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IR^3 FEATURE ARTICLES

Editorial Corner

Dr. Robyn Fiori

About the Editor

Dr. Robyn Fiori is a research scientist for the Canadian Hazards Information Service of Natural Resources Canada specializing in space weather. Her research is applied to the development and improvement of space weather tools and forecasts to be used by operators of critical infrastructures and technologies in Canada. Dr. Fiori's research has been published in numerous peer reviewed scientific journals, including the Journal of Geophysical Research, the Journal of Atmospheric and Solar-Terrestrial Physics, and Space Weather. Dr. Fiori received her B.Sc., M.Sc., and Ph.D., from the University of Saskatchewan, Department of Physics and Engineering Physics while studying in the Institute of Space and Atmospheric Studies. She can be reached at robyn.fiori@canada.ca.

This Issue

Issue 11 of IR^3 spans a wide variety of topics including nuclear power, marine shipping, space situational awareness, and infrastructure resilience.

Nuclear power plays an important role in Canada's power grid. **John Gorman**, President and CEO of the Canadian Nuclear Association, describes the development of small modular reactors (SMRs) in Canada. SMRs replicate large-scale reactors for small-scale deployments. The improved resilience, robustness, and flexibility of these systems offer green power solutions for a wide variety of locations.

Shipping is a crucial link in the global supply chain. **Bud Streeter** provides an in-depth assessment of potential risks associated with marine shipping and discusses considerations and strategies necessary for their management.

Infrastructure resilience is a critical topic in today's technology and infrastructure dependent economy. **Graeme Maag** describes the role GlobVision plays in infrastructure resilience with specific attention given to risk assessment to space assets, and safety management and health monitoring of hydro-electric dams and bridges.

The issue closes with an article entitled *Design Basis Threat and the Low Threat Environment* by **Rob Siefken**, **Jake Burns** and **Ross Johnson** who discuss techniques for the strengthening of a physical protection system so that high level threats can be swiftly dealt with, even if the current threat level is low, or if an unexpected threat becomes apparent.

Next Issue

We invite authors to contribute additional articles for Issue 12 relating to their experience in the field of infrastructure resilience. Draft articles of 2500-4000 words are requested by December 18, 2020. You may not have much time or experience in writing 'academic' articles, but IR^3's editorial board can provide guidance and help. Your experience is valuable and IR^3 provides an ideal environment for sharing it.

Can Small Modular Reactors Support Grid Resilience?

*John Gorman**
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Nuclear power has long been a part of Canada's power grid providing reliable and inexpensive power for decades. However, recent years have seen increasing pressure to reduce carbon emissions across the economy, while ensuring cost-effective and reliable power, as well as a demand for better access to larger sources of clean power in remote locations. These factors have driven the desire to replicate the success of large reactors on a scale suitable for deployment in areas with smaller energy demands. That change has been long in coming – but industry, government, and the public are now ready for it.

On December 1, 2019, the premiers of Saskatchewan, Ontario, and New Brunswick agreed to advance the development and deployment of small modular reactors (SMRs) to address climate change, regional energy demands, and economic development.

SMRs aren't just smaller than conventional power reactors; new designs also incorporate advanced safety and security features that could bolster the resilience of our power grids. The designs now being advanced are varied, and choosing wisely among these designs could have long-term effects on the future of nuclear power, the greening of our economy, and the reliability of Canada's electricity supply. Canada, with its extensive experience of nuclear technology, vast and varied geography, and with the second-largest reserves of uranium, is well placed to become a global leader in this field, with a global market estimated at $150 billion between 2025 and 2040.

I. An SMR Primer

All of Canada's 19 CANDU reactors are large, ranging from 660 to 900 megawatts of electricity each.

Large reactors are custom-built: their construction takes years, and the reactors stay put, generating electricity steadily for decades – which is ideal for providing inexpensive and clean baseload power. However, large reactors can't be moved around to accommodate changing needs. They are also too big for many communities and industrial operations across Canada.

Enter the small modular reactor. As its name implies, the SMR is small, topping out at 300 megawatts, which is enough to power a small city. Most unit designs would fit in a school gymnasium, and the reactor itself can be transported from factory to operating site on vehicles such as transport trucks. This means the reactor need not be manufactured onsite.

This leads to the second main feature of SMRs: they are modular which means that they can be mass-produced. This can save costs because manufacturing equipment and expertise does not have to be moved to the remote sites where some SMRs may provide the most benefit.

Small power reactors aren't new. The idea dates back to the 1940s[1], when the U.S. Air Force tried (and failed) to design small reactors to power long-range bombers. The U.S. Army managed to design and deploy eight small reactors to remote military sites, but ran into issues, such as malfunctions and leaks,

[1] See https://spectrum.ieee.org/tech-history/heroic-failures/the-forgotten-history-of-small-nuclear-reactors

and the Army could easily replace them with diesel generators. The U.S. Navy commissioned the first submarine powered by a nuclear reactor: the USS *Nautilus* launched in 1955 with a 10-megawatt engine, vastly increasing the range of submarines between refuelling, and changing the dynamics of the Cold War. The submarines' reactors were able to change their outputs to provide bursts of acceleration. This is not a standard feature of large power reactors, but it would be important to later SMR designs.

The earliest civilian small power reactors were also proposed in 1955, with performance ranging from the meltdown of the Fermi-1 reactor in 1966 to the 31-year operation of the Yankee reactor. Demand from small utilities prompted the commissioning of more small reactors, including one in Elk River, Minnesota. With its prefabricated parts and ability to fit on a rail car, this 22-megawatt reactor is considered the first SMR. However, it had a short lifespan, and several of that generation of small reactors suffered from other flaws, such as high costs.

The U.S. stopped commissioning civilian small reactors in 1968: engineers realized that with the technology available at the time, better designs and lower costs could be achieved through scale. Reactor sizes in the US and around the world have been growing since.

Though Canada has never had an SMR, its experience with small reactors goes back decades, beginning with the Zero Energy Experimental Pile (ZEEP) in Chalk River, Ontario, in 1945, which was one of the first reactors in the world to use natural uranium and heavy water – staples of Canada's reactors today. ZEEP was used for research purposes, as was its successor, the 10-megawatt National Research Experimental Reactor (NRX) in 1947. The National Research Universal (NRU) reactor was launched ten years later; NRU performed admirably until 2016, having generated large proportions of the world supply of isotopes needed for medical imaging and cancer treatment.

These reactors were not intended to generate power for the grid, but they helped to build Canadian expertise in nuclear technology, which in turn contributed to Canada's signature reactor design, CANDU (Canada Deuterium Uranium). This began in 1962 with a 22-megawatt prototype in Rolphton, Ontario, then the 200-megawatt commercial prototype at Douglas Point, Ontario, in 1968, followed by the first full-scale reactors at Pickering in 1971.

II. Resilience From Canada's Existing Nuclear Power

Since then, there has been little public appetite for tinkering with a design that worked well. Nuclear power has expanded in Canada, with the opening of the Darlington and Bruce power plants in Ontario, the Point Lepreau plant in New Brunswick, and Quebec's Gentilly plant (shut down in 2012; the others are all still operating). While the history of these plants could fill another article, the theme is that they supplied reliable baseload power for decades. Presently, they supply about 60% of Ontario's electricity and 36% of New Brunswick's.

In particular, these reactors have supported the resilience of Ontario's power grid in several ways:

- **Transition from coal –** By the late 1990s, links between adverse health effects and air pollution were firmly established, and Ontario could trace much of this to its coal-powered plants. In 2003, the province began to replace coal with nuclear energy, completing the switchover in 2014. Over that time, air quality improved significantly, reducing respiratory illnesses and deaths. However, even with the conservation measures set out in the province's 2007 Integrated Power System Plan, Ontario would have to supply electricity to make up for the closures of the coal-fired plants. As renewables were prohibitively expensive and variable, and the province was already near its hydroelectric capacity, it fell to the province's 18 nuclear power reactors to pick up the slack. Ontario modernized three reactors (Pickering A, Unit 1; and Bruce, Units 3 and 4) and returned them to service. Nuclear power, which made up 37% of

Ontario's power mix in 2000, stood at 62% in 2014. Correspondingly, premature deaths in Toronto attributed to air pollution dropped from 1,700 to 1,300 between 2004 and 2014, while hospitalizations fell from 6,000 to 3,550.

- **2003 blackout –** On August 14, 2003, a software bug in an Ohio-based energy company caused load-balancing to fail, expanding a local blackout into a catastrophic one, affecting 10 million people in Ontario and the United States. During this time, three of the reactors at the Bruce Nuclear Generating Station remained in operation at 60% reactor power and 0% grid electrical power as the reactors were designed to be able to decouple from the grid. They were reconnected five hours later.

- **Smart metering –** Nuclear power is one of the factors that made Ontario's Smart Metering Initiative, launched in 2004, possible. Smart meters allow for differential pricing by time of day, which can help residents regulate their own electricity consumption. Without the reliable and economical baseload power that nuclear plants provide, utilities have no economic incentive for charging different rates at different times of the day or night. Though the Auditor General of Ontario found in 2013 that smart metering had failed to reduce peak demand, her report[2] also noted that "Smart meters are the base infrastructure for developing a smart grid, which is the application of information and communications technology to improve the functioning of the electricity system and optimize the use of natural resources to provide electricity."

III. The Advent of SMRs

The high reliability of Canada's nuclear fleet meant that it didn't reach the news very often – which masked the research underway globally on designs that could further improve the performance, safety, and scalability of the plants. Improved scalability will allow SMRs to be matched to demand over a much broader power range than is possible with large reactors. Some are smaller, simpler versions of current reactor designs, while others incorporate fundamentally new features, such as using molten salt as a moderator or thorium as a fuel. These fuels are making SMRs practical.

Around the world, SMR designs are, for the most part, still conceptual. However, it would be a mistake to think of SMRs as simply a scaling down of the designs of existing reactors, which should continue to be built, especially because they provide the cheap electricity needed to green our economy. Rather, SMRs can expand the nuclear contribution to the grid by moving into areas where large reactors are not practical or economical:

- **Growing grids** – Not every grid is as big as Ontario's. As other provinces and territories phase out coal, SMRs can fill the gap, producing similar amounts of power without the carbon emissions and other pollution. The steady supply of nuclear power does not have to rely on fossil-fuel backups. Even the two provinces that now have nuclear power could use SMRs to add power incrementally, without the huge up-front costs of large plants.

- **Small-grids –** Most remote communities in Canada use fossil fuels to generate electricity, especially if it's not economical to build hundreds of kilometers of power lines to connect to the grid. As about 1 megawatt can power about 750 homes, an SMR could easily power a small city.

[2] See: http://www.auditor.on.ca/en/content/annualreports/arreports/en14/311en14.pdf.

- **Heavy industry** – Oil sands and mines are a big part of Canada's economy, but they are often remote and off-grid, and they need a lot of heat and power to operate.

IV. SMRs and Resilience

SMRs alone cannot resolve all of Canada's resilience issues, but they can provide a source of robust and resilient energy, as well as more quickly deployable energy sources to be used in recovery. Furthermore, SMRs offer significant reductions in carbon emissions, which will ultimately reduce the severity of climate challenges.

Several other advantages of SMRs could support resilience.

Islanding and Microgrids

One benefit is islanding: the ability to run part of the grid independently. As it is not possible to know in advance where a power grid might fail, or where a disaster might strike, islanding provides the benefit of being isolated from a cascading problem elsewhere on the grid. This has led to a recent surge of interest in the "microgrid", which demonstrated its effectiveness in California's 2019 wildfires, when the Blue Lake Rancheria microgrid[3] continued operating as power was shut off to millions of customers nearby. Another example is the above-mentioned power outage in 2003, when the Bruce reactors were able to provide power to the local area within a few hours, compared with a few days in many parts of the province.

Canada's sparsely populated geography necessitates long power lines connecting many small communities. Some are already isolated, especially in the north, running mainly on fossil fuels, but more are being connected to the grid – bringing all the risks of the vast distances between them. In the event of a downed power line in a remote area, for example, an SMR could continue to power a small island grid, protecting it from damage while the rest of the grid recovers.

Depending on where disaster strikes, SMRs could provide a further benefit to the local or larger grid: "black start" capability, meaning the ability to begin powering up the grid without any other backup power supply. So, if an SMR is the *only* power available on a disaster-stricken grid, it could be used to start up other sources of power, aiding in the overall recovery. The power configuration at the SMR pilot project now underway at the Oak Ridge Reservation in Tennessee is designed to allow for a black start.

Supporting Renewables and Grid Flexibility

Some SMR designs also have load-following capability: they can vary their power generation to match demand. If demand suddenly changes in an emergency situation, variable sources of energy can then quickly adjust output to match the remaining load and increase output as load is added. An SMR could fill this role, with near-zero emission of greenhouse gases.

Moreover, SMRs can continue to expand the role now played by nuclear plants in supporting the smart grid. Rolling out smart meters was only a first step in the smart grid, but an important one because the grid could then better support the development of local renewables, such as solar and wind installations. While these projects make up only a tiny amount of the overall power generation in Canada, they, too, can be islanded during a blackout. Because SMRs can vary their power output daily, or even minute-to-minute, they could stabilize the variable output of renewables during normal operation when the wind isn't blowing or the sun isn't shining.

Improving Security

SMRs could also contribute to grid resilience by offering a high level of security. Canada's existing nuclear fleet is already equipped with robust security forces, and is regularly inspected by the Canadian Nuclear Safety Commission to ensure that its measures to protect against physical attacks meet international standards. A similar level of security

[3] See: https://www.cbc.ca/news/technology/what-on-earth-newsletter-microgrids-green-energy-1.5437568.

pervades the entire supply chain for parts, equipment, software and fuel.

SMRs can further advance this security because their small size offers the possibility of underground, underwater, or offshore operation. The fact they can store years' worth of fuel onsite would present would-be aggressors with additional challenges, as transportation of fuel would be less frequent. Furthermore, modular construction would concentrate construction work in relatively few facilities, offering lesser vulnerabilities to exploit.

V. Canada and the Next Stages of the SMR Development

Several of these advantages have already been recognized by the US Department of Energy in its 2017 Small Modular Reactors: Adding to Resilience at Federal Facilities report[4], which recommended a pilot project by the Tennessee Valley Authority and regulatory changes to enable further development of SMRs. There are now about 150 SMR designs worldwide, and four SMRs are already under construction in Russia, China, and Argentina. The December 2019 announcement by the premiers of New Brunswick, Ontario, and Saskatchewan shows that Canada is very much in the game as well.

Canada is not starting from scratch. Canadian Nuclear Laboratories plans to have a demonstration unit built by 2026. Seven SMR designs are now in Phase 1 review by the Canadian Nuclear Safety Commission, demonstrating the general validity of the design. Three more designs have passed this review, and are now moving into Phase 2, a more-detailed examination of their safety. These designs vary, but they exhibit several of the features needed to support grid resilience.

For example, two of these designs, ARC Canada's ARC-100 and Terrestrial Energy's Integral Molten Salt Reactor (IMSR) have load-following capability that allow them to link seamlessly with renewable power, such as wind. The 195-megawatt IMSR design also features a replaceable core, which should extend its lifespan while lowering downtime for maintenance.

The movement toward deploying SMRs is driven, by far, more than Canadian industry. However, Ontario, Saskatchewan and New Brunswick have explicit plans to use SMRs on their grids while industry and remote communities, including some First Nations, have expressed interest. Growing awareness of the need for clean power has revamped interest from energy experts and some environmentalists who recognize that even a future based entirely on renewables depends on nuclear power to get there.

We don't know the future of SMRs nor which technology will emerge as the dominant one in Canada and around the world, but it is clear this is a time of opportunity – to explore, to invest, and, above all, to ensure that the next generation of nuclear power meets the long-term needs of Canada's power grid.

[4] See: https://www.energy.gov/ne/downloads/small-modular-reactors-adding-resilience-federal-facilities.

About the Author

John Gorman *is the President and CEO of the Canadian Nuclear Association. He has also served as the President and CEO of the Canadian Solar Industries Association, as Senior Vice President of Empower Energies, and as a director on the boards of numerous community and corporate organizations. Mr. Gorman is Canada's Designate to the International Energy Agency, and sits on the Executive Council of the Canadian Council on Renewable Energy.*

John has been recognized as one of Canada's CLEAN50 and is the recipient of the "40 Under 40" business award for excellence in business practices. He was awarded the designation of Climate Project Ambassador by Nobel Laureate Al Gore in 2008.

Assessing and Managing the Risks Associated with Marine Shipping

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While the benefits of commercial shipping as a vital contributor to Canadians' welfare and prosperity are widely agreed, the shipping industry has come under scrutiny and has met with opposition because of its potential harmful effects on human health and the environment.

The potential risks from shipping include air pollution, the release of greenhouse gases, spills of oil and other noxious substances into waterways, acoustic and physical disturbance of the marine environment and the introduction of alien and invasive marine species. These hazards are increased in areas where shipping routes intersect with human population centres, critical wildlife habitat, migration routes and traditional indigenous cultural, hunting and fishing sites. This article will explore how the marine shipping community is mitigating those acute and cumulative risks. In better managing these issues, the industry is adopting evidence-based information, prudent planning, broad consultation and cooperation with all stakeholders.

Enhancing sustainability means switching to new ways of operating, developing and integrating new technologies and establishing different global supply chains for fuel and support to these technologies. It is fair to say these will cost more in the near term and will take time to implement.

In order to play a role in bringing clarity to these issues, the Clear Seas Centre for Responsible Marine Shipping was established in 2015. It provides detailed analysis and research on the key issues around marine shipping and makes this information available to all Canadians through its website.

This article is based on a presentation made to the Infrastructure Resilience Research Group Workshop, in Ottawa, Ontario, on November 27, 2019.

I. About Clear Seas: Who We Are and What We Do

Clear Seas Centre for Responsible Marine Shipping is an independent not-for-profit organization that conducts research and communication programs related to sustainable marine shipping in Canada. The Centre was established in the summer of 2015 with initial funding from Transport Canada, the province of Alberta and the Canadian Association of Petroleum Producers.

Clear Seas does not advocate for a particular position; it simply seeks to inform the public and decision makers in order to support sound outcomes. It is an independent think tank that provides fact-based information on which to make sound choices. Our organization recognizes that given the right information, people will make the right decisions.

In this age, when attention is often focused on marine shipping and associated environmental issues, the public discussion space is invariably polarized; frequently clouded by questionable claims and misinformation; and crowded and fueled by social media. Clear Seas brings trusted, credible and fact-based information to help Canadians see through the fog and make informed decisions.

Communicating Complex Issues

By their nature, the issues related to marine shipping, its benefits, challenges and risks, tend to be complex, often technical and many-faceted.

Clear Seas' mission is to make those multifaceted issues understandable for the layperson. For instance, we may have a chemical engineer conduct a study on air emissions, but if the report requires the reader to be a chemical engineer to understand it, then we have missed the mark. Our goal is to be understood, and we publish all of our material online in both French and English.

In order to make our research available for all, Clear Seas publishes its studies and information on its website at www.clearseas.org.

II. The Value of Marine Shipping to Canada

It is important to provide some context regarding the benefits of marine shipping and how much Canada relies on it.

First, we have to underscore that shipping is an international activity and somewhere between 80-90% of global trade moves by ship. Just look around at what we're wearing, the computers and cell phones we're using, the furniture we sit on, the contents of where we live --- they all most likely came here by ship.

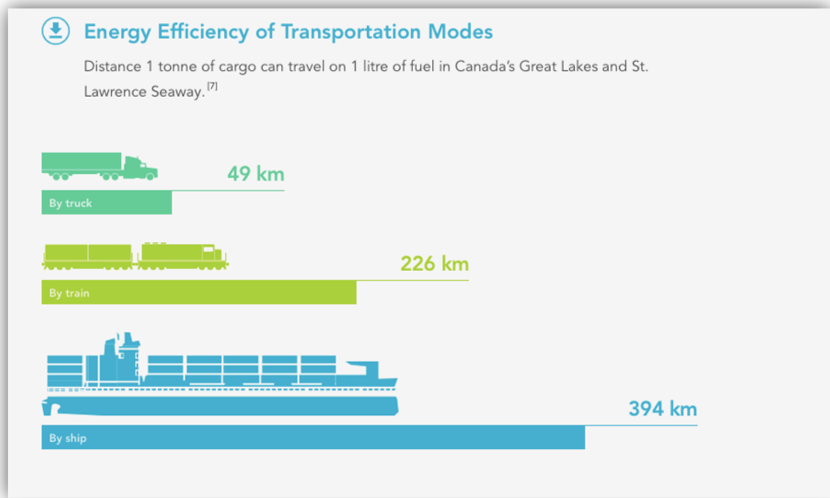
Shipping is a lifeline to our coastal and island communities on all three of Canada's coasts for essentials such as food and energy, as well as consumer goods. Shipping is also directly linked to our prosperity and well-being. It makes a $3 billion contribution to our Gross Domestic Product, and generates about 100,000 jobs. One study completed for Clear Seas by the Council of Canadian Academies identified that the value of shipping to Canada is worth approximately $30 billion per year, or the equivalent of the province of New Brunswick's GDP. Expectations are that the sector will continue to grow and most Canadians recognize its importance to our economy.

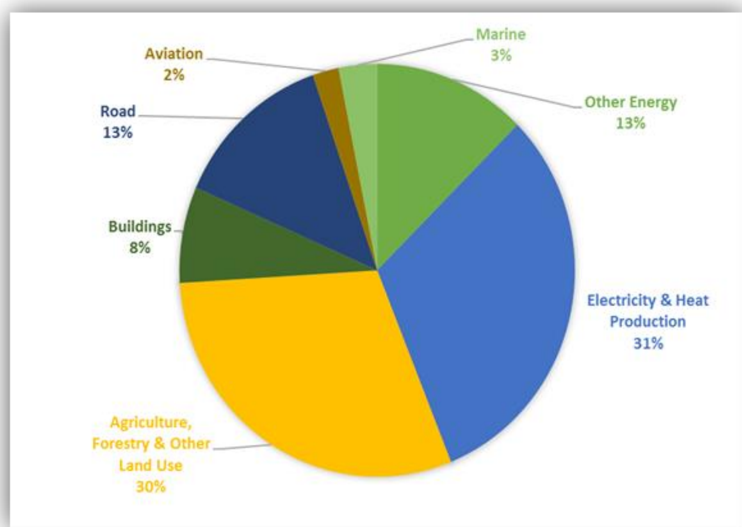
There are approximately 60,000 commercial ships in the world and the industry has come under much attention and scrutiny in recent times for its contribution to climate change. One study has equated the total Greenhouse Gas (GHG) emissions of the global shipping industry to that of Germany.

While the comparison is accurate, it should also be borne in mind that shipping is about eight times more efficient than moving the same cargo by truck, and almost twice as efficient as shipping by rail as illustrated by the graphic below.

While responsible for the release of less GHG per tonne-kilometre of cargo transported than other forms of transportation, ships contributed 2.2% of the world's total CO_2 emissions in 2012. In coming years, global shipping traffic is expected to grow in response to increased trade and economic growth. Unless additional measures to limit emissions from ships are adopted, GHG emissions from shipping could increase by as much as 20% to 120% by 2050, depending on economic conditions. The pie chart below shows that the marine transportation sector represents about 3% of GHG emissions.

While marine shipping is vital to our prosperity and well-being, and it is fuel efficient, it has an impact on our environment and on GHG emissions. The International Maritime Organization (IMO) has set a target of reducing GHG emissions to 50% of 2008 levels by 2050.





Greenhouse gas emissions by sector in 2017

III. Potential Impact of Shipping

In addition to the emission of GHGs, there are several other environmental issues related to commercial marine shipping. These include risks from oil spills, vessel strikes and collisions, wake damage, anchor scour, air pollution, invasive species, and acoustic disturbances.

Oil spills are at the top of this list. This isn't because they are likely, but due to the fact that 54% of Canadians think that this is the biggest risk associated with shipping in Canada.

Ship-sourced oil spills are rare events in Canada and, as shown in the graph below, have declined dramatically on a global scale over the past three decades despite increasing volumes being shipped.

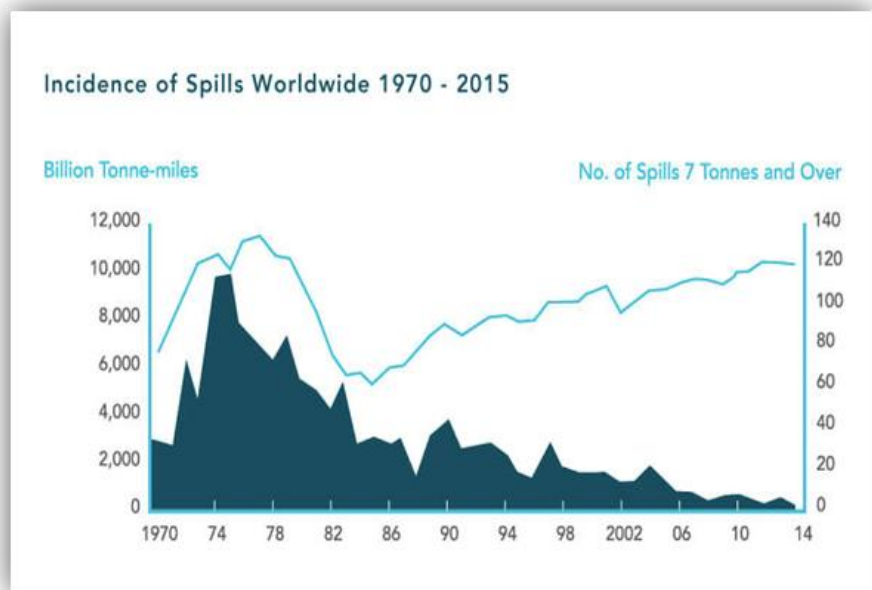
Still, research conducted on our behalf by the Angus Reid Institute finds that 39% of Canadians feel that the environmental risks of shipping oil outweigh the economic benefit.

Based on the same Angus Reid survey, endangering marine life through collisions or strikes is also a significant concern. The high number of North Atlantic right whale deaths in the Gulf of St. Lawrence in 2017, many attributed to vessel strikes, has raised the focus on this risk.

As large ships move near coasts, wake damage may also be a risk. This is something which is having an impact especially in the St. Lawrence Seaway as the water levels in the Great Lakes have been at or near record levels.

While ships sit at anchor, they move around with the winds and tides. Their long, heavy anchor chains scrape along the sea-bed, potentially endangering fragile eco-systems. This is an effect which is emerging as shipping traffic rises and ships are more frequently required to sit at anchor awaiting a berth to load or unload their cargoes.

Invasive species are foreign species that hitch rides in ballast water or on the hulls or underwater fittings of ships. They cross the ocean then can contaminate the local environment often killing off local species. In Canada, the zebra mussel is the best known of these invasive species. The map on the following page shows seven areas where invasive species brought in by commercial ships are having an impact. In Canada, disruptions caused by aquatic invasive species have an estimated cost of $5.5 billion per year from 16 invasive species alone.



Underwater Noise: Intersection of Critical Habitat and Shipping Routes

With increased marine traffic in Canada's coastal waters comes an increase in underwater noise from vessels. Commercial marine shipping is one of the main sources of human-made underwater sound and shipping's contributions to underwater noise have been increasing. Ships produce noise at frequencies ranging from 20 to 100,000 Hertz and can negatively affect marine mammals' ability to communicate, rest, reproduce, navigate, find prey and avoid danger. It can also change their behaviour and cause hearing loss, increased stress levels, displacement to quieter waters, even injury or death.

The Beluga whales in the St. Lawrence and the Southern Resident killer whales of British Columbia are two species which have come under some pressure due to underwater noise.

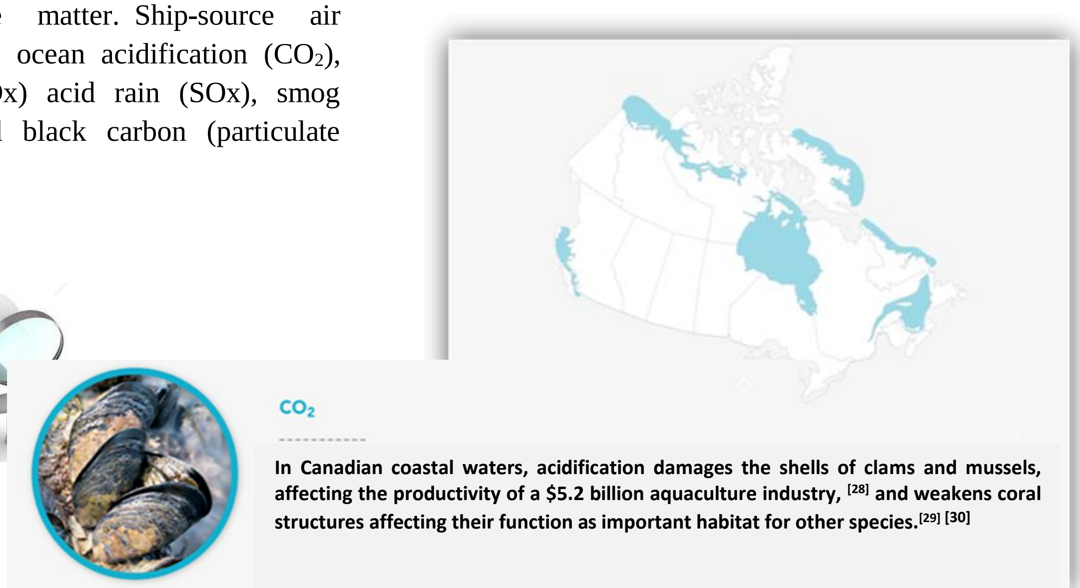
This map (located on the following page) shows three examples of where shipping lanes intersect the critical habitat of three whale populations: the Southern Resident killer whale in BC; the Beluga in the St. Lawrence; and the North Atlantic right whale in Roseway Basin off the southern tip of Nova Scotia. It is unlikely that Canada's major ports will relocate, so innovative ways must be found to balance the well-being of Canadians with stewardship of the environment. While this map shows where things are located, it does not really depict the level of activity in each region.

Impact of Air Pollutants

In addition to the previously discussed GHG emissions, commercial ships burn fuel for energy and emit several types of air pollution as by-products. Ship-source pollutants most closely linked to climate change and public health impacts include carbon dioxide (CO_2), nitrogen oxides (NOx), sulphur oxides (SOx) and particulate matter. Ship-source air pollution can also cause ocean acidification (CO_2), ground-level ozone (NOx) acid rain (SOx), smog (particulate matter), and black carbon (particulate matter).

Carbon Dioxide

When CO_2 is absorbed by seawater, the water becomes more acidic. This increase in acidity has adverse effects on marine life and ecosystems. As an example, ocean acidification from CO_2 damages the shells of clams and mussels, affecting the productivity of a $5.2 billion aquaculture industry in Canada.

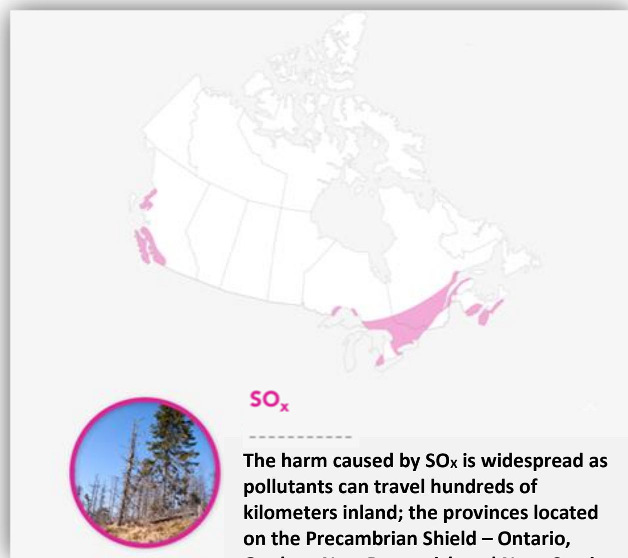


Nitrogen Oxides

Ground level ozone from nitrogen oxides (NOx) poses a risk to human health and causes an excess of nutrients in waterways and a drop in crop and vegetation productivity. This is a problem in some areas of Canada, including much of the coastline of Atlantic Canada, the St. Lawrence River and British Columbia's Lower Fraser Valley.

Sulphur Oxides

The harm caused by SO_x is widespread as pollutants can travel hundreds of kilometres inland; the provinces located on the Precambrian Shield – Ontario, Quebec, New Brunswick and Nova Scotia – are most affected by acid rain caused by SOx.

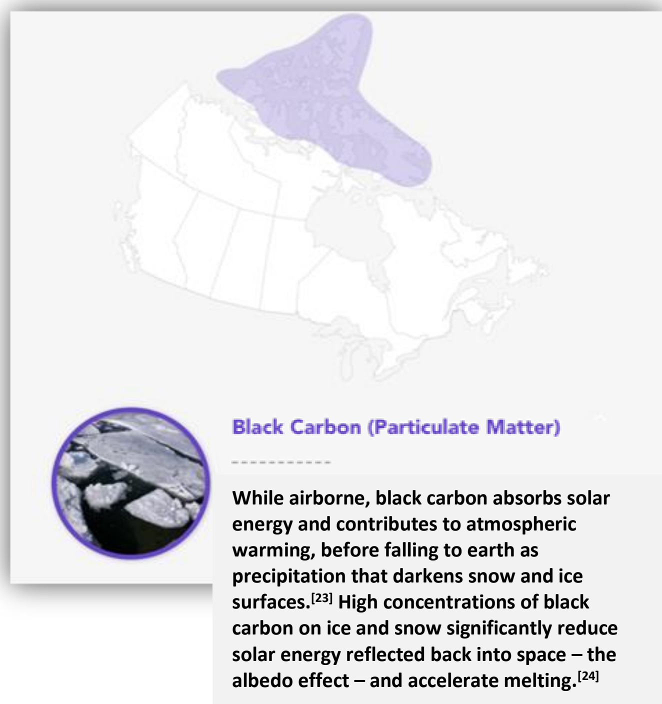


Particulate Matter

Particulate matter, along with ground-level ozone, is a key component of smog on Canadian coastlines. Ports where commercial marine shipping activities occur in the Atlantic provinces, Quebec, Ontario, British Columbia and some parts of the Arctic are particularly affected, but air pollution from ships can travel hundreds of kilometres inland, affecting more than 60% of Canada's population.

Black Carbon

Black carbon is the sooty black material that is discharged from gas and diesel engines, coal-fired power plants, and the combustion of other fuels, such as wood and charcoal. While airborne, black carbon absorbs solar energy and contributes to atmospheric warming, before falling to earth as precipitation that darkens snow and ice surfaces. High concentrations of black carbon on ice and snow significantly reduce solar energy reflected back into space – the *albedo* effect – and accelerate melting. Black Carbon is the second largest contributor to global climate change after CO_2.

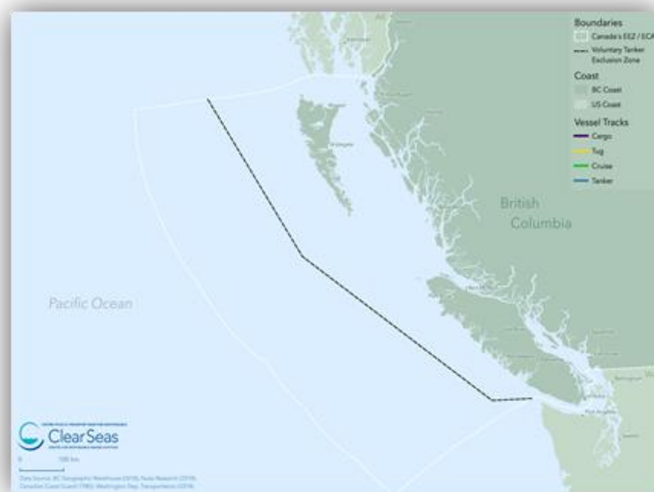


Ship Traffic

These two maps tell an important story about shipping traffic. The map on the left side below is recognizable as a map of the west coast of Canada.

The white line represents roughly the Economic Exclusion Zone. The black line is the Voluntary Tanker Exclusion Zone. It is commonly thought of as a remote and pristine region of Canada. It does not really provide a sense of the level of activity in this ocean area.

This area provides access to the ports of Vancouver, Prince Rupert, Seattle, WA, and Tacoma, WA, and cruise ship visits to the coasts of British Columbia and Alaska. The map to its right is the same map only now depicting three years of shipping activity taken from a study we currently have underway. This presents a compelling case why cumulative effects should be studied and considered as we address sustainability.



IV. Risks and Solutions

This article has reviewed the risks associated with the marine shipping industry. In terms of solutions, they are generally technological and operational /procedural, or a combination of the two. In any event, resolution needs to be grounded in sound research.

Oil Spills

As indicated earlier, oil spills are a rare occurrence in Canadian waters. The key approach to minimizing this risk has been to enhance prevention and vigilance, and to prepare and train to be ready should prevention fail.

Much has been learned and applied since the EXXON Valdez spill, which occurred 30 years ago in 1989. Tankers are now doubled hulled. They are inspected rigorously. Navigation equipment including integrated navigational charts with GPS, radar and AIS are now the standard. Pilotage and tug escorts are mandatory where necessary. Tankers are required to adhere to speed restrictions and limits imposed on their movements due to actual or imminent adverse weather. In addition, better weather forecasting and reporting, vessel traffic management and surveillance have all been implemented since that catastrophic event.

On the response side, professional response organizations have been established, which are paid for by industry. The federal government is developing area response plans and integrated local response plans where appropriate and training with all stakeholders, including response organizations, the Canadian Coast Guard, Indigenous communities and First Nations, local areas of government and others. In addition, the Ship-source Oil Pollution Fund, paid for by industry, provides potentially limitless funding to pay for a ship-sourced oil spill.

Vessel Strikes/Collisions

The key initiatives to reduce the chance of deadly vessel strikes have focused on the development of means to detect and track marine mammals in or near shipping channels. Visual or electro-optic means of detection have included the use of trained observers on board ships, crewed aircraft with trained observers on board, and internet broadcasting of voluntary reports of whale sightings. Work is ongoing to use drone aircraft instead of crewed airplanes.

The development of passive acoustic tracking of whale sounds is well underway using both fixed sea floor-mounted arrays and mobile underwater drones like the Slocum Glider. Operational solutions have examined dynamic speed restrictions, re-routing or lateral displacement of traffic patterns to minimize disturbances during key times.

Wake Damage

The probability of damage caused by ship wakes can be decreased by reducing speed, or ships loading conditions, or managing water levels where applicable.

Anchor Scour

Anchor scours could be reduced by installing mooring mechanisms instead of having ships use their own anchors. Increasing the efficiency of the supply chains to minimize or eliminate wait times for ships at ports – this means of course impacts on ports, terminals, rails and road traffic. This serves to highlight the need for a systems approach to address sustainability issues.

Air Pollution

Although it has lagged other sectors, the shipping industry is catching up in its quest to reduce air pollution. In Canada, for example, an emission control area (ECA) reducing sulphur emissions (to 0.1%) south of 60 degrees North out to the 200 nautical mile EEZ has been in place for several years.

As of January 1, 2020, international regulations additionally require all ships to reduce sulphur emissions from 3.5% to less than 0.5% by mass when operating outside the ECA.

There are two broad courses of action open to ship owners: either switch to compliant fuels, or use Exhaust Gas Cleaning Systems commonly known as scrubbers. There is still some uncertainty under the new regime. Only about 6% of ships are expected to go the scrubber route. These are multi-million dollar installations which generally need to be retrofitted and often need to be scheduled to align with ship dockings and refits.

To complicate matters, though it has decreased, there has been uncertainty about the supply chains for compliant fuels. There is also uncertainty about the environmental impacts of one type of scrubber – the open loop systems, which have been prohibited by some nations.

Greenhouse Gas Emissions

In order to reduce GHG emissions, ships can switch to other fuels; however, there is a great deal of uncertainty surrounding the availability and reliability of alternate fuels, at least in the near term. Some fuels, such as LNG, offer some reductions, but are viewed as an intermediate step. Others, such as hydrogen, offer great potential, but their technological developments are not yet mature enough to be adopted.

Regardless of the next fuels to be used, a shift will take time as equipment needs to be modified and handling of procedures and training reviewed. Moreover, given that shipping is a global industry, supply chains supporting chosen fuels must be developed. Fuel efficiency can be enhanced through new designs, hulls, fittings, low-friction coatings and the addition of sails, including Flettner rotors (the four vertical cylinders pictured below), which harness the wind to assist in propulsion.

Finally, slow-steaming – reducing ship speeds to operate with greater fuel efficiency is being examined. There are currently conflicting assertions regarding the benefits and consequences of "slow steaming". This is not surprising given the complexity of the question: vessel size (including capacity and characteristics), supply chain throughput requirements, distance covered, and navigational considerations are but some of the many variables that can affect conclusions. It is not clear if there is a one-size-fits-all solution, but again, it requires a systems approach, rather than an individual ship perspective. This is another area which merits more research.

Invasive Species

More sustainable operational practices revolve around the measures taken to exchange ballast water well out to sea, and frequent cleaning of the hull and underwater fittings. Technical approaches rely on anti-fouling coatings, or other technologies such as ultraviolet light or electrical signals to neutralize unwanted hitchhikers.

Acoustic Disturbances

Operational approaches to minimizing acoustic disturbances are principally speed reductions and lateral displacement. There is also a focus on measuring ships' acoustic signatures and encouraging the development and adoption of design standards for quieter ships.

Picture: Courtesy of Norsepower Ltd., Finland

V. Collaboration

It is clear that addressing the risks that have been highlighted here require efforts of a broad range of actors. This includes the federal and provincial governments; natural resource sector; Indigenous peoples; coastal communities; the shipping industry; response organizations; port authorities; marine pilots; academia; NGOs and ENGO; and the international community.

There has been much activity and collaboration in the past few years, much of which has been invigorated by Canada's Oceans Protection Plan, the IMO's increased focus on sustainability, and the full realization by industry of the impacts of climate change.

It seems there is general agreement among stakeholders with the vision of the need to protect the environment while fostering growth. Although the stakeholders involved may generally agree on the need to achieve balance, they still offer very diverse perspectives on "how" this common vision is implemented.

VI. Impact on Shipping

So far, this article has focused on how shipping impacts the environment, but it must be noted that the environment and its changes will also have impacts on shipping.

Future increases in sea levels may have impacts on traffic patterns, drive port infrastructure requirements, create concerns about ships' air draughts and overhead clearances. Interestingly enough, some areas of the Canadian Arctic could see a lowering of sea levels. It is not clear what, if any impact this may have on shipping in and out of places like Churchill, Manitoba. There is also uncertainty over the polar sea route and speculation about reduced rainfall in Central America and its impacts on the Panama Canal, which relies on rain-fed lake water to lift ships over the Isthmus of Panama.

VII. Conclusion

In conclusion, recognizing that shipping is but one link in the global supply chain and that the marine environment is very dynamic and undergoing constant change, it must be underscored that we need to take a systems approach to addressing issues that are not necessarily fully scoped or understood. While we should avoid the so-called "paralysis of analysis," it is very important that we understand the second and third order effects of options before decisions are made.

There is still much to learn about sustainability in the marine environment, and about shipping in particular. It is probably most important to maintain clear communications between stakeholder groups. Clear understanding between regulators, industry, indigenous groups and other stakeholders is fundamental.

The collaboration, for instance, on dynamic speed control in the Gulf of St-Lawrence has been impressive, as has the voluntary slow down for the Southern Resident killer whale instituted in the Salish Sea.

Finally, it is important for people to understand that although moving to a more sustainable footing is already underway and has been for some time, there are limits to the industrial capacity to implement change. Likewise, we need to be realistic about the technological readiness levels of proposed solutions. In the near term, it will cost more and take time. We just need to acknowledge that.

About the Author

Bud Streeter *is the Chair of the Board of Directors of the Clear Seas Centre for Responsible Marine Shipping. He retired as President of Lloyd's Register Canada Limited and Americas Manager of Naval Business and External Affairs at the end of 2017, capping a career of nearly 50 years in the marine industry. He is a 1973 graduate in Marine Engineering from the Canadian Coast Guard College. His early career included many positions in the Coast Guard and Marine Safety, and executive positions with Marine Atlantic Inc. He served as Director General, Marine Safety, Transport Canada, between 1996 and 2002; during which time he was Head of Delegation to many International Maritime Organization meetings and other international gatherings. He left Transport Canada to join Lloyd's Register where he held several positions in the Americas. He was appointed to the Canadian Advisory Council on National Security and served as a marine security advisor from 2005 to 2009. In 2013, he was presented with the inaugural Medal of Excellence from the Canadian Institute of Marine Engineering and was cited for his commitment to marine safety and mentoring young maritime professionals. In 2018, he was appointed as Honorary President of the Canadian Institute of Marine Engineering.*

GlobVision's Role in Infrastructure Resilience

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GlobVision Inc. is a small, woman-owned, Montreal business that has been active and highly successful in developing and providing Artificial Intelligence (AI)-based software solutions for critical mission, business, operations, and safety applications in Infrastructure and Utilities since before the turn of the millennium.

For over two decades, GlobVision has worked closely with infrastructure owners and operators to determine and fully understand their needs and obligations, as well as their desires for significant advancement of processes and technologies currently in use for health and safety management of their assets. In response to this fast-emerging need, GlobVision has developed a disruptive host of technologies, such as: Diagnostic, Prognostic and Health Management (DPHM); Fault Detection and Isolation (FDI); and Intelligent Structural Health Monitoring (iSHM), and delivered them to clients across a wide range of industries and sectors, including: Space, Aerospace & Defence, and Utilities & Infrastructure. All of these technologies are based on advanced Machine Learning and Scientific Modeling/Computing algorithms; today, what we publicly call "Artificial Intelligence (AI)". In all these activities, GlobVision has met with commercial success both at home in Canada and abroad.

Through leveraging partnerships with universities and government agencies such as Natural Resources Canada, GlobVision spends typically more than 30% of its total annual activities on R&D to advance scientific and engineering methods as they apply to the health and maintenance of critical infrastructures, such as transportation bridges, hydro-electric power dams and, most recently, in the surveillance of space assets; specifically Space Situational Awareness (SSA) for the Department of National Defence (DND), Canadian Armed Forces (CAF), and the Canadian Space Operations Centre (CANSpOC).

SSAVision is an AI-enhanced Software-as-a-Service (SaaS) solution for detection, prediction and risk assessment of threats to space assets. SSAVision has been in development at GlobVision for more than five years and has been in continuous testing by DND/CAF for over two years, and recently has been adopted in full operations at CANSpOC/DND.

SSAVision is an integrated and automated network-centric service providing actionable SSA information and informed decision-support capabilities to spacecraft operators for the protection of space assets, increased service availability, and improved operational performance. SSAVision acquires high-fidelity orbital and space environment data from international sources. It applies innovative state-of-the-art analyses to the data and presents analytical and visual results to spacecraft operators for optimized orbit tracking and monitoring and for identification of threats/risks.

Actionable SSA information provided to SSAVision users include: planetary and localized (i.e. spacecraft-centric) space weather data, conjunction assessment and aggregated risks, proximity detection, orbit trending and pattern of life analysis, object re-entry analysis, and more. Operators can view 3D animations of conjunction/proximity events in real or simulated (faster-than-real) time and can customize the analyses to suit their needs and operational requirements.

SSAVision meets the stringent needs of the defence space community and provides additional protection to military SIGINT assets, as well as commercial satellites, thus increasing their availability and optimizing operational life. It substantially contributes to the reliability and resilience of space operations and the use of the increasingly congested, contested, competitive and convergent space environment.

SSAVision builds, in part, on work that GlobVision has previously done for the Canadian Space Agency, among others, on Mission Planning Systems; Spacecraft Health Monitoring and FDI; advanced Spacecraft Simulators; Space Mission Analysis, Design and Optimization; and even Space Medicine Decision Support Systems. Detailed work on these previously completed projects has certainly provided a "domain awareness" that has been critical to the success of SSAVision. Other experiences in related fields (at the technology level) have contributed as well, which are subsequently discussed.

I. INTELLIDAM

IntelliDAM™, a key heritage product of GlobVision, is perhaps the longest standing example of GlobVision's commercial success. IntelliDAM™ was born of GlobVision's extensive know-how in advanced data analytics combined with the dam performance and safety management expertise of BC Hydro and Hydro Quebec, two major hydro-electric producers in Canada and, arguably, across the globe.

The result is the only system on the market that can be used to evaluate most aspects of dam behavior, performance, health, and safety based exclusively on instrumentation data.

IntelliDAM™ makes it possible to manage dam safety and health monitoring data, be it from a concrete or embankment structure. Data analyses and interpretations are facilitated by a unique and coherent set of modeling tools; thereby enabling behavior monitoring and health assessments that save time, improve performance, result in more efficient operations, and increase safety.

IntelliDAM™ assists users, from inspectors and operators in control rooms to dam engineers and long-term planners, to increase their knowledge and understanding of the evolving relationships between various operational and environmental parameters / variables within a dam. This, in turn, enables them to better understand the bigger picture, and to manage dams using a holistic approach, in addition to capturing the health of its individual elements. Through cutting-edge analysis capabilities and flexible modeling tools, IntelliDAM™ makes it easier to not only detect and quantify anomalies and out-of-spec behaviour in a dam, but also investigate, explain, and notify those that may require immediate intervention. It also makes it possible to explain features of the data that otherwise may have been falsely construed as anomalies.

The software allows equally easy and fully contextual visualization of sensor data for time scales ranging from real-time or near real-time stream, multiple single-point-in-time readings (e.g. data from inspections and non-destructive tests) to several years of historical data. This, and many advanced features, including AI and machine learning algorithms for data analysis empower dam owners to extract vital information from data recorded by various types of dam and environmental sensors, and ultimately better understand the dynamic behaviour and big picture (performance, health and safety) of both concrete and embankment dams.

GlobVision has supplied IntelliDAM™ and its components in Canada and to 75% of the Scandinavian hydro-electric dam owners/operators.

II. INTELLIBRIDGE

Similarly, IntelliBRIDGE, GlobVision's solution for intelligent structural health monitoring (iSHM) of bridges, has met with great success on Montreal's Champlain Bridge, allowing it to remain in safe operations until it was replaced in 2019 by the new Samuel de Champlain Bridge.

IntelliBRIDGE provides critical information about bridge performance, health and safety, which are often hidden in multivariate and highly correlated data (both dynamic and nonlinear correlation). Note that the human brain cannot visualize beyond three variables/dimensions, and cannot process and correlate a variable simultaneously with two or more other variables, especially when the relationships tend to be dynamic and nonlinear in nature. Also, many bridge response variables contain damage signatures that are simultaneously shadowed by responses to environmental (e.g. temperature variations) and operational (e.g. traffic) factors. Human brains can hardly separate these simultaneous effects on bridge response to extract damage signatures especially that early damage signatures are relatively much smaller than, and thus buried in, other responses.

IntelliBRIDGE greatly simplifies accessing, storing and aggregating data from multiple sources and formats, and provides intuitive data visualization capabilities. The software rapidly becomes an essential tool for real-time monitoring and provides the basis for ensuring the health and safety of bridges assisting users in the extraction of complex and detailed information hidden in the instrumentation data to enhance the performance of operations and bridge health and safety. As a result, bridge owners/operators drastically reduce the time required to perform monitoring activities, thereby allowing a better utilization of available man-hours and skills to monitor complex structures.

The Champlain Bridge was known to be problematic and a particularly challenging structure as it approached its end-of-life. GlobVision designed and built custom models for the Champlain Bridge using historical data for several years, and embedded these in IntelliBRIDGE. Using IntelliBRIDGE, GlobVision was able to provide new insights into the conditions of the various segments of the structure to the highly capable engineering team that operates the bridge. This was achieved using primarily deformation (tension and compression) sensor data (via fiber optics) and frequency domain (or vibration) analysis, complemented with other structural and environmental data.

Prior to the installation of IntelliBRIDGE, the bridge operators used to conduct monthly structural load tests requiring a full structure shutdown and a small army of participants to conduct the tests. The load test concept was simple and conventional: On a structure closed to regular traffic (to eliminate "impurities"), drive a heavy truck (48 tons) at a known constant speed (10km/h) while measuring the impacts and stresses (via deformation readings) applied to each segment of the structure in both directions (I.e. on both the southbound and northbound sides of the structure).

This particular test required several hours to complete, many human elements that required training and "choreography" and many equipment elements to close and secure the structure and, particularly, to execute the test procedure. This was a highly valuable exercise, but, understandably, it took several months to build a database of comparable data so that "differential diagnoses" could be made with confidence. Of course, complicating the whole exercise was Montreal's known extreme weather temperature swings ranging from the -30s C in the winter to the +30s C in the summertime.

The resulting data required more than a week's work for a team of engineers to compile and analyse the data, and to produce the reports requested by the bridge operators. Moreover, this 1-week time was required of analysis of data only from the "edge" girders of the bridge, whereas the bridge structure had several other girders too.

Following the installation of IntelliBRIDGE, the data experts, engineers and scientists at GlobVision were able to demonstrate to the engineering team at the PJCCI that even better results could be obtained, on an on-going basis, by using in-situ, real-time data, and for all bridge girders, at a tiny fraction of the time required by manual analysis. For example, because of the nature and complexity of the monthly load tests, and because it required closing the structure, the tests were naturally undertaken during the very early hours of the morning. One of the consequences of conducting the tests at this time of day was that the structure was not subject to the radiation of the sun and its warming effects, and to the contrary, the structure typically had 6 to 8 hours after sunset to lose heat from its thermal mass. Using real-time data, conducted at all hours of the day using real traffic, proved to be more beneficial, now that the resultant data could be properly analyzed and interpreted.

As a bonus, it was available 24/7 throughout the year and required only minutes, if not seconds, to produce the required reports.

Consequently, the monthly dedicated load tests were stopped. The termination of this activity alone saved the bridge owners/operators the equivalent of several times the investment in IntelliBRIDGE every year.

On this same structure, extensive repairs were undertaken, over a period of several years, to ensure its continued safe operations until the replacement structure could be commissioned. IntelliBRIDGE was used extensively during and following each repair to identify those segments of the structure that most needed repair to confirm the efficacy and sufficiency of each repair immediately following the repair activity. This was accomplished using only existing sensors and required no additional sensors, cost or effort to execute; the information created from the data was available immediately to engineering management too.

III. Services

In addition, GlobVision has supplied advanced data analytics services, for particularly challenging engineering applications in utilities and infrastructure, for organizations and clients like Transport Quebec, the Norwegian Geotechnical Institute (NGI), etc., when they face unforeseen anomalies in their structures or when problems are presented for which no answer is obvious.

GlobVision has developed, over a period of many years, advanced knowledge and processes and proprietary algorithms specifically targeting infrastructure resilience. As an example, the ability to distinguish *reversible* effects (mostly environmental and operational) from *irreversible* effects (mostly damage/fatigue related) is a key concern to almost all infrastructure operators.

The impact of severe temperature change is particularly prevalent in Canada where many infrastructure elements are exposed to blistering heat in the summer and severe cold six months later; and more importantly, sometimes large day/night temperature differences, as well as large temperature fluctuations in short periods of time (as short as even a day or two days). Coefficients of thermal expansion and contraction (CTE) are carefully analyzed by experienced engineers at the structure design stage and are commonly monitored during the lifetime of the structure.

However, the constant expansion and contraction eventually has an impact, as do other conditions, such as materials degradation due to erosion, corrosion, infiltration, efflorescence or other phenomenon. Highly precise estimation of the progression of irreversible damage and, as corollaries to this, the Remaining Useful Life, Probability of Fracture, Time to Failure (thus repair) and Priority of Intervention can be accurately calculated.

In one case, an experienced IntelliDAM client approached GlobVision with a special request. One of the concrete buttress dams they owned and operated was showing signs (from visual inspection) of two significant fractures in the concrete structure. The only data available were the reports of the periodic visual inspections that, naturally, increased in frequency as the damage became more apparent.

Also supplied were the analyses the engineering team had done and the conclusions they had arrived at. The engineering management questioned, however, the validity of the conclusions and requested GlobVision to perform advanced analyses, using proprietary methodologies, to confirm/reject the conclusions.

After only a few weeks, GlobVision was able to clearly demonstrate that one of the fractures was progressing at a rate of 13% smaller than that calculated and the other at a rate of 18% greater than that calculated, once environmental data was applied to and environmental effects were estimated and removed from the equations. The result was a clear understanding of the reversible vs. irreversible (i.e. damage) effects the concrete structure was exhibiting. This allowed the client to focus the efforts of their repair and maintenance activities on the fracture that posed the highest risk resulting in an optimal (i.e. lower cost and higher benefit) approach to the ongoing safe operations of the structure.

The above example clearly shows the impact of advanced data analytics (including our proprietary AI and ML models) as a benefit to "micro-level" analyses.

In another case, using GlobVision's profound experience utilizing space-based remote sensing data, specifically InSAR (Interferometric Synthetic Aperture Radar) data, as an overlay to in-situ survey data, GlobVision was able to detect and estimate "macro-level" movements and settlements over time, to millimeter/centimeter level, in a major structure, which were otherwise not reliably calculable by traditional means. This insight allowed the client to undertake measures that were never imagined as being required to ensure the safety of the long-term operations of this major structure.

Ontario Power Generation (OPG) has been a client of GlobVision since 2004 with 24/7 support and maintenance via VPN remote access and relies on GlobVision's advanced software, including Data Validation System (DVS) and Water Records Accounting (WRA), to provide regulatory requirements compliance as a mandatory component of their day-to-day operations.

GlobVision has, for decades, provided consulting services to engineering organizations such as the Norwegian Geotechnical Institute (NGI) who have relied on GlobVision to provide advanced analyses of high speed train bridge crossings in Italy, and the globally famous SWECO (Swedish Engineering Company) that demonstrated the use of space-based, remote sensing data to capture, analyze and correlate with in-situ data to measure and display the structure settlements/movements of major structures in three (3) axes.

The above GlobVision's products, technologies and advanced mathematical approaches are but a few of the very many examples and applications for state-of-the-art AI, ML and other data-intensive analysis methods, founded in science and experience, to apply to and improve the resiliency of infrastructure elements. This is what we have termed as *intelligent Structural Health Monitoring* (iSHM), applicable to many types of infrastructure and almost agnostic to the type of the structure being monitored. GlobVision is proud of being the industrial pioneer of iSHM, providing a wide range of iSHM software and services that are field-proven, that result in the enhanced resiliency of infrastructure owned and operated our clients.

About the Author

***Graeme Maag** has over 40 years of experience in various technical and commercial roles in both small business and in very large businesses. Prior to joining GlobVision some 8 years ago, he spent almost 2 decades in the space and defence sector, and as much time at the helm of a private business.*

Design Basis Threat and the Low Threat Environment

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I. The Problem: What are you protecting against?

A design basis threat helps you to ensure physical protection systems are developed to meet the challenges of the existing threat. What do you do when the threat appears to be negligible?

II. What is a Design Basis Threat (DBT)?

"*A DBT is a comprehensive description of the motivation, intentions, and capabilities of potential adversaries against which protection systems are designed and evaluated. Such definitions permit security planning on the basis of risk management. DBT is derived from credible intelligence information and other data concerning threats, but is not intended to be a statement about actual, prevailing threats*."[5]

A properly developed DBT is a powerful tool. The DBT defines the reasonable and credible threat that a site is likely to face, which in turn allows risk-based decisions to be made about the capabilities of the physical protection system (PPS) needed to safeguard it. The completed DBT document is very sensitive in nature and should be safeguarded as such.

There are four themes in a DBT:[6]

1. **Insider/outsider adversaries**. A potential adversary is any person or persons, including insiders or outsiders, who have the capability and intent to commit a malicious act against the facility and/or operations;
2. **The relationship between malicious acts and unacceptable consequences**. The purpose of the DBT is to prevent malicious acts which will lead to unacceptable consequences at the site. These unacceptable outcomes or consequences are specified in the document;
3. **Attributes and characteristics**. Potential adversaries are examined to determine their motivation, intention, and capabilities, and may be categorized into three groups – high, medium, or low threat. This information is listed in the DBT in as much detail as reasonably possible; and
4. **Design and evaluation**. The DBT is used to establish performance goals for the design and evaluation of the physical protection system, particularly concerning the capabilities and intentions of potential adversaries and how that would influence the physical protection

[5] IAEA Nuclear Security Series No. 10, Implementing Guide - Development, Use and Maintenance of the Design Basis Threat, International Atomic Energy Agency, page 1

[6] IAEA Nuclear Security Series No. 10, Implementing Guide - Development, Use and Maintenance of the Design Basis Threat, International Atomic Energy Agency, page 4

system's ability to detect, delay, and respond to an attack.

A DBT is the result of group effort. Law enforcement, intelligence community, and security professionals are needed to provide information on potential adversaries, including their motivations, capabilities and intentions. Site operations and maintenance personnel will help shed light on unacceptable consequences, and security staff and security system technologists provide information on the capabilities and limitations of the physical protection system. Local law enforcement provides critical information on response force composition, capabilities, procedures, and response times which are necessary to determine how long the physical protection system needs to hold out for.

III. A Few Thoughts on Malicious Acts and Unacceptable Consequences

The malicious acts that we are most concerned with are those which will lead to consequences that site owners/operators consider to be unacceptable. These could be attacks which:

- create on-site conditions which prevent operation of the site for a specified period. For example, the destruction of critical equipment within a facility which prevents it from operating as it is supposed to;
- create off-site conditions which prevent or inhibit operation of the larger system which the site is a part of. For example, an attack on a control room could be used to create unacceptable conditions elsewhere on the system which the control room manages; or
- kill or maim personnel.

IV. DBT Organization

The DBT is organized into several sections. They are:

1. Definitions
    a. Design Basis Threat
    b. Outsider
    c. Insider
    d. Unacceptable Consequences
    e. (Any other special terms necessary for understanding the site or system)
2. Threat Levels
    a. High Threat
    b. Medium Threat
    c. Low Threat
3. Unacceptable Consequences of Physical Attack on the Site (or system which the site supports)

In the DBT, the section on asset protection levels is used to ensure that a high consequence asset is protected at the level it deserves versus a low consequence asset. The owners/operators of the site determine the appropriate threat and asset protection level (APL) for the asset. This ensures the right amount of protection is used for the value of the asset.

According to the International Atomic Energy Agency (IAEA), each of the three threat statements (High, Medium, and Low) contains the following information:

- *Motivation: political, financial, ideological, personal;*
- *Willingness to put one's own life at risk;*
- *Intentions: radiological sabotage of material or of a facility, theft, causing public panic and social disruption, instigating political instability, causing mass injuries and casualties;*
- *Group size: attack force, coordination and support personnel;*
- *Weapons: types, numbers, availability;*
- *Explosives: type, quantity, availability, triggering sophistication, acquired or improvised;*
- *Tools: mechanical, thermal, manual, power, electronic, electromagnetic, communications equipment;*

- *Modes of transportation: public, private, land, sea, air, type, number, availability;*
- *Technical skills: engineering, use of explosives, chemicals, paramilitary experience, communications skills;*
- *'Cyber' skills: skills in using computer and automated control systems in direct support of physical attacks, for:*
    - *intelligence gathering,*
    - *computer based attacks,*
    - *money gathering, etc.*
- *Knowledge: targets, site plans and procedures, security measures, safety measures and radiation protection procedures, operations, potential use of nuclear or other radioactive material;*
- *Funding: source, amount and availability;*
- *Insider threat issues: collusion, passive or active involvement, violent or non-violent engagement, number of insider adversaries;*
- *Support structure: presence or absence of local sympathizers, support organization, logistical support;*
- *Tactics: use of stealth, deception, or force.* [7]

When determining this information, it is important to use the principle of economy of effort. A principle of war, economy of effort *"…is best summarised as creating the right effect, in the right place, at the right time with the appropriate resources*."[8] An adversary's direct-action unit will have little room for mistakes, and even less room for extravagance. They will likely tailor their tools, equipment, tactics, manpower, weaponry, and explosives to the minimum required to reasonably ensure completion of their mission. While important at this stage, it becomes even more important later when the Vulnerability Assessment Team[9] is designing scenarios based on the APL to test the physical protection system. For example, when determining the amount of explosives the adversary is likely to bring, assume that it is the minimum amount of explosives required to destroy the target, not a multiple of that amount. The adversary would not want to carry too little to do the job, or too much to carry home.

V. I've Created a DBT. Now What?

The DBT is passed to a System Effectiveness Analysis (SEA) Team, which is comprised of experienced personnel from security, operations, maintenance, law enforcement, cybersecurity, and anyone else who has knowledge which may be useful to solving the analytical problem. The SEA Team creates reasonable and credible attack scenarios, then uses the Vulnerability of Integrated Security Analysis (VISA[10]) process to wargame these scenarios against the PPS. They learn system vulnerabilities and potential improvements in the process, which can then be used to upgrade the system if the risk demands it.

[7] IAEA, Page 16
[8] Ministry of Defence Joint Doctrine Publication 0-01 UK Defence Doctrine (Fifth Edition) dated November 2014. page 50. Available online at https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/389755/20141208-JDP_0_01_Ed_5_UK_Defence_Doctrine.pdf

[9] The vulnerability assessment team tests the finished physical protection system, much like a penetration test. This differs from a Systems Effectiveness Analysis Team, which is a much wider-based team that works to improve the physical protection system.
[10] The VISA process is a vulnerability assessment tool that uses a specified DBT to determine the overall system effectiveness of an integrated PPS. It was developed by the Science Applications International Corporation (SAIC) in the 1970s, and it is used by industry and US government agencies. For an example of the VISA in use, please see https://www.wapa.gov/About/the-source/Documents/technology-symposium-Basin-Electric-DBT-implementation.pdf

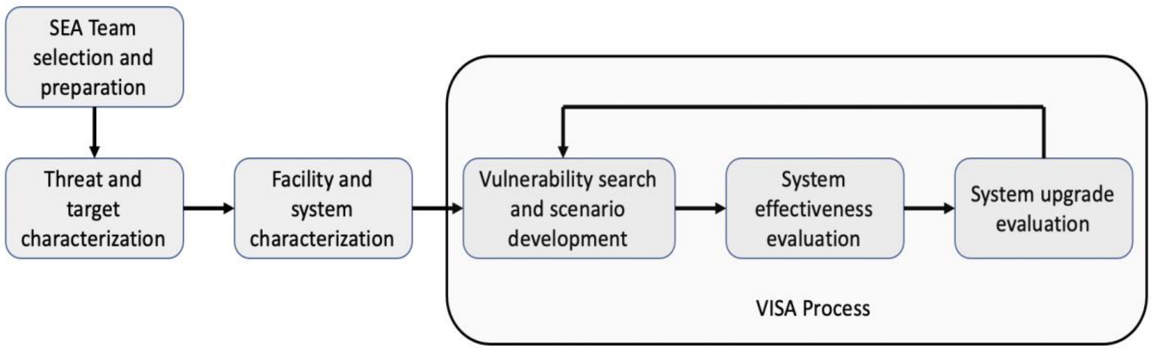

Figure 1: System Effectiveness Process

VI. The Problem of the Low Threat Environment

What do you do if there is no history of attacks against the site? What if there is no history of any attacks against similar sites in the region or country? What if there are no known adversary groups who have shown the capability or intention of attacking this, or any similar site? If we follow the idea of a 'reasonable and credible threat,' then there is no threat, therefore, no reason for a physical protection system.

But what if the site is critical to your organization? You will want to protect it anyway, as the loss of it might be more than the organization is willing to bear, and there is always the chance that something was missed in the threat assessment process.

In this case, when the threat assessment concludes with a vanishingly small threat, the DBT process turns to an assessment of what it would take to achieve the unacceptable consequences. The DBT itself would not look any different; what changes is the process used to get there.

This doesn't mean that you must develop a PPS that is capable of defeating an outsider high threat attack if there is no threat of one. Instead, the DBT allows you to develop scenarios that model this type of attack to learn where your PPS falls short in preventing unacceptable consequences. Using this information, you can make informed, risk-based decisions and develop threat response plans for use if conditions change and the threat escalates. This path relies heavily on early warning, though, so you will have to ensure that your organization's relationship with the law enforcement and intelligence community is maintained.

VII. Conclusion

In an environment with little or no known threat, the design basis threat process may leave you with a physical protection system that is unable to fully protect the asset if conditions change quickly or if a previously unknown threat becomes apparent. Artificially creating an asset protection level that considers a notional adversary attempting to achieve an unacceptable consequence allows you to restore the full range of flexibility to your PPS and model more destructive attacks than the threat level may support at the time. This allows you to develop and document upgrades to your PPS that can be swiftly deployed if the threat increases.

About the Authors

Rob Siefken *is a National Security Specialist at the Department of Energy's Pacific Northwest National Laboratory (PNNL), where he coordinates, leads, trains, develops and implements projects. These projects include: border and physical security, vulnerability assessments, design basis threat development, instructor development, and other non-proliferation-related efforts that support multiple countries around the globe. Mr. Siefken's accomplishments include: 1) Publishing and implementing several border security training and workshop curricula; 2) Developing and leading national security assistance programs to many countries around the globe; 3) Recognized as an SME and go-to implementer for Department of State, Export and related Border Security (ExBS) program; 4) Former protective force instructor for the Department of Energy's National Training Center; and 5) Retired military officer – U.S. Army Special Forces. A participant with the North American Electric Reliability Corporation (NERC), Mr. Siefken is a member of the Electricity Information Sharing and Analysis Center's (E-ISAC) Physical Security Advisory Group (PSAG). The PSAG consists of a group of subject matter experts who support the E-ISAC in advising electricity industry participants and governmental agencies on threat mitigation strategies, incident prevention and response, training, emerging security technologies, and other relevant topics to enhance electricity industry physical security and reliability. Mr. Siefken supports PNNL's National Security Directorate by implementing several international and domestic security assistance and non-proliferation programs because of his background, knowledge, experience, and skills. Rob's hobbies include: hunting, fishing, and woodworking in and around the Tri-Cities of Washington State.*

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Recommended Critical Infrastructure Security and Resilience Readings

Felix Kwamena, Ph.D.*
Email: felix.kwamena@carleton.ca

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UPCOMING EVENTS

2020- 2021

EVENT	DATE / LINK
Training Courses **Watch for new Dates**	https://carleton.ca/irrg/training/ **Suspended Due to COVID -19**
4th International Security and Resilience Symposium **Watch for new Date**	https://carleton.ca/irrg/cu-events/4th-international-urban-security-and-resilience-symposium/ **Cancelled Due to COVID -19**
3rd Economic Environmental Security, and Resilience Workshop Theme: A Multi-stakeholder, Multidisciplinary Approach to Addressing Challenges and Leveraging Opportunities **Watch for new Date**	November 10, 2020 https://carleton.ca/irrg/cu-events/economic-security-resilience/ **Cancelled Due to COVID -19**
2020 IRRG Dean's Lecture The Dean's Annual Lecture Series – Infrastructure Security and Resilience: Economic Security, Resilience. **Watch for new Date**	November 18, 2020 (4:00 PM – 6:30 PM) https://carleton.ca/irrg/cu-events/2020-deans-lecture/ **Cancelled Due to COVID-19**

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https://carleton.ca/irrg/journal/