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Tornado Mitigation in the Canadian Prairie Region

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Disaster Mitigation

- In Canada, approximately 80% of disasters are due to extreme weather events such as tornadoes, hurricanes, hail storms etc (Hwacha, 2005).
- Canada is gradually shifting from the ways governments have historically approached disasters, through response and recovery methods, to mitigation strategies (Emergency Management Act c.15, 2007).
- Canada's National Disaster Mitigation Strategy (PSC, 2010) highlights the need to “apply and promote scientific and engineering best practices in order to build a knowledge base for sustainable, cost-effective mitigation decisions that contribute to community resiliency”.

Tornadoes in Canada

- According to Environment Canada (EC), an average of 43 tornadoes per year occur across the prairies provinces and about 17 occur across Ontario and Quebec.

Source: (Grosvenor et al, 1998)

Research Objective

To study, analyze, model, simulate and propose improvements to plans and systems to mitigate the impacts of tornadoes in the Canadian Prairies

- Statistical analysis of historical Canadian Prairie data on tornadoes
- Network Modeling and Simulation of the tornado detection, warning and communication (TDWC) network
- Comparison of the Canadian and US TDWC systems
- Stated preference analysis of how Calgary households and vehicle-drivers will evacuate (or not) in response to tornado warnings
- Analysis of the total time consumption for warning, communication and evacuation
- Analysis of False Warning and Missed Events in the Canadian Prairies
- Recommendations for the stakeholders involved in the TDWC process

1. STATISTICAL ANALYSIS OF THE TORNADO DATABASE

No of Tornadoes Reported

Population vs. Time

Model Fitting

Model

$$T_o(t) = T_A e^{\beta P^k} t^\alpha$$

$$T_o(t) = 1987.2 e^{22.6P^{\wedge}-2.1} t^{-0.796}$$

Overall Trend

Model (Last 70 years)

$$T_o(t) = 1987.2e^{22.6P \wedge -2.1} t^{-0.796}$$

Polynomial Trend for [T observed – T vs. t,P]

$$M(t) = 0.1935 - 1.267t + 0.074t^2 - 0.00087t^3$$

} (+)

R^2 of the overall trend = **0.616**

A cyclic nature for the observed tornado frequency with a period of around 65 years

2. ANALYSIS OF THE TORNADO DETECTION, WARNING AND COMMUNICATION SYSTEM IN CANADA

Objective:

- To model the tornado warning and communication process using the network modeling approach, simulate the network and propose improvements

Network Modelling Approach:

- Application of network modelling in emergency situations is an emerging approach that can be applied to model and analyse disaster scenarios. Such an approach for tsunami mitigation network analysis has been reported by Fernando et al. (2008), Ruwanpura et al. (2009) and Wickramaratne (2010).

Tornado Detection, Warning and Communication Network

- A** - Conditions are favourable for severe weather development
Severe Thunderstorm Watch issued
- B** - Recognize Severe Thunderstorm triggers (Tornado may be possible)
Severe Thunderstorm Warning Issued / **Public** - Activate Preparedness Plan
- C** - Conditions are favourable for tornado development
Tornado Watch is issued
- D** - Tornado may be probable, imminent or immediately occurring
Tornado Warning is issued
- E** - Public Receive Warning / **Act Immediately**

Network Simulation – Monte Carlo Simulation

There is a 50% chance that tornado detection, warning and communication can be completed within 20.5 minutes or less.

SPC vs. Local Activity Sequence

Network with SPC Activity Sequence

The average time consumption for the activity sequence is 23 minutes which is slightly higher than the time consumption of the overall network.

Network with Local Level Activity Sequence

Even if a higher time is consumed for the TDWC network, much of this time is allocated for tornado detection and verification.

Once a tornado threat is verified the message can be disseminated immediately to the public through AEA system.

3. STATED PREFERENCE SURVEY

-Tornado Evacuation Behaviour Analysis

- Nearly 500 Calgarians took part in the online survey and provided information on how they would respond to tornado warnings after receiving them.
- The respondents were asked to assume that they received a tornado warning; and, their intended evacuation responses when at home and driving were collected separately.

Variable	Response Categories	Percentage
Gender	Male	66.0
	Female	34.0
Age	Below 30	13.5
	Between 30 and 50	52.8
	Above 50	33.7
Dwelling Type	Single Detached Dwelling	74.6
	Other	25.4
Household Size	One	12.8
	Two	32.3
	Three or More	54.9
Presence of School Aged Children	Yes	33.5
	No	66.5
Presence of People with Reduced Mobility	Yes	6.2
	No	91.7
	Not Answered	2.1
Household Income	Less than \$50,000	9.3
	\$50,000 - \$120,000	36.8
	Above \$120,000	40.1
	Not Answered	13.8
Level of Education	Up to High School	7.1
	Training after High School	32.8
	Undergraduate Degree	38.5
	Postgraduate Degree	19.0
	Not Answered	2.6

Household Responses

Warning Sources

Please rate each likely source of warning to **your household** in case of a tornado (1-Least likely, 5-Most likely).

Evacuation Actions

Household Evacuation	Ranking Average (1-6)
Go to a safer area in the basement	1.47
Lie down in a bathtub	3.20
Go to a safer building within the neighbourhood	3.39
Drive away to avoid the threat	3.70
No evacuation action	3.79
Other	5.46

Driver Responses

Warning Sources

During your trip, from what sources are you likely to receive the warning?
(1-Least Likely, 5-Most Likely).

Evacuation Actions

Evacuation for Drivers	Ranking Average (1-7)
Drive away from the direction of the tornado	1.71
Drive to the nearest building	2.73
Seek roadside shelters, such as bridges, highway overpasses and stop underneath	2.74
Stop on the roadside and stay in the vehicle	4.23
Do nothing and continue driving	4.85
Stop on the roadside and hide under the vehicle	5.26
Other	6.49

Analysis Results

Household Evacuation

- Respondents who are aware that the lowest level of shelter is generally the **safest location** during a tornado would be more likely to **take safer evacuation actions**, such as going to the basement within 5 minutes.
- Those who **seek more information** about an official warning before deciding to evacuate are more likely to **spend more time** before going to the basement or taking another evacuation action.
- People who intended to **pick up children** from schools or outdoor events are more likely to **spend more time** before completing their evacuation actions.

Driver Evacuation

- People who receive warnings about tornadoes from other road users are more likely to take shelter inside or under the vehicle than drive away from the direction of tornado.
- The odds of seeking roadside shelters versus driving away by people who receive warnings through mobile text alerts are much lower compared to people who do not get warnings through mobile text alerts.
- People who get warnings through **local radio** are more likely to **take roadside shelters** compared to the drive away action.

4. TOTAL TIME CONSUMPTION FOR WARNING, COMMUNICATION AND EVACUATION

Objective:

- To compare the total time consumption with the warning lead time

Warning issuance to the warning receipt point

(Network Simulation)

+

Warning receipt point to the evacuation completion point

(Public Survey)

- Curve fitting procedures required for this analysis used EasyFit software

Overall Time Consumption

Household Scenario

- Warning issuance to the warning receipt point

- Warning receipt point to the evacuation completion point

Driving Scenario

- Warning issuance to the warning receipt point

- Warning receipt point to the evacuation completion point

Overall Time Consumption

Household Scenario

- There is around 25% chance that the evacuation can be completed by a household within 10 minutes from the warning issuance point.
- Increasing the time by 5 minutes gives a 75% chance for a household to complete evacuation.

Driving Scenario

- There is nearly a 33% chance that a driver can complete evacuation within 10 minutes from the warning issuance point.
- If the time is 15 minutes, there is an 80% percent confidence that a driver can complete evacuation prior to a tornado touchdown.

5. IMPACT OF FALSE WARNINGS AND MISSED EVENTS ON TORNADO WARNING PERFORMANCE

		Tornadoes Observed	
		Yes (T)	No (T')
Tornadoes Forecasted (or Warned)	Yes (W)	p True Warning	r False Warning
	No (W')	q Missed Event	s Status Quo

- A true warning for a tornado is a clear communication to the public to evacuate to safer places prior to an actual occurrence.
- A **false warning** can be considered to be a situation when the public is warned about a tornado and one actually does not occur.
- A **missed event** is a situation where a tornado touchdown occurred without an advance warning being issued.
- This status quo infers the correct detection of the situation that there is no tornado potential within a thunderstorm, thus, no warning is required.

Analysis of Tornado Warnings in the Canadian Prairies

Venn Diagram of tornado warning, occurrence records from 2003 to 2012

True Warning, False warning, Detection Probabilities given a Severe Weather Bulletin

Probability of True Warning $P(T/W)$	Probability of False Warning $P(T'/W)$	Probability of Missed Event $P(T/W')$	Probability of True Detection $P(W/T)$	Probability of False Detection $P(W/T')$
12.6%	87.4%	10.7%	39.8%	35.4%

Household Decision Tree for a Tornado

p = Probability of a tornado given that a warning has been issued

- The expected disutility of responding to a warning $E(R) = p(U_2) + (1-p)(U_1)$
- The expected disutility of not responding to a warning $E(R') = p(U_3)$
- The household will choose to respond if $E(R') > E(R)$

$$p > \frac{1}{1 + \left(\frac{U_3 - U_2}{U_1} \right)}$$

Household Decision Tree for a Tornado

- Inequality

$$p > \frac{1}{1 + \left(\frac{U_3 - U_2}{U_1}\right)}$$

- $(U_3 - U_2)$ - the additional disutility or the consequences of not responding to a tornado warning
- U_1 - Negative consequences of responding to a false warning

When the consequences of not responding to a tornado warning is higher;

even a low probability of a true warning p is sufficient to trigger evacuation response.

When the negative consequences of responding to a false warning is higher;

it is necessary to have a higher value for p to initiate response actions.

Warning Decision Tree for Forecasters

Warning Decision Tree for Forecasters

- The forecaster should choose to issue a warning if the expected disutility of not giving a tornado warning is greater than the expected disutility of giving a warning
- Fundamental inequality of decision making for tornado warnings

$$r > \{ 1 - [P(T/W') / P(T/W)] \} / [1 - (U_2/U_3)]$$

Case (i) When the Missed event probability- $P(T/W')$ is greater than the true warning probability- $P(T/W)$;

Any response probability r or even a complete non response ($r=0$) is sufficient to justify a warning.

Case (ii) When the Missed event probability- $P(T/W')$ is smaller than the true warning probability- $P(T/W)$;

The response probability has to be higher than a certain positive value to justify a warning.

6. RECOMMENDATIONS

Stakeholder	Recommendations
SPC	<ul style="list-style-type: none"> Check the sufficiency and efficiency of the technological and human capacity to detect tornadoes and take remedial measures (Subsections 8.1.1 and 8.1.2) Implementation of an organized group of spotters to get true ground information (Subsection 8.1.3) Develop interactions with the local emergency managers (Subsection 8.1.4) Promote the use of Weatheradio as the primary warning source (Subsection 8.1.5)
CEMA	<ul style="list-style-type: none"> Conduct annual information sessions and drills to improve the awareness and preparedness at the individual, institution and community levels (Subsections 8.2.1 and 8.2.4) Develop interactions with the SPC, spotters and the public to get tornado information and activate the Alberta Emergency Alert(AEA)system (Subsections 8.2.2 and 8.2.5) Utilize various communication media, including traditional local media (radio and TV), the Internet, social media and smartphone applications, in order to reach a diverse population with different preferences (Subsection 8.2.3)
AEMA	<ul style="list-style-type: none"> Strengthen the AEA system to verify tornado information at the local level (Section 8.3)
Schools	<ul style="list-style-type: none"> Practice evacuation drills in the spring season (Subsection 8.5.1) Improve the awareness of parents regarding school evacuation measures (Subsection 8.5.2)
Calgary's Road Operations Centre	<ul style="list-style-type: none"> Initiate the use of variable message signs for severe weather warnings including tornadoes (Subsection 8.6.1) Educate drivers on how to respond to a tornado emergency (Subsection 8.6.2) Study traffic management technologies for responses to a tornado warning (Subsection 8.6.2)
Media	<ul style="list-style-type: none"> Educate the public by facilitating discussions about tornado preparedness and response in the spring and summer seasons(Section 8.7)
Police	<ul style="list-style-type: none"> Be ready to respond once a tornado touchdown is reported (Section 8.8)
The Public	<ul style="list-style-type: none"> Improve the awareness of weather alerts, watches, warnings and evacuation actions (Subsections 8.9.1, 8.9.3, 8.9.6 and 8.9.7) Observe to recognize the environmental cues of tornadoes (Subsection 8.9.2) Develop a family preparedness plan in responding to a tornado (Subsection 8.9.5)