Canadian Food Inspection Agency | Agence canadienne d'inspection des aliments

Innovative Food Safety Tools to Mitigate Risk using Quantitative Risk Modelling & Machine Learning

National Academies of Sciences - Food Forum

National and International Perspectives on Risk Assessment and Tools to Mitigate Risk

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Canada

Disclosure Statement

I have no conflicts to disclose

Outline

1. Canadian Food Inspection Agency

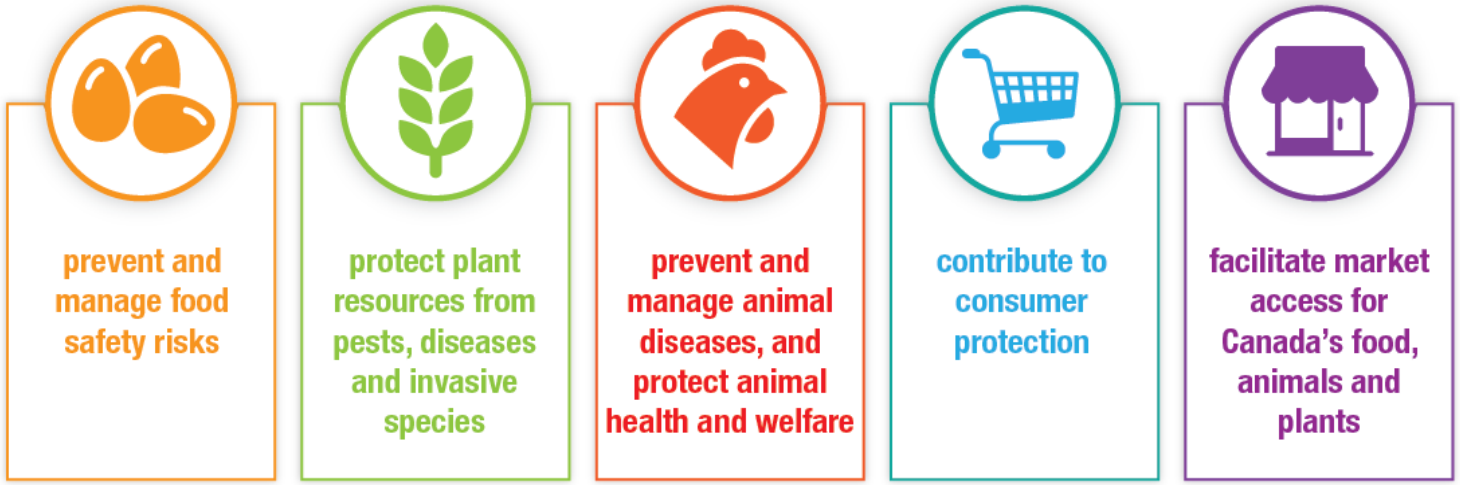
2. New Tools to Mitigate Risk

    I. Food Import Risk Explorer Model
    II. FISHnet
    III. MIST

3. Model Integration

Mandate of Canadian Food Inspection Agency

The CFIA develops regulations and delivers inspection and other services to:

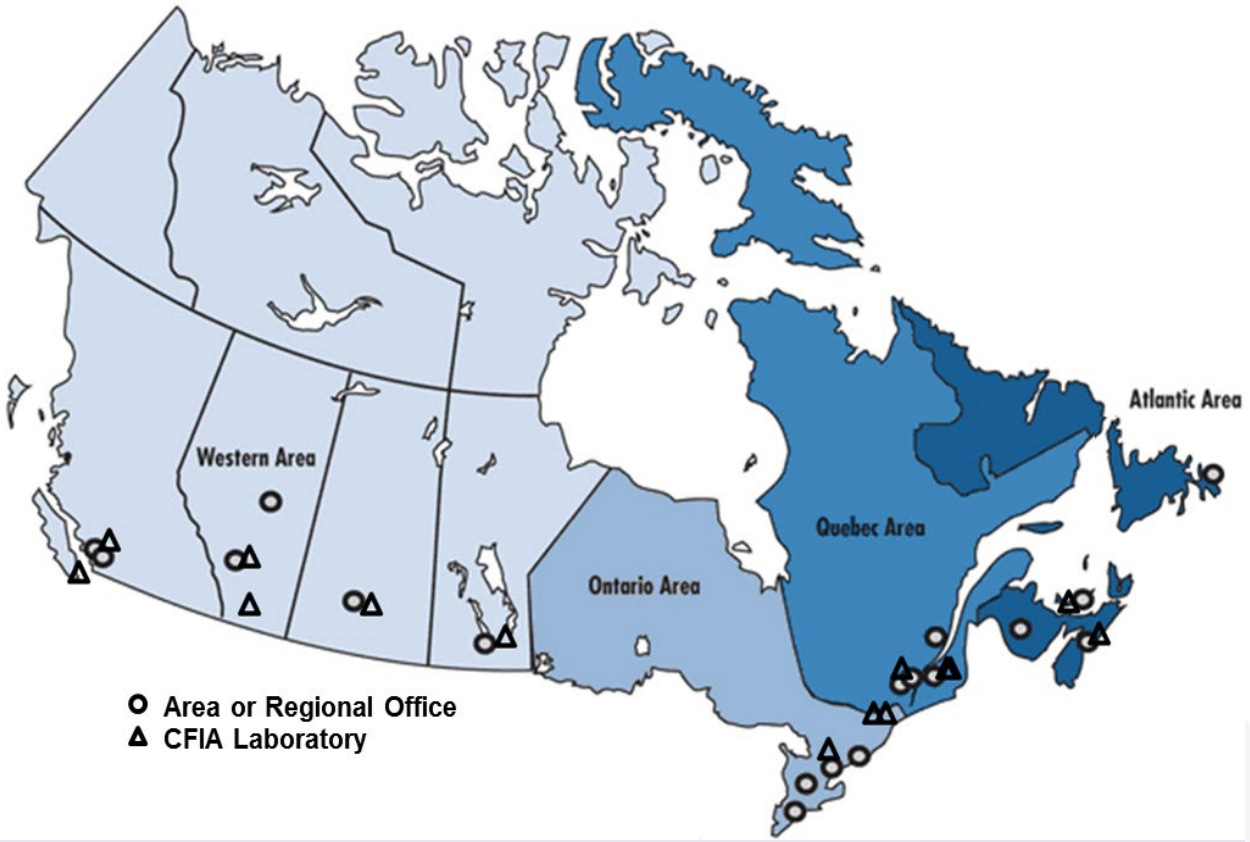


Vision

To excel as a science-based regulator, trusted and respected by Canadians and the international community.

CFIA at a Glance

- Created in 1997 - consolidating federal food, animal and plant inspection activities into a single agency.
- National headquarters in Ottawa
- 4 Operational areas:
  - West
  - Ontario
  - Quebec
  - Atlantic
- 18 regional offices and 160 field offices
- 400+ offices in non-government sites



The CFIA employs over 6,700 highly-skilled and trained professionals across Canada.

Scope of Risk Science at CFIA

- Risk-based activities to support decision-making are conducted by CFIA in three Program areas:
  - Animal Health
  - Plant Health and
  - Food Safety (limited to those informing food safety program design and implementation whereas Health Canada is responsible for risk assessments to establish food safety standards)
- Risk-based activities are also conducted to assess program performance, and support integrated risk management at the Agency level

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Advanced Data Analytics and Risk Modelling

Food Safety Science Directorate, Science Branch

Science-based evaluations and data-driven analytical solutions to support and inform program design and risk management decisions

What We Do:

- Develop new innovative quantitative risk models such as FIRE and FISHnet
- Build Machine Learning /AI Models
- Design Predictive risk models (time series)
- Perform Advanced data analytics (Meta-analysis, Bayesian Analysis, MCDA)
- Provide Epidemiology and statistical data analysis services for risk-informed Program design
  - Pathogen Reduction
  - Modernized Food Program

Food Import Risk Explorer (FIRE) Model

The Challenge (Issue)

Further improve CFIA's ability to systematically identify and prioritize risks related to imported food

- Need to focus resources to where they will be most efficient and effective at mitigating risks

FIRE – A Business Solution

An innovative model that **estimates imported food safety risks in Disability Adjusted Life Years (DALYs)** at the **food-hazard-country of origin** level

FIRE allows us to:

- **Compare relative risks** across commodities for different food-hazard-country of origin combinations
- **Prioritize risks** to be analyzed to inform program design and work plans; only one piece of information to help in decision making

Model Building Blocks & Architecture

Data Collection: Trade Partners and Import Volumes

- Mapping what's coming into Canada by common name using Harmonized System Codes
- Country of Origin data

What's being Imported and from Where?

Trade **Data**
Statistics Canada

CFIA Sample Results
(Step 1 - Hazard Identification)

- Mapping what hazards are being found and their prevalence
- Source attribution

What Hazards are we are finding in imported food?

Hazard **Data**
CFIA Sampling Data (**Microbial** Chemical, Allergens).

Consumption
(Step 2 - Exposure Assessment Exposure of consumers to hazard)

- Determining what is being consumed and how much?
- Exposure is by serving size
- Predicting the number of organisms in the food

What foods are Canadians eating with the hazard?

Consumption & Serving Size **Data**
Health Canada, published Canadian Data & Irish Database

Food Processing
(Step 3 - Dose Response Assessment Modelling – Hazard Characterization)

- Risk is different between organisms /hazards
- Variables include if consumed raw or cooked, growth during storage for example

Predicting changes in the food/risk due to Processing

Data is generated using Dose-Response Curves & Canadian burden of disease studies

Risk Characterization
(Step 4 - estimates level of risk)

Estimated risks are converted to a metric - *FIRE becomes a Comparative Risk Assessment Model*

Results Health Outcome

FIRE produces ranked lists at *Food x Hazard x Country* level measured using a common currency (Disability Adjusted Life Years - DALYs)

** FAO and WHO. 2021. Microbiological risk assessment - Guidance for food. Microbiological Risk Assessment Series No. 36. Rome

FIRE Algorithm

$$DALYs_{CFH} = \frac{Trade_{CF}}{SS_F} \times P(Exp)_{CFH} \times P(Ill|Exp)_{CFH} \times DALYs_H$$

Where the output ($DALYs_{CFH}$) is **Canadian DALYs** for a ***food-hazard-country of origin combination***, and:

C, F, H - Country, food, and hazard respectively.

$\frac{Trade_{C,F}}{SS_F}$ - Number of servings of the specified food from the specified country (Statistics Canada Trade data)

$P(Exp)_{C,F,H}$ - Probability the food from the given country is contaminated with the hazard (i.e., prevalence) (CFIA data)

$P(Ill|Exp)_{C,F,H}$ - Probability of a becoming ill after exposure to a contaminated serving (by country, food and hazard). This value is affected by dose (i.e. dose-response relationship), and incudes consideration of cooking and/or growth.

$DALYs_H$ - DALYs per case for the specified hazard (Havelaar 2012)

Example - Comparative Risks using FIRE Model Results

Country	Food	Hazard	Risk (DALYs)
A	Lettuce	*E. coli* O157	820
B	Lettuce	*Salmonella*	658
C	Fresh Herbs	*Salmonella*	262
A	Blackberries	Norovirus	136
A	Blackberries	E. coli O157	59
B	Blackberries	*Salmonella*	51
A	Fresh Herbs	*Salmonella*	39
C	Fresh Herbs	*E. coli* O157	27
A	Lettuce	*Salmonella*	21
A	Fresh Herbs	*Salmonella*	16
C	Blackberries	Norovirus	11
B	Lettuce	*E. coli* O157	8
B	Fresh Herbs	*Salmonella*	6
B	Blackberries	Norovirus	4

Total DALYs: 2118

Country

Country	Risk (DALYs)
A	1091
B	958
C	69

Country A has a higher relative risk than Country B or C.

Food

Food	Risk (DALYs)
Lettuce	1507
Fresh Herbs	350
Blackberries	261

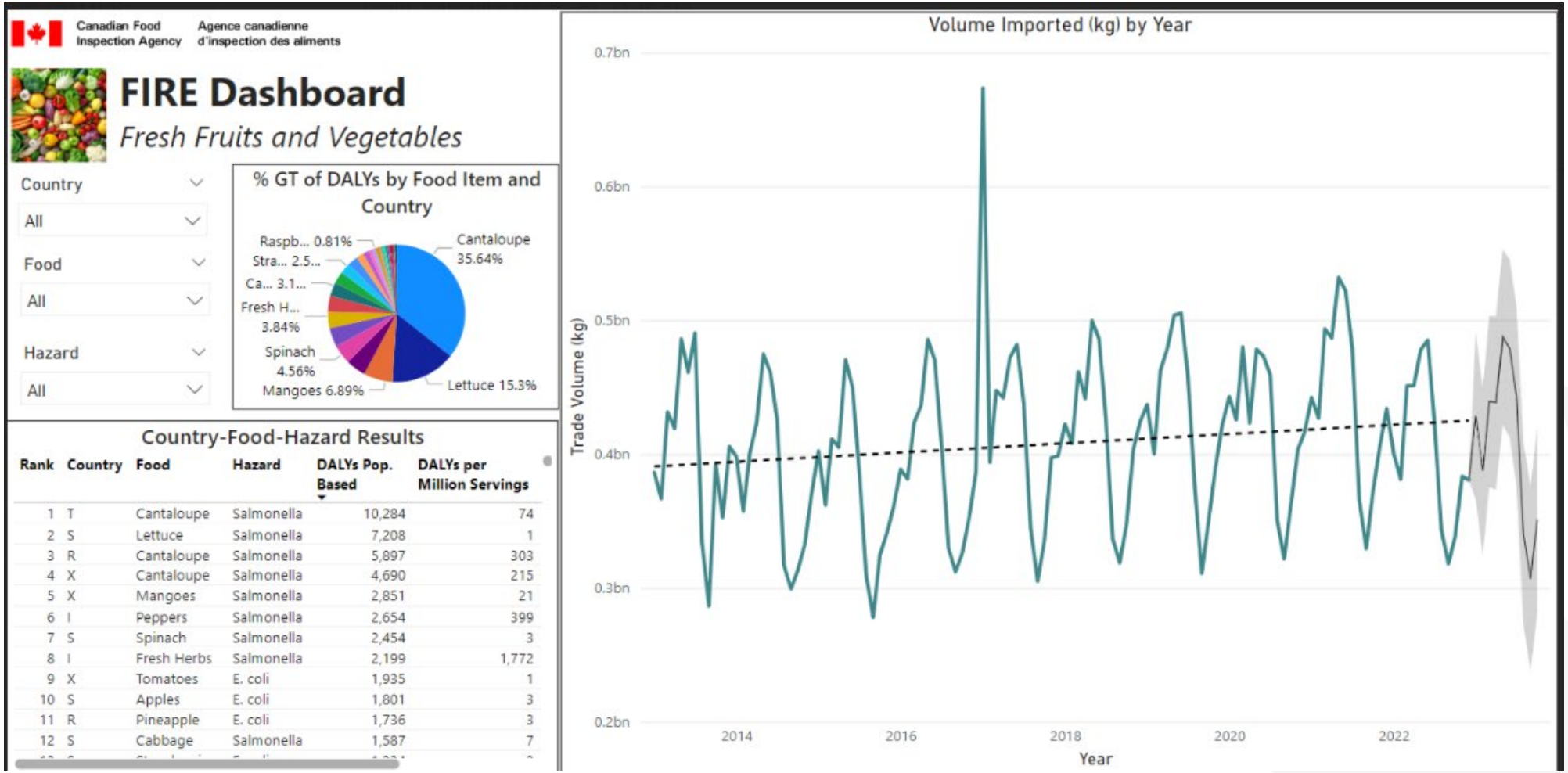
Lettuce has a higher relative risk than Fresh Herbs or Blackberries.

Hazard

Hazard	Risk (DALYs)
Salmonella	1053
E. coli O157	914
Norovirus	151

Salmonella has a higher relative risk than *E. coli* O157 or Norovirus.

Using a Power BI Dashboard to "*Tell the Story*"



FISHnet

The use of machine learning models will enable us to be more strategic and strengthen our ability to predict and prevent risk, which will in turn inform program design and delivery and allow inspection staff to make smarter, and faster decisions.

The Challenge

Import Inspection Process – Food Monitoring Plan

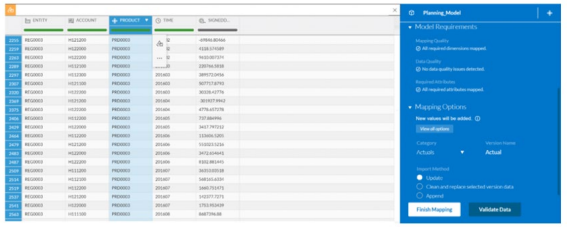
Arrives in Canada – Released by Canadian Border Services Agency

Food Sample Collection Plan

Inspectors select imported shipments for inspections at facility

Inspector travels to facility to conduct the inspection

Samples are submitted to appropriate lab for analysis - results recorded



1000's of lines

Misdeclared Import Surveillance Tool (MIST)

Food Import Misrepresentation Targeting Tool

Misdeclared Import Surveillance Tool (MIST)

MIST is a risk-based predictive screening tool created to help prioritize inspections of incoming import shipments at highest risk of containing undeclared or misdeclared products coming to Canada. It applies a risk-weighted ranking for auto-approved Harmonized System Codes (HS Codes) that do not require CFIA review for release approvals and are therefore more likely to be used to bypass Canadian import requirements.

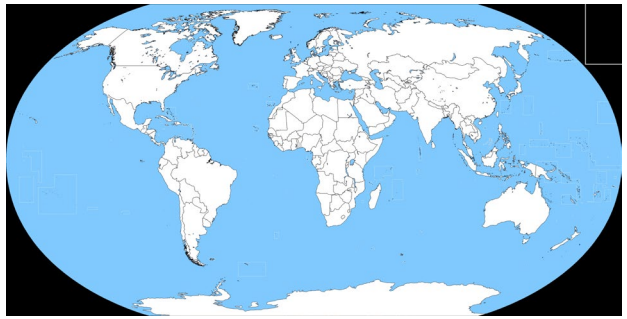
Auto Approved HS Code (1 to 5)

Port of Entry (1 or 5)

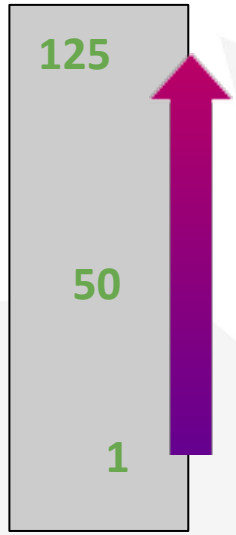
Main Marine Ports (Toronto, Halifax, Vancouver, Montreal) and Int'l Airports
Score = 5

Others
Score = 1

Country of origin (1 to 5)

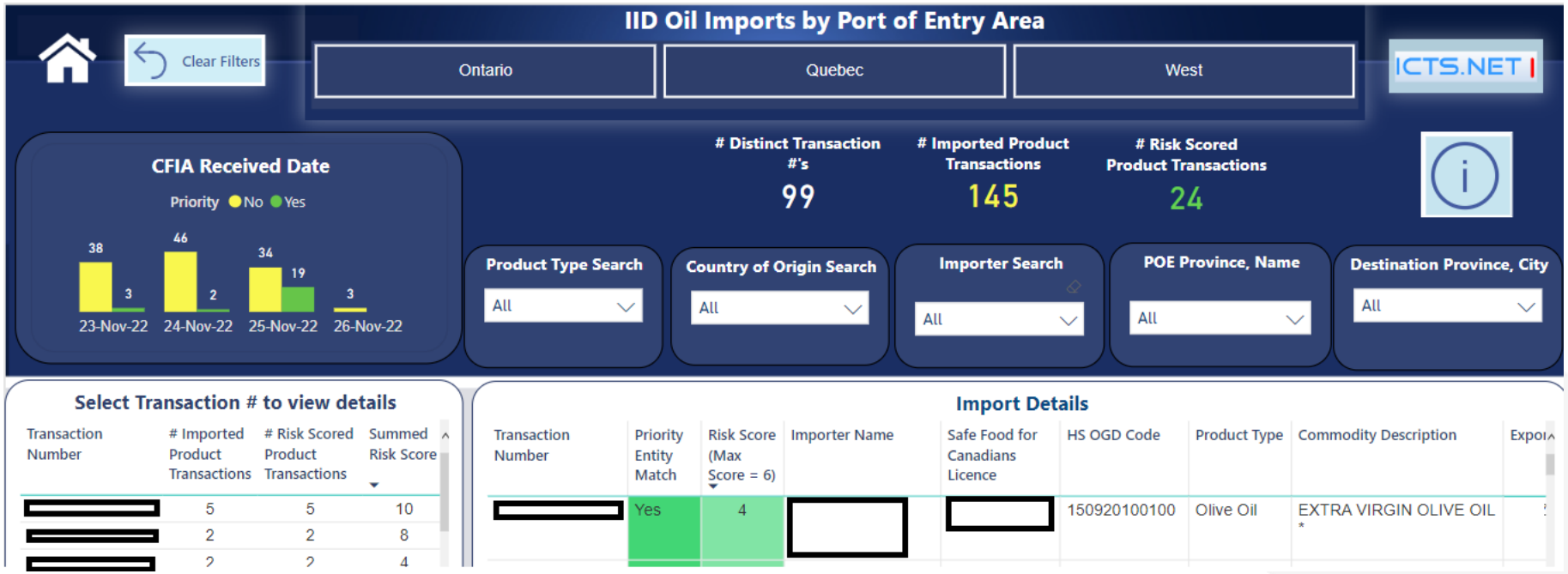


Potential Risk Scores

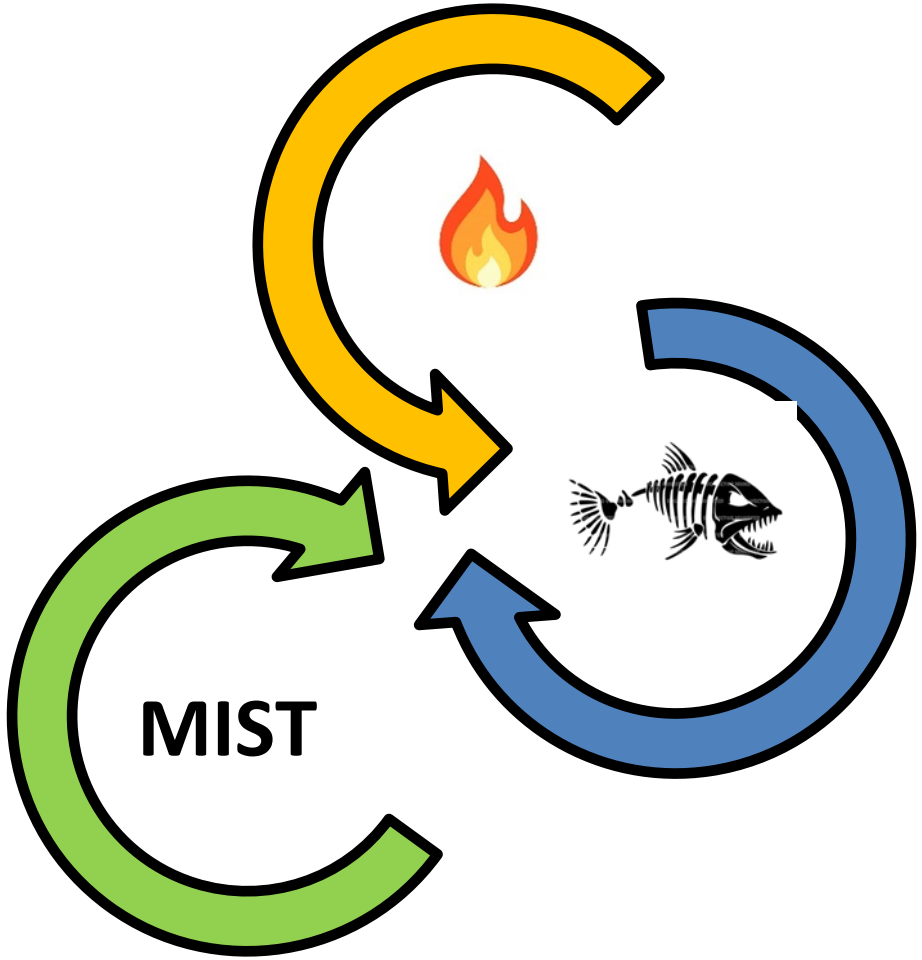


Food Import Misrepresentation Targeting Tool

Power BI is used to screen imports and identify high risk shipments to inspectors in near-real time - Import data is automatically assessed against established risk factors



Risk Models will Complement Each Other



Risk Based Program Design and Import Inspections

Paradigm Shift towards Prevention

Partners and Collaborators

Collaborations and Engagements

Science Branch
- Microbiology team
- Chemistry team
- Risk Intelligence and Outreach team
- Risk Assessment Division (IRA/ERA team)

Operations Branch
- Operational Intelligence, Targets and Enforcement
- Office of Food Safety Recall
- Planning, Reporting and Analytics Division

International Affairs Branch
- Food Imports
- Horizontal and Strategic Initiatives
- Technical Cooperation

Policy and Programs Branch
- Import Food Safety
- Results, Assessments and Measurement

Corporate Business Management
- Horizontal Enterprise Management and Integration

IBSDB
- Enterprise Data Solutions Division
- Risk and Analytics (CRM team)

Risk Modelling Collaboration

Canada
- Public Health Agency of Canada
- Health Canada
- Risk Sciences International (RSI)

International
- United States Food and Drug Administration
- United States Department of Agriculture

Data Acquisition

- Statistics Canada
- Department of Fisheries and Oceans
- Health Canada
- Public Health Agency of Canada

Tiwari, A., Lindgren, C.J., C. Semple, J. Falardeau, C. Sparr, M. Elgarf, & A. Ghiba. 2023. FIRE: the Food Import Risk Explorer, a tool for the comparative risk assessment of imported foods in the Canadian food supply. Society for Risk Analysis Annual Meeting, December 10-12. Washington, DC.

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Thank You for Your Time
Questions?
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Example: ***Salmonella*** **in Fresh Herbs from Country X**

Step 1: Calculate the proportion of imported food consumed.

$$\boldsymbol{DALYs_{CFH}} = \frac{\boldsymbol{Trade_{CF}}}{\boldsymbol{SS_F}} \times \boldsymbol{P(Exp)_{CFH}} \times \boldsymbol{P(Ill|Exp)_{CFH}} \times \boldsymbol{DALYs_H}$$

Amount of Fresh Herbs imported from Country X[1]:
$Trade_{CF}$ = 146,057 kg

Serving size of Fresh Herbs[2]:
$SS_F = 41$ g

[1] Data retrieved from Statistics Canada - Canadian International Merchandise Trade Database.
[2] Lyons, J (2013). *The Irish Food Portion Sizes Database.* Available at: https://www.iuna.net/

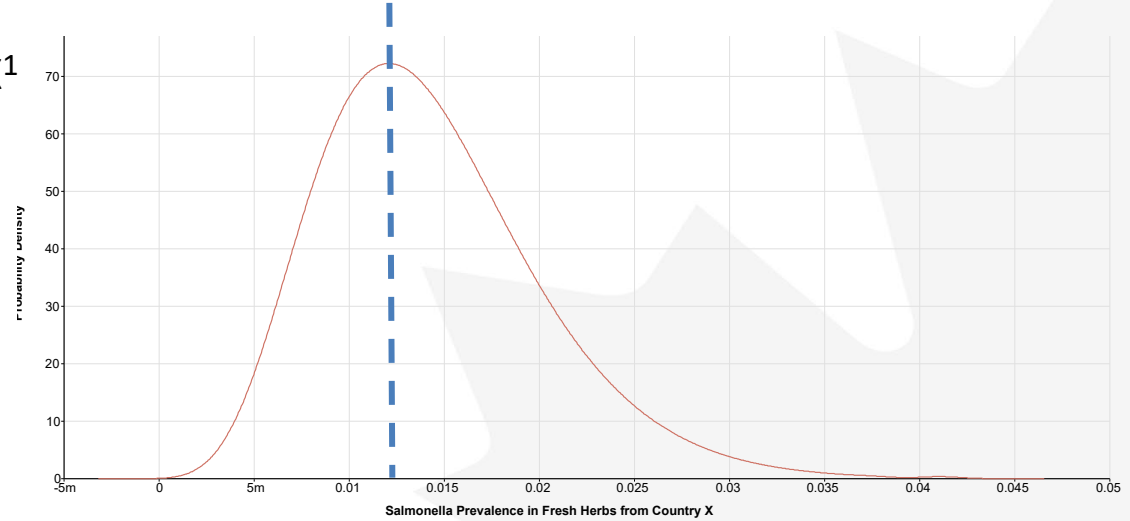
Example: ***Salmonella*** **in Fresh Herbs from Country X**

Step 2: Calculate the probability that food from a given country is contaminated by the hazard.

$$DALYs_{CFH} = \frac{Trade_{CF}}{SS_F} \times P(Exp)_{CFH} \times P(Ill|Exp)_{CFH} \times DALYs_H$$

Beta distribution of *Salmonella* in Fresh Herbs from Country X[1]

Taking the mean value (blue dashed line), the prevalence is about 1.43%



[1] Data from CFIA food surveillance programs.

Example: *Salmonella* in Fresh Herbs from Country X

Step 3: Calculate the probability that a person will become ill after exposure to the hazard.

$$DALYs_{CFH} = \frac{Trade_{CF}}{SS_F} \times P(Exp)_{CFH} \times P(Ill|Exp)_{CFH} \times DALYs_H$$

$$\begin{aligned} P(Ill|Exp)_{CFH} &= f_H(dose_{CFH}) \\ &= 1 - (1 + (dose_{CFH}/51.45))^{-0.1324} \\ &= 1 - \left(1 + \left(\frac{2.46\ CFU/serving}{51.45}\right)\right)^{-0.1324} \\ P(Ill|Exp)_{CFH} &= 0.0062 \end{aligned}$$

Beta-Poisson model for *Salmonella*[1]:

$f_H(dose_{CFH}) = 1 - (1 + (dose_{CFH}/51.45))^{-0.1324}$

Where,

$$\begin{aligned} dose_{CFH} &= SS_F \times 10^{C_{CFH}+G_{FH}-LR_{FH}} \\ &= 41\ g \times 10^{\log(0.06\frac{CFU}{g})+0-0} \\ dose_{CFH} &= 2.46\ CFU/serving \end{aligned}$$

$f_H(d)$ - Hazard specific dose-response model dependent upon the ingested dose d
C_{CFH} - Concentration of hazard ($\log_{10}$) by country, food, hazard
G_{FH} - Growth of hazard ($\log_{10}$) by food and hazard; 0 for *Salmonella* on Fresh Herbs
LR_{FH} - Reductions in hazard concentration ($\log_{10}$) post sampling, and prior to consumption (e.g., cooking); 0 for Fresh Herbs

[1] World Health Organization. *Risk assessments of Salmonella in eggs and broiler chickens*. Vol. 2. Food & Agriculture Org., 2002.

Example: *Salmonella* in Fresh Herbs from Country X

Step 4: Multiply by the number of DALYs per case for the specified hazard

$$DALYs_{CFH} = \frac{Trade_{CF}}{SS_F} \times P(Exp)_{CFH} \times P(Ill|Exp)_{CFH} \times DALYs_H$$

Number of DALYs per case of illness for *Salmonella* (non-typhoidal)[1]: 0.049

Table 4
Overall disease burden, disease burden per 100.000 inhabitants and mean disease burden per case of illness in the Netherlands, 2009.

Pathogen	DALY per year		DALY per 100,000 inhabitants		DALY per 1000 cases of illness	
Discount rate	0%	1.5%	0%	1.5%	0%	1.5%
Bacteria – infectious						
Campylobacter spp.	3250	2890	19.8	17.5	41	36
STEC O157	125	98	0.7	0.6	143	113
Salmonella spp.	1270	1100	7.7	6.7	49	41
Listeria monocytogenes (perinatal)	27	16	0.16	0.09	9190	5460
Listeria monocytogenes (acquired)	87	80	0.53	0.49	1140	1050
Listeria monocytogenes (total)	114	96	0.69	0.58	1450	1220
Bacteria-toxin-producing						
Bacillus cereus	112	112	0.7	0.7	2.3	2.3
Clostridium perfringens	536	531	3.3	3.2	3.2	3.2
Staphylococcus aureus	770	761	4.7	4.6	2.6	2.6
Viruses						
Norovirus	1480	1310	8.9	7.9	2.4	2.1
Rotavirus	1820	1630	11.0	9.9	4.9	4.4
Hepatitis A virus	142	123	0.86	0.75	167	145
Hepatitis E virus	24	20	0.15	0.12	460	380
Protozoa						
Cryptosporidium spp.	69	67	0.4	0.4	2.9	2.8
Giardia spp.	162	159	1.0	1.0	2.1	2.1
Toxoplasma gondii (congenital)	2270	1330	13.8	8.1	6360	3730
Toxoplasma gondii (acquired)	1350	1020	8.2	6.2	3170	2400
Toxoplasma gondii (total)	3620	2350	23.0	14.3	4610	2990

[1] Havelaar, Arie H., et al. "Disease burden of foodborne pathogens in the Netherlands, 2009." International journal of food microbiology 156.3 (2012): 231-238.

Example: ***Salmonella*** in Fresh Herbs from Country X

Putting it all together…

$$\boldsymbol{DALYs_{CFH} = \frac{Trade_{CF}}{SS_F} \times P(Exp)_{CFH} \times P(Ill|Exp)_{CFH} \times DALYs_H}$$

$$= \frac{146{,}057\ kg}{41\ g} \times 0.0143 \times 0.0062 \times 0.049 \frac{DALYs}{case}$$

$$\boldsymbol{DALYs_{CFH} = 15\ DALYs}$$

Result is 15 DALYs for *Salmonella* in Fresh Herbs from Country X.