visibility <0.5 NM;
U = waterway type measure; and
V = traffic pattern measure.

In keeping with the main risk-reduction goals of VTS, the index can be interpreted as follows:

- First, add the tonnage of petroleum cargoes, chemicals, and bunker fuels, weighted by 0.9 (a 90/10 split between polluting cargoes and people is assumed based on the apparent historical reasons for establishing VTS systems).
- Then, add the number of passengers and crew onboard, weighted by 0.1^2. Cargo vessel crews are added directly but the impact of crews and passengers on other vessel types is reduced to reflect the apparent historical consideration given these vessel types when considering the need for VTS (i.e., by taking the square root for tugs, cruise ships, and passenger vessels, and the cube root for ferries). These vessel types appear to have been considered less in need of VTS.
- Next, the above base VTS index is multiplied by
  - The square root of January and July mean visibility conditions minus percent of time visibility is less than 0.5 nautical mile [the square root is used to reduce the effects of very high measures relative to low values; mathematically, a measure of 36 percent is 36 times as large as a measure of 1 percent, but, in

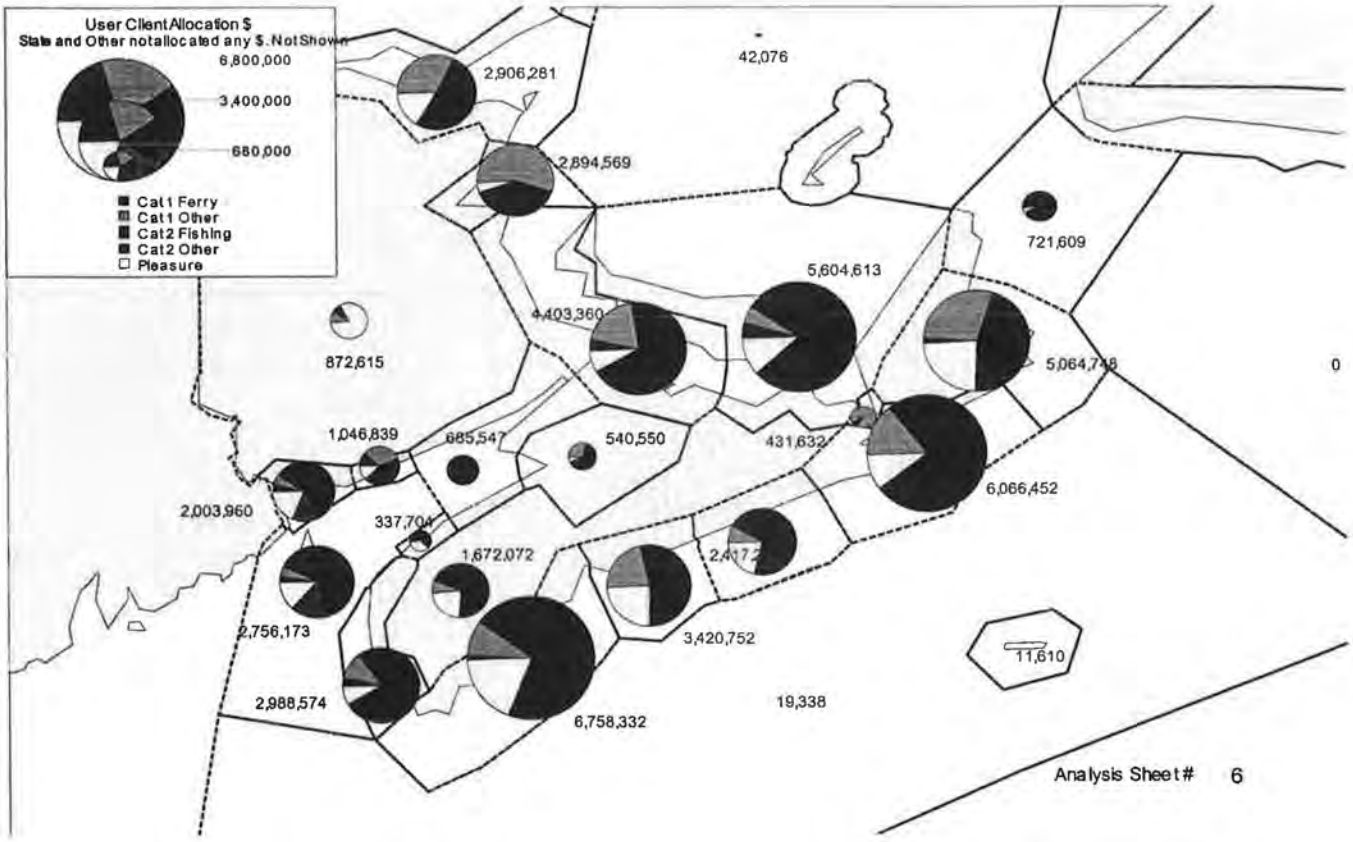

FIGURE 3 Short-range navigation aids: cost by client group (example only).

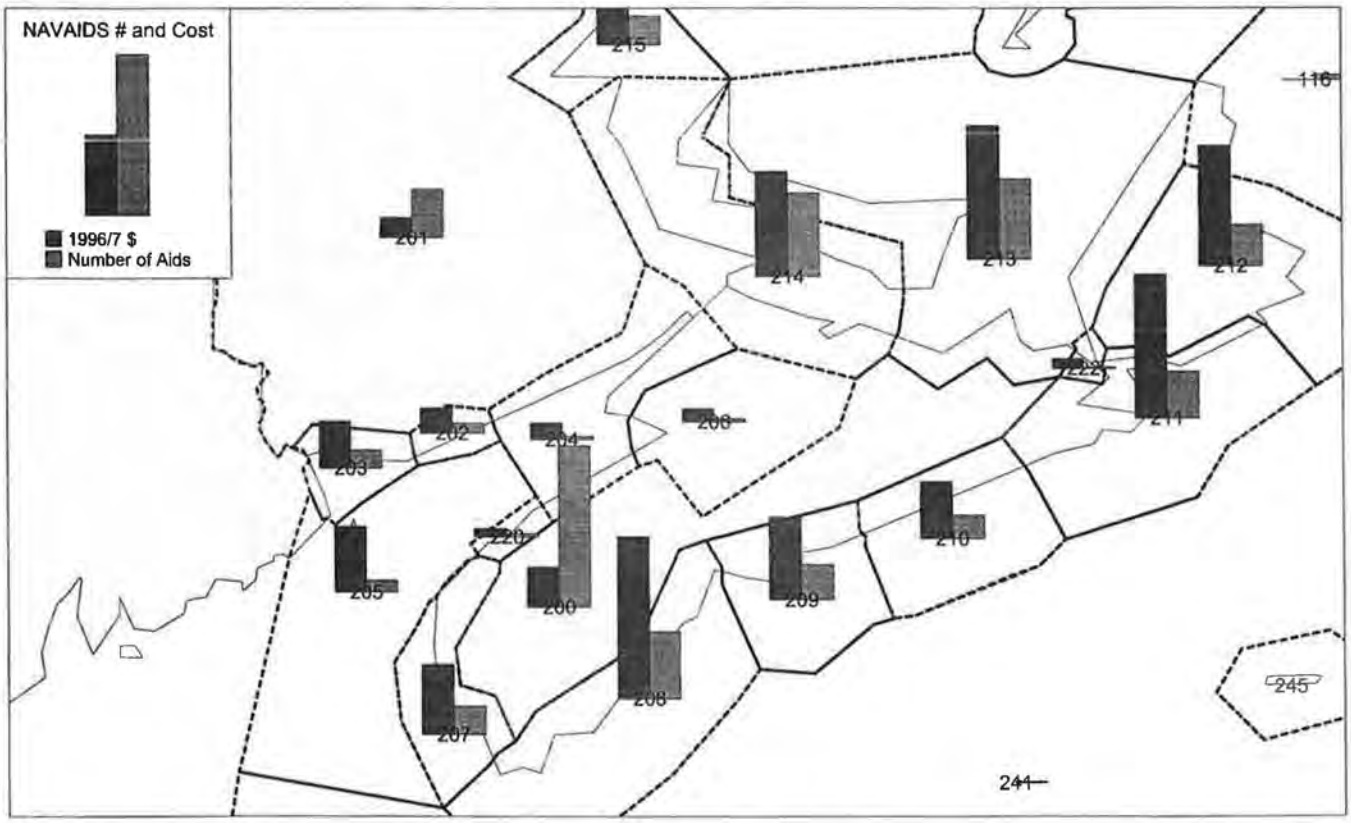

FIGURE 4 Short-range navigation aids: total cost versus number (example only).

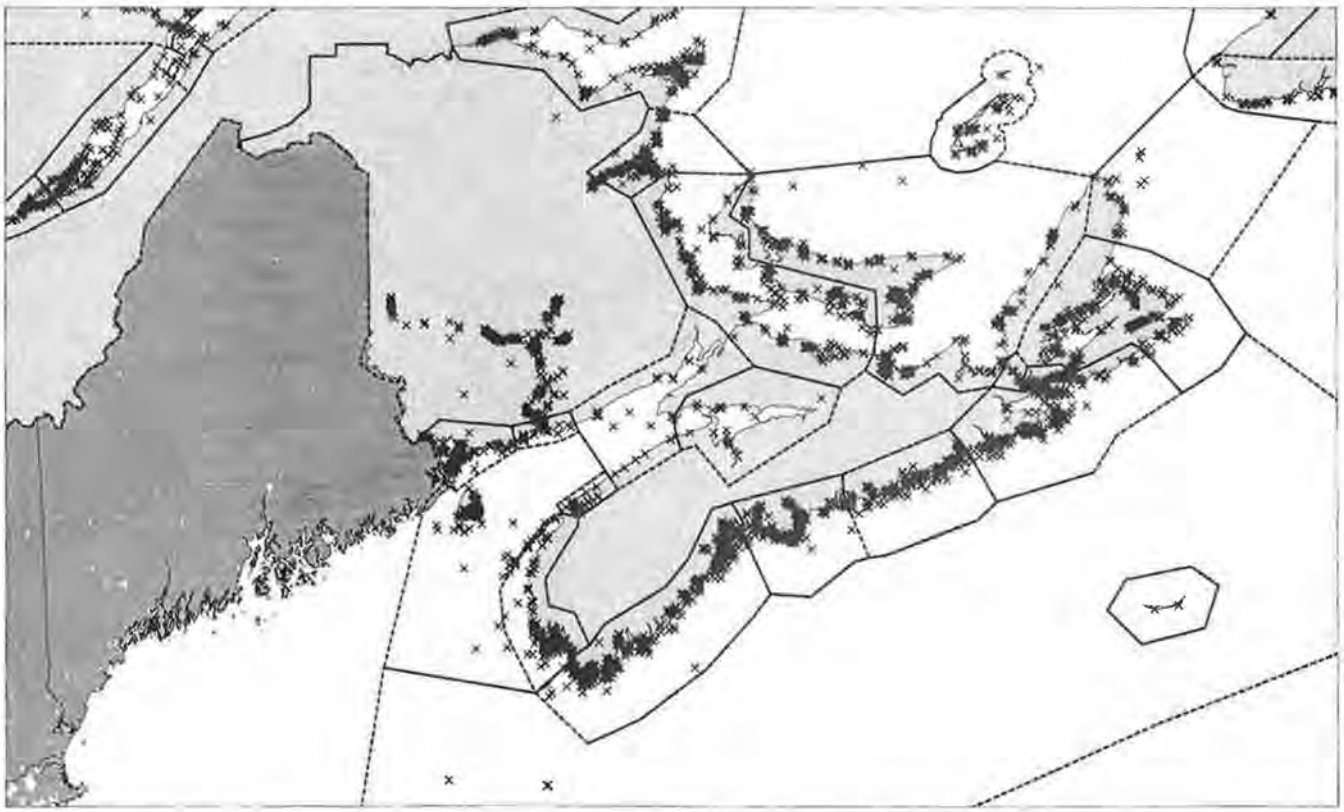

FIGURE 5 Location of CCG navigation aids (as of November 1998).

terms of risk, it is not likely 36 times as dangerous to the mariner—taking the square root reduces a measure of 36 percent to only 6 times as dangerous as a measure of 1 percent (values less than 1 percent were set to 1)];

– Our assigned measure for waterway type (where confined waters receive a higher, or riskier, value than open waters); and

– Our traffic pattern measure (where areas with complex vessel movement patterns receive a higher value than areas with simple patterns).

StatCan records for 1997 show about 8 million metric tons of petroleum movements for Placentia Bay. However, the new transhipment depot at Whiffen Head near the Come-by-Chance refinery in Placentia Bay started receiving offshore crude oil in 1998 and could handle over 30 million metric tons annually in 3 or 4 years. Next year, Placentia Bay is expected to record 15 million metric tons (combining Come-by-Chance and Whiffen Head). Thus, we assumed 15 million metric tons for Placentia Bay in this VTS risk index analysis.

Figure 7 presents the resulting VTS index on a map of Canada. The top 20 study areas account for 80 percent of the risk as measured by the index. Ten of the current 12 VTS centers include at least one of these areas in their zone. Figure 8 presents a demonstration index for search and rescue (SAR).

Other Risk Management Issues

Individual Versus Societal Risk

One must be clear about the kind of risk that is being addressed/ranked. A risk-based approach almost always looks at total or societal risk (e.g., the expected mean cost of all casualty impacts in a waterway during a 12-month period). Individual risk, on the other hand, addresses the particular losses experienced by a particular entity, person, group, region, and so forth—for example, the expected loss from one vessel transit through a specific waterway or the expected losses for a single ship during a given year (this is the risk that an insurance company would cover). Most recent government initiatives relate to an attempt to minimize societal risk. However, while theoretically producing the greatest overall good for society, the implementation of societal risk-reduction initiatives often conflicts with the equitable delivery of individual risk-reduction services.

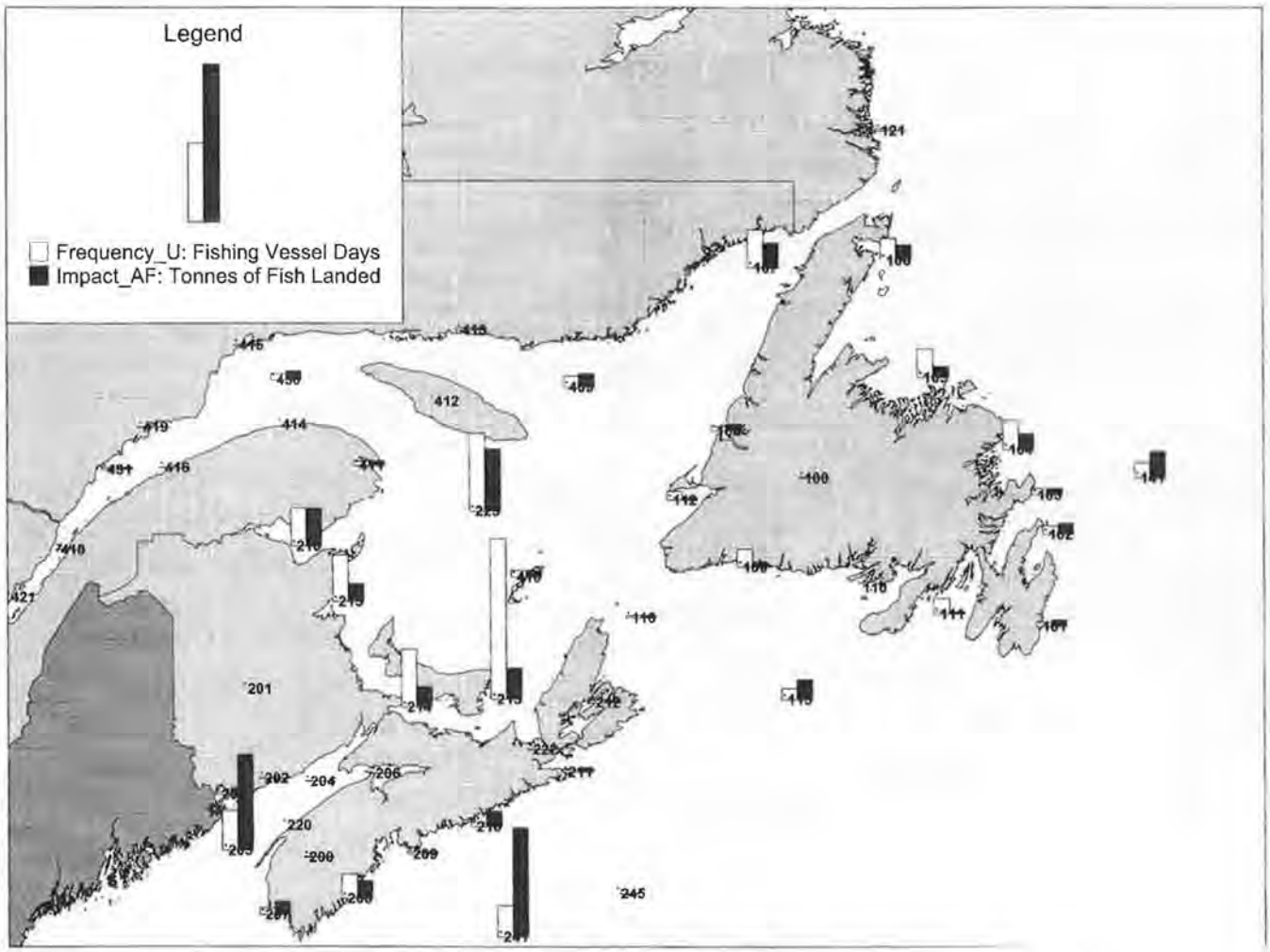

FIGURE 6 Fishing vessel days versus metric tons of fish landed (Source: F&O Canada Data, 1995 and 1996).

Level of Service

If, as the optimization of societal risk implies, one invests only in those areas that produce the greatest risk-reduction benefits for the resources available, how does one justify the cutoff point to individuals who fall below the line. For example, the greatest societal good might be gained from investing only in heavily trafficked waterways and doing nothing in the remaining ones. However, individuals across the country will receive significantly different safety services and benefits, which often is not acceptable. Consequently, most public services, including health care, postal services, and so forth, attempt to provide a minimum level of access (although not necessarily a similar minimum level of service). For example, SAR in Newfoundland is available to anyone in distress, as it is in the Great Lakes. However, it may take several hours to reach an incident off Newfoundland compared with only a few minutes in the Great Lakes.

In the past, most public safety or risk-reduction services have attempted to allocate resources so that a minimum level of accessibility is available to each individual across the country. Only recently have we attempted to maximize societal risk with any real resolve. However, this strategy can conflict directly with the goal of providing equitable risk-reduction services to all individuals if taken to its logical conclusion where only those individuals above the cutoff point receive services. Not surprisingly then, compromises between individual and societal risk have been and continue to be made.

Risk Perception

Human activity is not, and cannot be, risk-free. Nevertheless, there is no generally acceptable minimum level of risk or risk-reduction service level for any human activity. People accept risk because of the benefits the

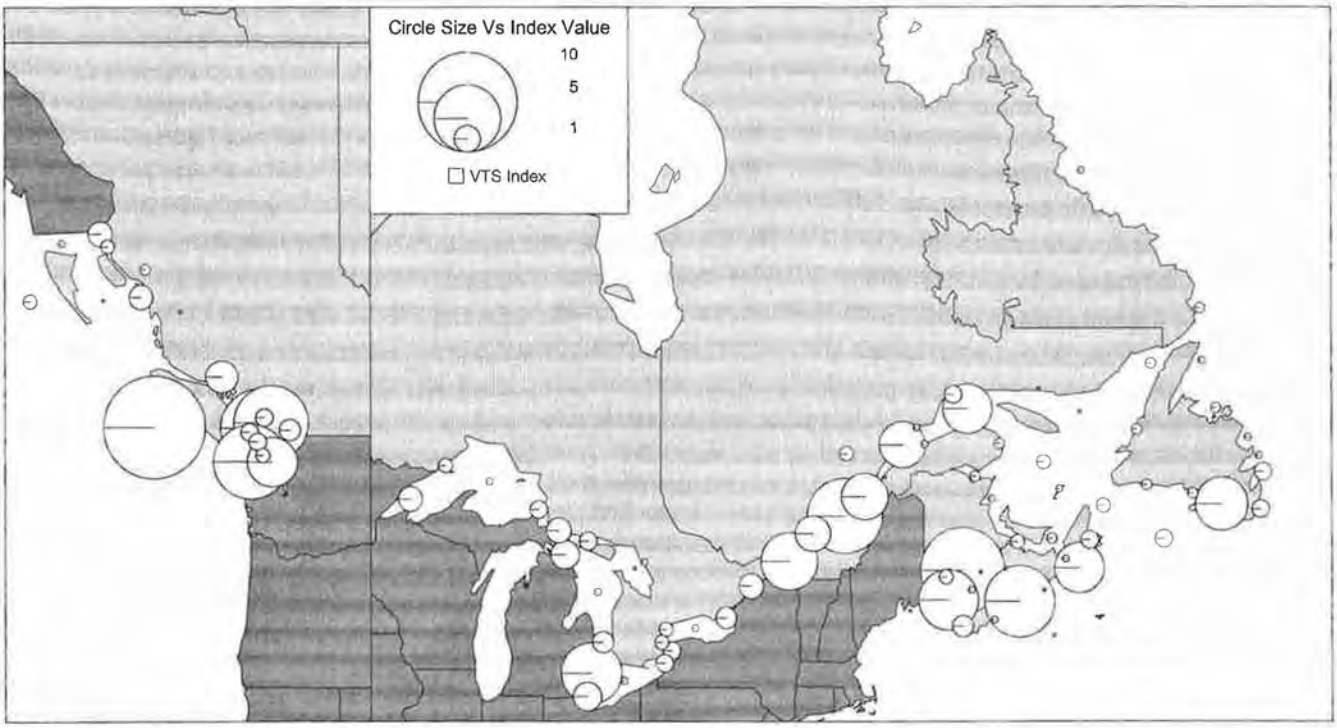

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FIGURE 7 VTS risk index (example only).

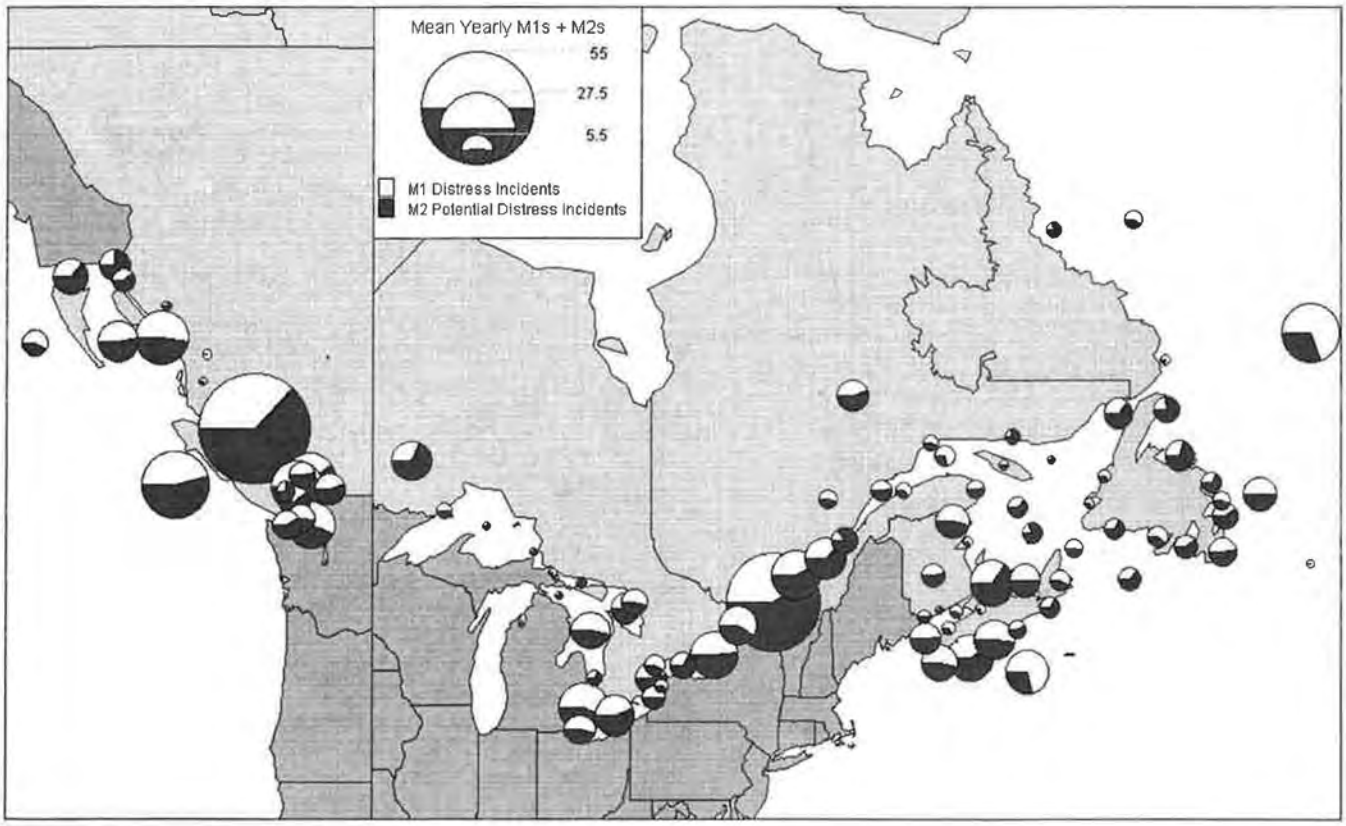

FIGURE 8 Risk Index 2 for search and rescue and distress safety.

risk-producing activity generates. Reducing risk in one area usually means that another area receives less resources for risk-reduction efforts. Furthermore, society has never demanded the same level of risk (i.e., safety) for all activities (Fischhoff et al., 1978).

Experimental psychologists have shown that society ranks risk consequences according to four basic factors (Slovic, 1987):

- Is the risk understood—dying from heart disease is more acceptable than dying from some unknown problem caused by bioengineering;
- Is the risk controllable—people generally accept a much higher level of risk when they are driving their own automobile than when they put their life in the hands of someone else (e.g., airline pilot, vessel master);
- Is the risk potentially catastrophic—most people have more fear of a death that involves large numbers of victims (e.g., a large ferry sinking) than of a fatality related to a small accident (e.g., pleasure boat sinking); and
- Is the risk dreaded—death from radioactive fallout, fires, explosions, and drownings is feared much more than death from natural causes (e.g., stroke).

The public also believes that some hazards occur very frequently even though they are actually quite rare (Fischhoff et al., 1993). For example, botulism, airplane crashes, tanker spills, ferry accidents, and violent crime are often considered to be more common than automobile accidents or strokes because every instance of the former is published in the press, whereas the latter are rarely mentioned.

Accident Cause and Risk Reduction

High breaking waves, strong winds, fog, or busy channels that increase vessel risk can rarely be modified directly. However, the factors that put a vessel in a vulnerable position often can be addressed so that the frequency of future accidents is reduced (e.g., not sailing under such conditions, installing marine aids or VTS, and so forth). Furthermore, the consequences of accidents that do occur can also be addressed so that they are mitigated or made less serious (e.g., wearing life jackets often prevents persons involved in a capsizing accident from drowning before rescue takes place, establishing pollution response centers can sometimes reduce the quantity and spread of spilled oil, and so forth).

Whereas proposed risk-reduction solutions address either accident frequency or accident consequence, solutions themselves can also be categorized as passive or active. Passive solutions include things such as design improvements (e.g., better flotation or a higher free board requirement in a construction standard, double hulls for tankers). Active solutions would encompass ongoing programs such as operator training, licensing, and inspection of vessels.

Compliance is another aspect that must be considered when solutions to reduce risk are being proposed. Again, compliance strategies are often classified as proactive or reactive. Education and publicity that identify a new standard or requirement are considered a proactive compliance strategy, whereas fines or withdrawing licenses are considered reactive.

There is one other consideration that society makes, albeit subconsciously, when demanding or supporting safety improvements. There is often more willingness to spend resources to reduce actual risk than to prevent statistical risk. For example, actual lives can be personally identified—those people rescued from the water after a boat capsizes. Statistical lives involve persons who were prevented from drowning and can never be identified personally—those who did not drown because of the placement of navigation aids. The same applies to oil spills—society appears to be more willing to spend money on cleaning up an actual spill after they see it on television than on preventing statistical occurrences that could happen in the future (through more funding of preventative programs). Of course, preventative strategies usually cost less in the long run.

Conclusion

With a fully supported ORCA system, coast guards and other marine organizations should be able to realize savings while ensuring high levels of safety. ORCA allows easy accessibility to data that managers need for making informed decisions. ORCA promotes a culture of openness in data management and allows all levels of an organization to benefit from the work of others.

References

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Fischhoff, B., A. Bostrom, and M. J. Quadrel. Risk Perception and Communication. *Annual Review of Public Health*, Vol. 14, 1993, pp. 183–203.

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