EVALUATING THE IMPACTS OF EXTREME WEATHER EVENTS ON THE INFRASTRUCTURE DEVELOPMENT OR CONSTRUCTION INDUSTRY IN ONTARIO

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ABSTRACT

In Canada, construction companies are facing disruptions to their operations due to bad or extreme weather conditions such as thunderstorms, heavy precipitation, flooding, heatwaves and snowstorms, which cause project delays, loss of productivity and increased financial costs. This sector is prone to more disruptions due to increase in the frequency, duration and intensity of extreme weather events due to future climate change. This study examined the impacts of extreme weather events on infrastructure development companies and investigated their current practices and actions to alleviate these impacts. A survey questionnaire was developed and administrated to owners, managers, engineers, supervisors and planners of construction companies. Apart from descriptive evaluations, the survey responses were quantitatively analyzed to determine the impact of bad weather conditions on the construction companies. The findings of this study suggested that most construction companies' operations were delayed due to bad or extreme weather events. However, construction industry is not adopting proactive measures to avoid or minimize these impacts. The main environmental factors impacting construction companies, included flooding, high winds or thunderstorms, warm/cold temperatures, heatwaves and snow/ice storms. These bad weather impacts were more significant for non-government construction companies as compared to those working in the government sector. Indirect impacts of bad weather included disruptions to their supply chain networks and changes in customer behaviours; however, these impacts were minor compared to direct environmental impacts. The study found that both government and non-government sector construction companies granted accommodations to the workers during bad weather conditions; however, government sector companies were more accommodating as compared to non-government companies.

The study results also provided insight into the financial impacts of extreme weather events on construction companies. Weighted average losses for government sector companies were $2,200 per day of bad weather as compared to $8,155 per day for non-government companies. This suggested that non-government construction companies may experience serious financial consequences due to bad or extreme weather events. Study results further showed that there were no adequate guidelines, protocols or standards available to construction companies to adapt their operations and planning for extreme weather events. The study also highlighted the lack of adequate insurance products available for the construction sector to deal with bad weather. There was little tendency shown by the construction companies to use new technologies to deal with bad weather conditions. Therefore, there is an urgent need to develop guidelines, protocols or standards for construction companies by involving all levels of the government and relevant private sector organizations. This study helps to determine the nature and scale of extreme weather impacts on construction industry and explores what strategies may be developed to alleviate these impacts and risks. Such knowledge will help companies better plan and manage their operations and effectively use their human resources. It will help in timely delivery of services and savings in costs by the infrastructure development companies, which are a major contributor to the Canadian economy.

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CHAPTER 1

1. Introduction

1.1 Study background and Literature Review

Short term and long term changes in climate and extreme weather events are impacting almost all major sectors of the Canadian economy such as forestry, agriculture, municipal water management systems, transportation, buildings, construction industry and tourism. The main reason for the increase in Earth's temperature and changes in climate is the industrial revolution and increase in greenhouse gas emissions. The average global surface temperature has increased by 1.0 ℃ (0.8℃ and 1.2℃) between 1880 to 2017 (IPCC 2012; 2018). This temperature increase is about 0.2 ℃ per decade and it is much higher in high latitudes and urban areas due to heat island effects. In Canada, mean annual temperature has increased by 1.7 ℃ from 1948 to 2016 and this change is 2.3 ℃ for northern regions in Canada. Warming is projected to increase at almost double the rate of global mean temperature in Canada in the future (Bush et al., 2019). Warmer temperatures in recent decades are causing extreme weather events such as heatwaves, intense precipitation, drought, and flooding to become more severe and frequent in many parts of the world, including Canada (IPCC 2012; 2018; Bush et al., 2019). According to the IPCC (2018) report, 20–40% of the global human populations lives in regions that have already experienced warming of more than 1.5℃ above pre-industrial temperatures in at least one season by the 2006–2015. Currently, 58% of the world's population lives in cities or urban areas and this portion will increase to 68% by 2050 (IPCC, 2012). In Canada, this proportion is >80% (Statistics Canada, 2018). This increase in urban population and urban living will require more infrastructure development that will cause further increases in greenhouse gas emissions. The

impact of environmental and climatic changes on nature and society will depend on how humankind responds to these changes through technological innovations, economic decisions and changes in the lifestyle (Moss et al., 2010). Drastic greenhouse gas emission reduction measures are required by every nation to limit warming to 1.5°C, while achieving sustainable development and poverty eradication goals as agreed in Paris Agreement under the United Nations Framework Convention on Climate Change in 2015.

The construction industry is a major economic sector in Canada, employing more than 1.2 million people (Statistics Canada, 2019). This sector is the fifth largest employer in the country. Canada's construction industry represents about 6% of Canada's gross domestic product, contributing $73.8 billion to the economy (Statistics Canada, 2019). In Canada construction companies are facing disruptions in their operations due to bad and extreme weather conditions, resulting in loss of productivity and increased costs. Specifically, extreme weather events can cause major work delays, harm the equipment and materials, cause injuries to workers, damage and disrupt construction sites (Johnson and Buck, 2013). However, there is lack of studies that focus on extreme weather impacts on the construction sector in Canada. This sector will be prone to more damages and disruptions due to increase in the frequency, duration and intensity of extreme weather events because of future climate change. In particular heavy precipitation, flooding, heatwaves and windstorms may be major factors impacting construction sector.

In a literature review, Siraj and Fayek (2019) discussed in detail the risks for construction projects. They found that adverse or bad weather was the most frequently mentioned risk factor for construction projects. These adverse weather conditions included rainfall, snow, temperature

and windstorms. In their literature review, 46% of 130 articles highlighted these risk factors. Unforeseen changes in weather and unanticipated extreme weather events impact the progress of construction projects, causing critical work delays and compromising the successful completion of the project (Ballesteros-Pérez et al., 2017; Akinci and Fischer, 1998). Wedawatta et al. (2011) studied small and medium-sized construction companies in United Kingdom (UK) and showed that these companies are among the worst impacted by the extreme weather events and they are highly vulnerable section of the UK economy. Williams et al. (2018) studied the climate risks for the S & P 500 index companies, suggesting that increase in the frequency and severity of extreme weather events could impact earnings of their asset management companies. It may also include delays and cancellation of construction activities.

In Canada, Martin et al. (2017) have discussed the potential impacts of severe weather on residential buildings and construction industry in Ottawa, Ontario. These impacts include risks to structures and workers as well as insurance liabilities and lack of construction industry related regulations and policies. Harty et al. (2007) has highlighted the impact of environmental change for construction industry and argued that climate change and extreme weather events, dwindling natural resources and demographic change could introduce new challenges for the construction sector in the coming decades. This investigation focused on the potential effects of environmental change on structures in Ottawa, Ontario and explored how development organizations in Ottawa region confronted various types of extreme events. As indicated in their study, flooding, wind, freezing rain and heat waves were prominent extreme events that may impact infrastructure. Warm temperatures and heatwaves also diminished the work efficiency in building sector (Martin et al., 2017). An important example of a major extreme event impacting

almost all sectors of economy and life is 1988 ice storm in parts of Ontario and Quebec that caused widespread damage to houses, trees and electrical infrastructure and is considered among the worst natural disasters in the Canadian history (Kerry et al., 1999).

Because of climate change, the frequency and intensity of extreme weather events is expected to increase (IPCC 2012; 2018). Wazneh et al. (2019) have analysed the impacts of past and future climate change on extreme weather events for southern parts of Canada from 1981 to 2100. In the literature, it has been generally recognized that extreme weather events impact the profitability in the infrastructure development sector (Twidle, 2018; Williams et al., 2018). As mentioned earlier, these impacts may include delays in work, damage to construction sites and equipment, reduced efficiency or health risks to workers and financial loses due to increased material and insurance/liability related costs. Therefore, companies must plan their projects very carefully to avoid project delays or damages to construction sites (Johnson and Buck, 2013). Work delays and associated penalties can be very costly and may also include legal costs. Working in extremely warm weather may cause mental and physiological impacts on construction workers, diminishing their performance and efficiency, which may also delay projects (Hancher and Abd-Elkhalek, 1998). Kadiri et al. (2014) argued that it is an obligation of the management of the construction companies to eliminate or distinguish these risks.

Major construction companies in Canada carry out a large portion of their work over large geographic areas such as road construction, power grids, natural gas pipelines and communication infrastructure. Most of this work is performed over summer periods, while activity in the winter season is limited, except for some specific projects that require frozen

grounds. Because of the shorter work season in Canada, delays in projects due to bad or extreme weather may become major risk factors for construction companies, impacting not only the timely completion of projects but also the quality of work. Bad weather-related risk factors may emerge at any stage of the construction project and they may occur more than once over the project's life cycle (Zou et al., 2007). Therefore, avoiding or minimizing these risk factors is among key issues faced by these companies. They may have very serious consequences for the overall project completion and added costs for these companies (Aecon Group Inc. 2016).

1.2 Research problem or knowledge gaps

Bad or extreme weather events can impact the quality, success and timely completion of the projects and hence profitability of the construction companies (Wedawatta et al., 2011). Identifying the nature and severity of these effects is important for project planning, cost estimates, required human resources and timely completion of the projects (Moselhi et al., 1997). Weather changes can have both positive and negative effects. Sometimes these impacts many be indirect as well. For example, heavy rain, flooding or snowstorms can disrupt transportation systems, supply chains and customer demands (Gritzo, 2016). Weather changes or extreme weather events can affect the water supply required for construction sites, upset the supply of raw materials, or damage the crucial foundations for large projects such as refineries and transportation systems (Bapna, 2012).

Wedawatta et al. (2011) further suggested that the biggest effect of extreme weather events on construction industry finances was due to the absence of workers, loss of productivity and interruptions in accessing the project sites. Delays in construction activity are a common issue in

the infrastructure development industry and can extend project completion timelines and increase costs. There is a general tendency among infrastructure development organizations or construction industry not to consider extreme weather events as a significant issue or danger to their business practices and develop and adopt appropriate management techniques to alleviate them. Absence of appropriate planning to deal with bad or extreme weather events could fundamentally influence the capacity of construction companies to withstand and deal with these events, which many results in cost overruns. Construction companies or contractors may also have to assume liability to pay for project losses and delay costs. These impacts may be further amplified due to future climate change.

Climate scientists suggest that bad or extreme weather conditions are increasing in frequency and intensity and extreme events that were predictable from historical patterns are now becoming more random and frequent (McBean, 2012). Climate change and extreme weather events are considered major challenges confronting the construction industry and the construction industry seems not well prepared to deal with them (Mills, 2003). Regardless of the gravity of the issue, few researches have conducted comprehensive analysis or studies about how bad and extreme weather event may impact construction industry and how these industries have prepared themselves to deal with them (Ballesteros-Pérez et al., 2015; Hasan et al., 2018). These studies are lacking in Canada, where impacts of extreme weather and climate change are expected to be much more severe. This research study will contribute to fulfill these knowledge gaps regarding extreme weather events and their impacts on the resilience of construction companies. This study will identify the major impacts or hazards associated with the bad or extreme weather events for

the construction companies and what measures can be taken to improve the versatility and performance of these companies.

1.3 Study Objectives

The overall objective of this research is to investigate the impacts of bad weather or extreme events on infrastructure development sector or construction industry in Ontario, Canada by conducting a survey. The specific objectives are to:

a) Examine the impact of extreme weather events on infrastructure development sector or construction industry.
b) Identify the construction company's perception of extreme weather event associated risks and their impacts.
c) Determine the nature and scale of extreme weather impacts on construction industry and explore what strategies may be developed to alleviate these impacts and risks.
d) Explore the decision-making process of construction industry to deal with bad weather or extreme events.

This study will help to determine the nature and scale of the bad or extreme weather impacts on construction companies. It will help in developing protocols and decision-making frameworks which can be used by the construction companies to better plan and deal with bad weather and extreme events, manage their operations and effectively utilize human resources.

CHAPTER 2

2.1 Methodology

In this study a questionnaire was developed in order to collect relevant data from different construction companies. It was intended to seek input from various stakeholders including owners, managers, supervisors, engineers and planners to explore how changes in extreme weather events are impacting operations, employees, costs and profitability of this important economic sector. A list of total 450 construction companies or infrastructure development organizations from both government and non-government sectors was compiled using information from various sources, including Info Canada, dataset for infrastructure development companies and by searching websites of construction companies. The participants of this study were contacted through emails to explore their willingness to participate in the survey. The self-administered survey approach used in this study is the most common surveying techniques used in the literature (Dillman, 2002). McLafferty (2003) mentioned that questionnaire survey studies have been widely utilized to investigate individuals' perceptions, actions and practices. The online survey has significantly higher response rate than the email attached survey approaches, however, there is no difference in response speed or response bias (Dommeyer and Moriarty, 2000).

The survey was conducted on-line using McMaster Lime Survey tool. Prior to the administration of the survey, research ethics approval was obtained from by the McMaster University Research Ethics Board. Willing participants were asked to provide their consent before taking the on-line survey. People filling out this survey included owners, managers,

engineers, supervisors and planners associated with infrastructure development companies as well as employees of provincial, local or municipal government and conservation authorities associated with infrastructure development sector.

Prior to developing questionnaire for the survey, a literature review was conducted in order to determine the nature of problems faced by the construction companies and available knowledge, resources, protocols and policies, as described earlier in the introduction section of this thesis. In total 13 questions were developed to cover a range of major aspects as described in Section 2.2 on Research Questions. The questionnaire was specifically planned for seeking data about the impacts of bad weather or extreme weather events on the infrastructure development industry and construction companies. The study area included the province of Ontario in Canada; however, the majority of construction companies were located in Southern Ontario region (Figure A). Some of these companies were operating at national level.

In total 50 companies out of a total of 450 that were contacted responded to the survey. Of these, 20 were from the government and 30 were from the non-government (30) sectors. Further details of the survey design and survey questions are given in Appendix A and B. Data analysis was conducted using MS Excel and R studio software.

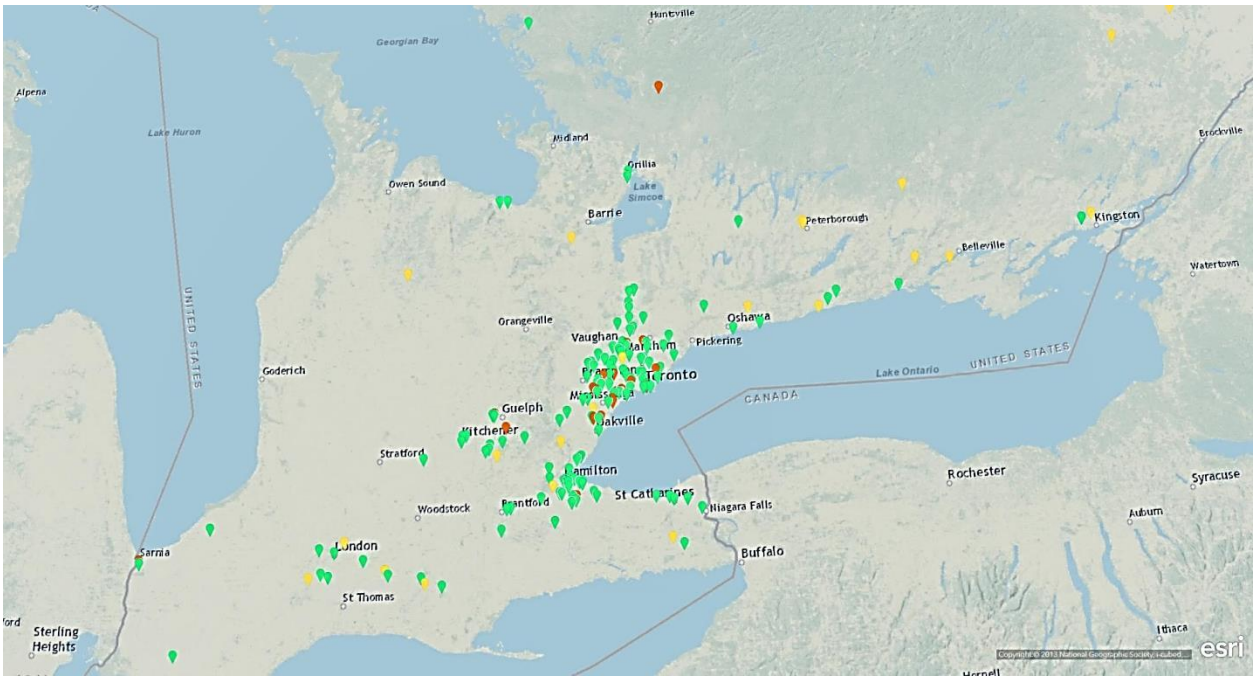

Figure 1: Location of the construction companies participating in this study.

2.2 Research aspects covered in the survey

The following key aspects were covered in the survey with a specific question asked about each.

1. Types of extreme weather events impacting the construction companies.
2. Delays in company operations due to bad weather.
3. Disruptions in supply chain due to bad weather.
4. Accommodations to construction workers due to bad weather.
5. Bad weather impacts on customer behavior.
6. Financial losses of construction companies due to one day of bad weather conditions.
7. Use of decision-making frameworks by the construction companies to deal with extreme weather events.

8. Availability of insurance products to construction companies to deal with bad weather conditions.
9. Availability of guidelines, protocols or standards to infrastructure development sector or construction industry from the Canadian government.
10. Adoption of new technologies to deal with bad weather condition.
11. Overall impacts of extreme weather events on company's operations, workers and profitability.
12. Scope or level of planning by the construction companies to deal with bad weather conditions.

2.3 Analysis of extreme weather impacts on construction companies

In order to explore the determinants of construction company's response attributes and characteristics for bad or extreme weather conditions, an ordinal logistic regression model was fitted and utilized. The order response model was chosen for analysis as it allows more than two response categories of the dependent variable. The construction company's attributes and characteristics level, where "Never, Seldom, Sometime, Often and Almost Always" were converted in an ordinal scale where "0" stands for "Never" and "4" stand for "Almost Always" in the model.

The following specification of an ordinal response model was used:

$$Y_i = \beta X_i + \varepsilon_i \qquad (1)$$

Where Y_i is the latent and continuous measure of construction company attributes and characteristics, where i ranges from 0 to n. β is the coefficient associated with the explanatory variables. X_i is the vector of explanatory independent variables describing extreme events and ε_i is the random error term. Y_i takes on values 0 through n generating an ordered portioning of the latent level of construction company characteristics and attributes into the observed categories according to the following scheme:

$$-\infty < \mu 1 < \mu 2 < \cdots < \mu n - 1 < \_\infty \qquad (2)$$

where μ represents threshold parameters in which $\mu 0 = -\infty$ and $\mu n = \infty$.

The observed level of usage can therefore be represented as:

$$Y_i = 0 \; if \; Y_i \leq 0$$

$$= 1 \; if \; 0 < Y_i \leq \mu 1$$

$$= 2 \; if \; \mu 1 < Y_i < \mu 2 \qquad (3)$$

T-statistics and p-values were calculated and used to determine the statistical significance of the coefficients associated with the response variables. Results were interpreted based on their statistical significance.

Different factors such as construction operation, supply chain, accommodation for workers, customer behaviour, new technologies, insurance products, government guidelines and company operation and worker's profitability can be influenced by the severity of extreme weather events. This modelling analysis would help to quantify and prioritize the responses from the survey data collected in this study.

CHAPTER 3

3. Results

3.1. Basic information about survey participants and organizations

In total 50 governments and non-government construction companies provided their perspectives and comments in response to the survey. Responding organizations included general contractors, specialized contractors, professional civil engineers, developers and conservation authorities. It shows that almost all key sectors of the construction industry were covered in this survey. It is worth noting that for some sectors such as trade associations, developers, approval agencies, watershed management and control, general engineering consultants etc there were only one or two respondents.

Table 1 shows the scale of operations and nature of participating construction industry. It also shows the position of respondent in the organization. The scale or area of operations of most participating organizations was municipal or local level (31), followed by provincial level (15). Four organizations worked at national level and were probably large organizations either from Government or private sections. It shows that almost all levels or scales of construction companies or organizations were covered in the survey including local, municipal, provincial and national levels. In total 30 respondent from non-government construction companies participated in the survey, while 19 respondents worked in the government sector organizations. The people who responded to this survey mostly worked at the top and department level management positions (38) and remaining (12) worked at the non-management level (Table 1).

This basic information suggests that the survey responses were received from 11.11% of the respondents contacted and the respondents were from all major sectors of the construction industry operating at local, municipal, provincial and national levels. This information is very valuable and would help in interpreting the results of this survey. It also provides confidence in the quality and validity of information that was collected in the survey.

Table 1: Information about survey participants and organizations.

Scale of operations of construction company		
National	Provincial	Local/Municipal
4	15	31
Nature of industry		
Government	Non-government	Prefer not to answer
19	30	1
Position of respondents		
Management	Non-management	
38	12	

3.2. Impacts of weather conditions on the operations of construction companies

Construction companies from both government and non-government sectors indicated that their operations were affected by the bad or extreme weather events (Figure 2). The distribution of their responses for each bad or extreme weather category is shown in Figure 3 and the statistical values of fitted ordinal logistic regression models such as pseudo R-square, standard error, t-statistic and p-values are shown in table 2 along with log likelihood and AIC. Log likelihood values show the measure of goodness of fit for model so the higher the value of likelihood better is the fit of the model and Akaike information criterion (AIC) values indicate the out of sample prediction error and thereby relative quality of model for a dataset, where the lower AIC value

indicates the better fitted model (Table 2). Survey results showed that flooding and high winds or windstorms were the most important weather factor which affected the operations of both government and non-government construction companies or infrastructure organizations (Figure 1; Table 2). Survey results also indicated that snowfall, warm or cold temperature and heatwaves were also among major factors (Table 2). However, the impacts of snowfall, warm or cold temperature and heatwaves were more significant for the non-government construction companies as compared to governmental sector, in particular, heatwaves, which were considered very important by a significant number of participants. Frost and high humidity were also mentioned as important for some private sector companies.

There was a clear difference in responses from government and non-government organizations for drought impacts, where only government organization considered it extremely important or very important, where it was slightly important or not at all important for private sector organizations. Frost was not considered an important factor by government organizations, while frost as well as frequent changes in freeze and thaw cycle may cause significant damage to infrastructure already developed or in progress. This aspect is very important for the municipal sector or the project executed by the large construction companies spanning over more than one year or winter season. Overall, flooding was considered the most important factor, in particular, by the government organization, which almost exclusively listed it as extremely important (Figure 1; Table 2). Flooding may cause major disruptions and damages of construction projects.

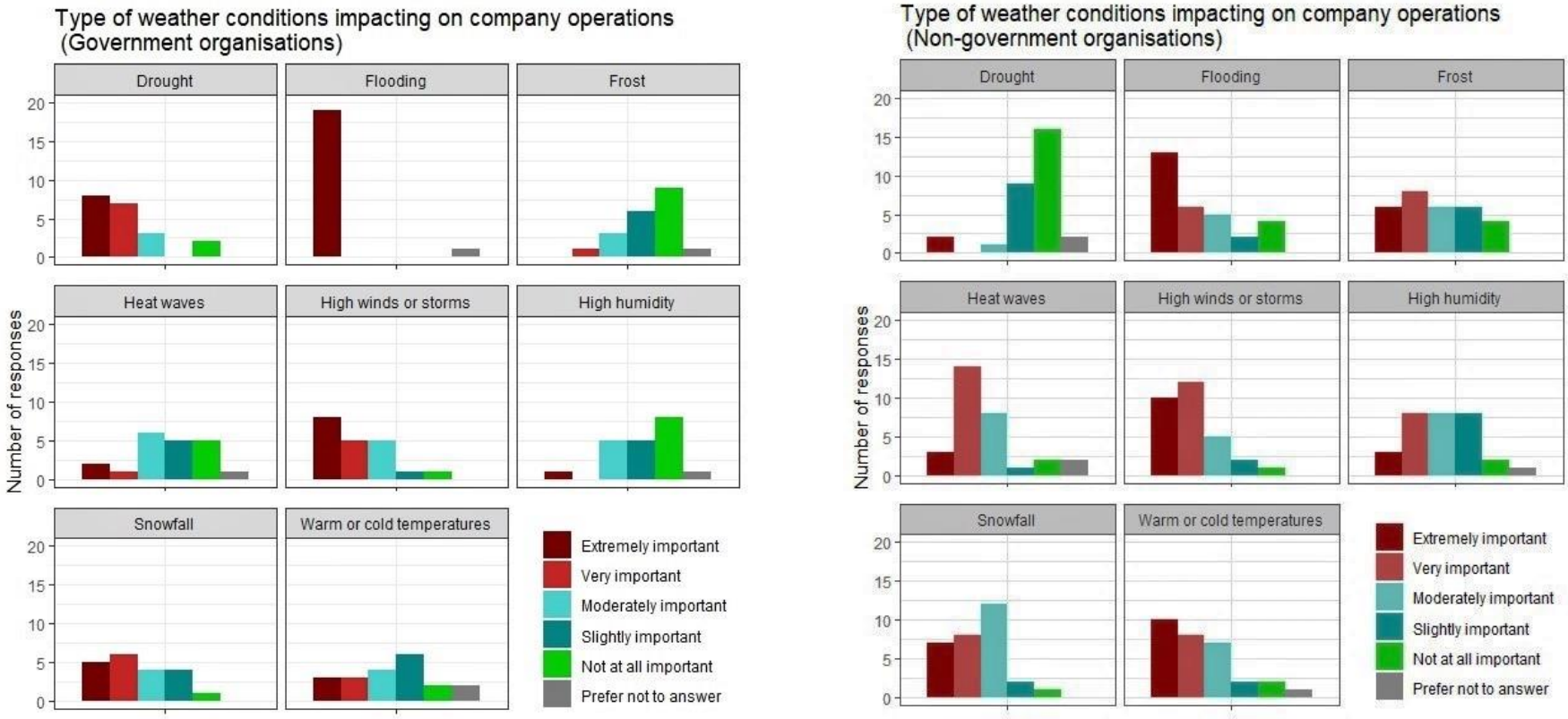

Figure 2: Different types of extreme weather events impacting the governmental and non-governmental company's operations.

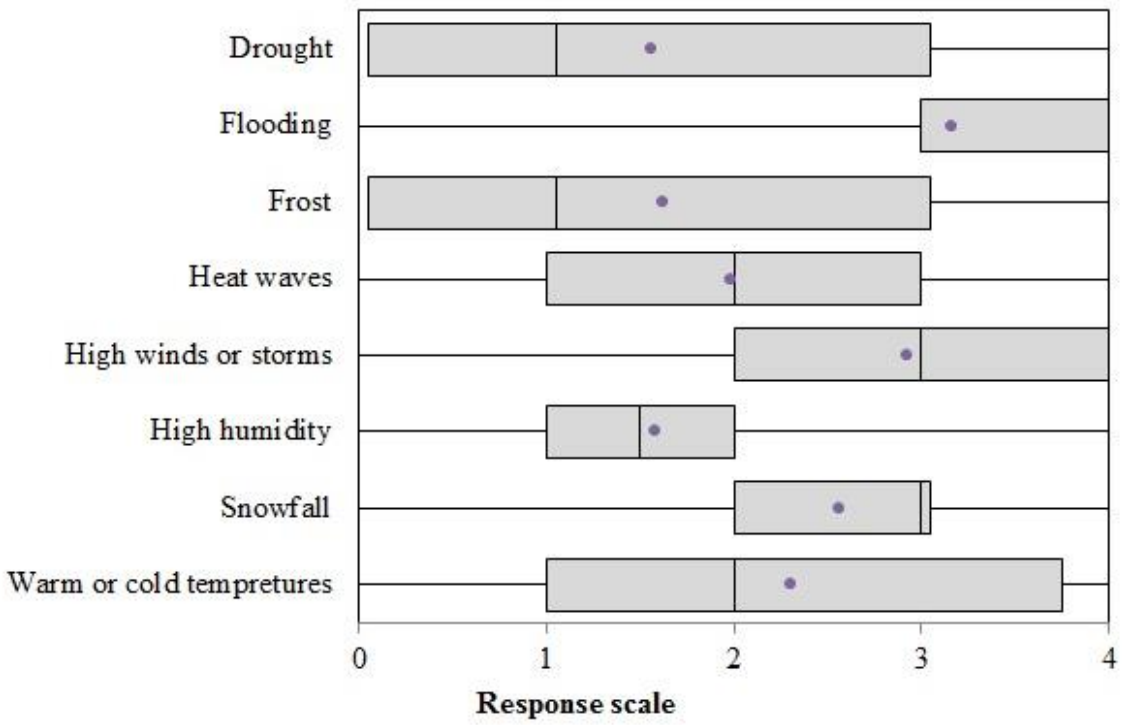

Figure 3: Response of survey participants for each category of bad or extreme weather event impacting company's operations. Survey responses for "Never", "Seldom", "Sometime", "Often" and "Almost Always" were converted to scores of 0, 1, 2, 3 and 4, respectively.

Table 2: Results of the ordinal logistics regression model of construction company's attributes and extreme weather events in Ontario. Statistically significant values are marked by stars (*).

Extreme weather events	*Estimate*	*Std. Error*	*z Value*	*P Value*
Warm or cold temperature	-1.848	1.104	-1.674	0.094.
High Humidity	-0.1989	1.423	-0.140	0.889
Flooding	2.991	1.356	2.206	0.027*
Drought	-0.863	0.868	-0.995	0.320
High winds or storms	3.775	1.734	2.177	0.029*
Heat waves	2.069	1.413	1.465	0.143
Frost	1.259	1.035	1.216	0.224
Snowfall	3.593	1.761	2.040	0.041*

* Significance level <= 0.05 (5% chance of error)
. Significance level <= 0.1 (10% chance of error)

Statistical values for model fit	
Number of observations	50
Log likelihood	-58.62
Pseudo R-square (R^2)	0.137
AIC	146.58

3.3. Frequency of delays caused by bad weather in company operations

As part of the survey questionnaire, construction companies were asked how often bad weather conditions cause delays in company's operations. Most construction companies (40%) working in the non-governmental sector mentioned that they had been always or often impacted bad weather events during their construction operation, while 47% mentioned that they were impacted sometimes (Figure 4). The government sector construction companies suggested that they were slightly less impacted by bad weather condition or extreme weather events, where only 20% companies mentioned that their operations were always or often impacted and 40% companies stated that they were some time impacted.

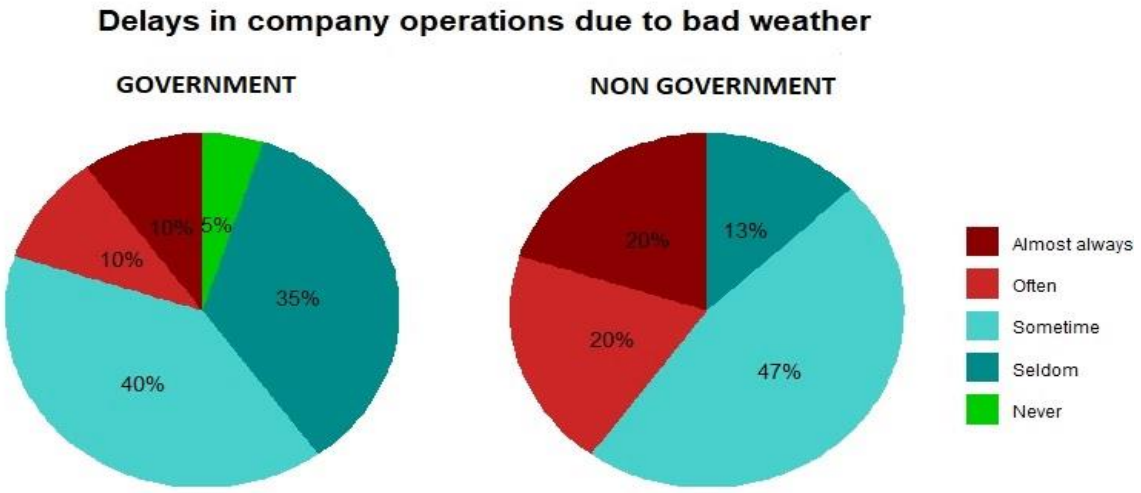

Figure 4: Delays in construction operations of government and non-government sector companies due to bad or extreme weather events.

3.4 Bad weather-related impacts on the supply chain of construction companies

Survey results indicated that bad or extreme weather events did not have significant delays in supply chain of construction companies in government sector construction companies, where only 5% companies reported that it often caused delays as compared to 14% companies in the non-government sector (Figure 5). However, both government and non-government sectors mentioned the occurrence of these delays sometimes for 25% and 54%, respectively. Supply chain of most government companies (50%) was seldom impacted by bad weather as compared **to 26% of those belonging to non-government sector.**

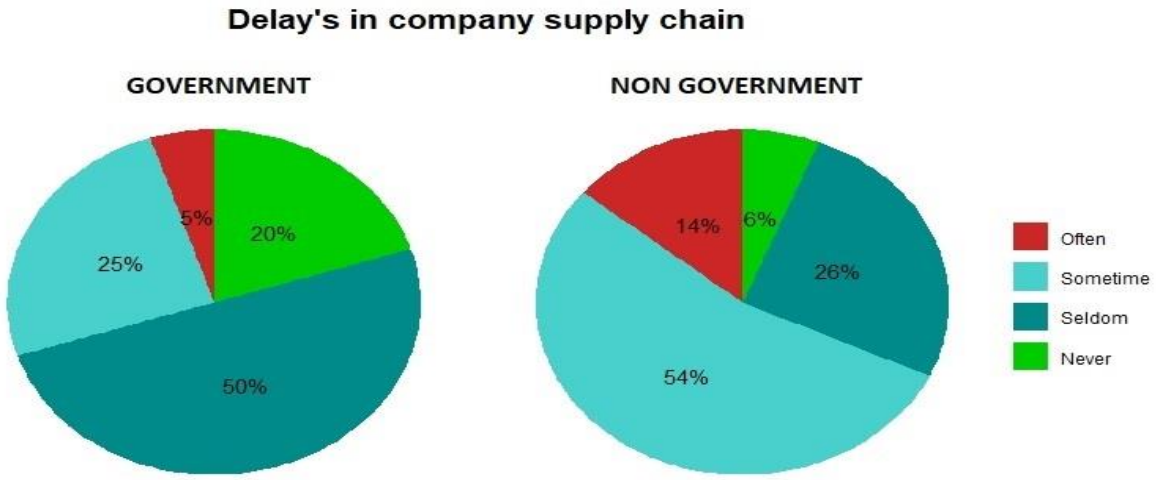

Figure 5: Impacts on construction projects due to delays in supply chain caused by bad weather conditions.

3.5 Accommodations given to workers due to bad weather conditions

Majority of construction workers work outside and experience all sort of weather conditions. Bad or extreme weather conditions can not only impact their work efficiency but also their health and safely. Extreme weather conditions make workers less productive. In particular, high winds or storms can be an important factor for certain operations such as tall buildings and using construction cranes. Survey results indicated that most construction companies have provided accommodations to their workers for bad or extreme weather events. 35% companies in the government sector and 30% companies in the non-government either always or often provided these accommodations, while their response for providing these accommodations sometimes was 40% and 36%, respectively. This aspect is very important for the overall operation of the companies and timely completion of the project. Any major accident or human tragedy at the construction site may delay whole project for extended period.

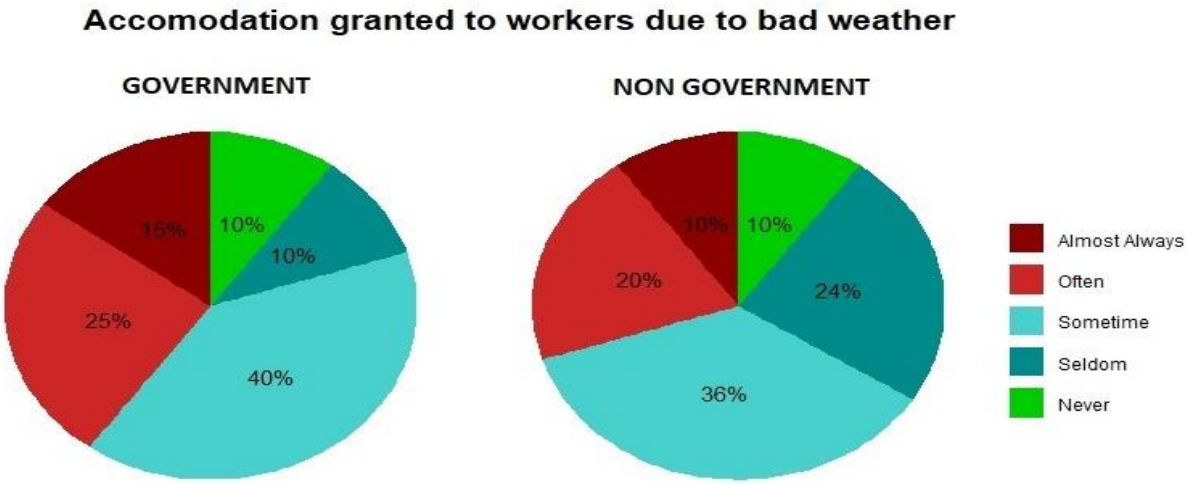

Figure 6: Accommodations granted to workers the construction companies due to bad weather conditions.

3.6 Impact of bad weather conditions on the behavior of customers

In this survey study, respondents were asked whether if they have observed any impacts of bad weather on customer behaviour in construction sector as shown in Figure 7. Responses from the construction companies on the customer behaviour revealed that only 35% respondents from government sector and 42% respondents from non-government sectors identified occurrence of bad weather impacts as almost always or often, while 45% government and 34% non-government sector companies mentioned that bad weather sometime impacted the behaviour of the customer. Only 20% respondents from both government and non-government sectors organizations mentioned that customer behaviour was seldom impacted by the bad or extreme weather conditions.

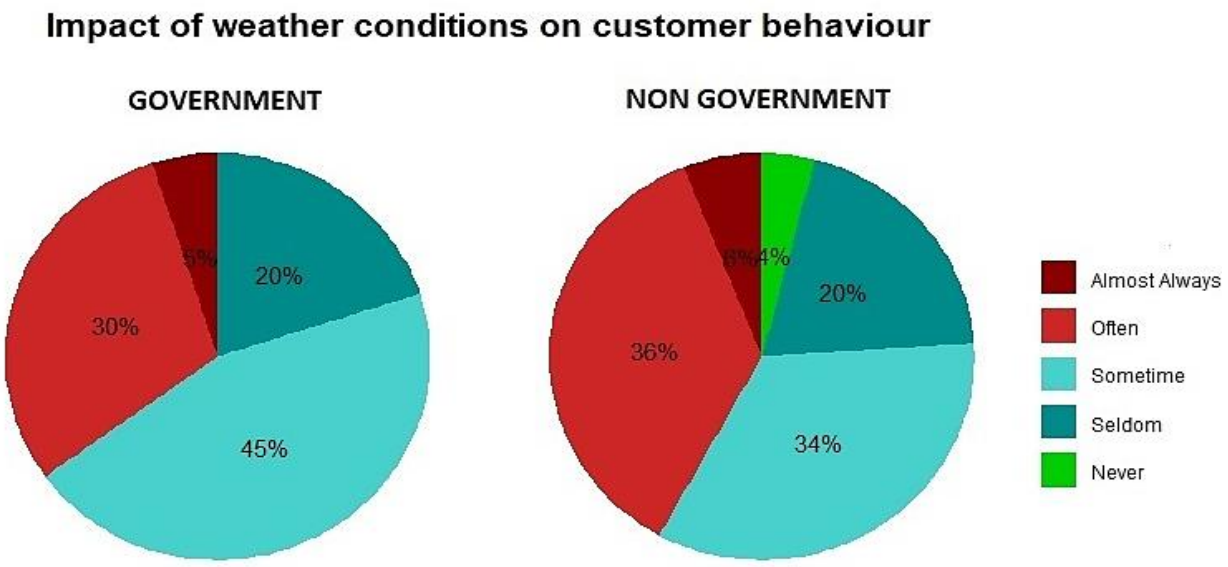

Figure 7: Impact of extreme weather events on consumer behaviour in construction sector.

3.7 Impacts of bad weather on the financial losses of construction companies

In order to investigate monitory losses experienced by the construction companies due to bad or extreme weather conditions, they were asked to provide information about approximate losses caused by one day of bad weather conditions. The responses to this survey question provided an insight into the financial impacts of extreme weather events on construction companies, specially in non-government sector, which has majority of small and medium companies (Figure 8, Table 3). Per day losses for government sector organizations ranged from $100 to $10,000, while these losses for non-government organizations were substantially higher and ranged from $100 to $100,000. These per day data were weighted by number of respondents to calculate average per loss for each sector (Table 3). Weighted average loss for government sector companies was $2,200 per day of bad weather, while it was $8,155 per day for non-government companies. It shows that bad weather can have serious financial consequences for these companies. These effects can be direct, such as closure of project sites or extensive damage or they can be indirect and can occur over time such as increase in material or labour costs. These results show that non-government construction companies, which play an important role in any economy were much more seriously impacted by the bad or extreme weather impacts (Figure 8). However, there might be uncertainty in these cost estimate because 70% respondents from government construction companies and 33% from non-government companies chose not to answer this question. Therefore, this could mean that either they were reluctant to answer this question or they may not be facing any financial losses.

The risk of extreme events is not generally considered at organisation level in the non-government sector. It is important that every non-government construction company consider

these extreme events in their project planning to minimize the negative consequences on construction projects. Bad or extreme weather conditions that may potentially disrupt construction projects occur quite frequently in Canada and Ontario. Table 4 shows numbers of days with snowfall and precipitation in Ontario over 1971-2010 period. On average snowfall occurred for about 57 days in each major region in Ontario and precipitation occurred on average for 158 days. These are quite a significant number of days, when these companies may face work delays and disruptions to their work and hence financial losses. These average number of bad weather days were integrated with the average per day costs in each sector to estimate overall average annual losses by the companies for two major weather condition, snowfall and precipitation as shown in Table 5. These costs are significant, in particular for non-government sector construction companies. It may have serious implications for the infrastructure development sector because non-government companies are a major part of the construction industries. They employ majority of workers and contribute to income generation and taxes.

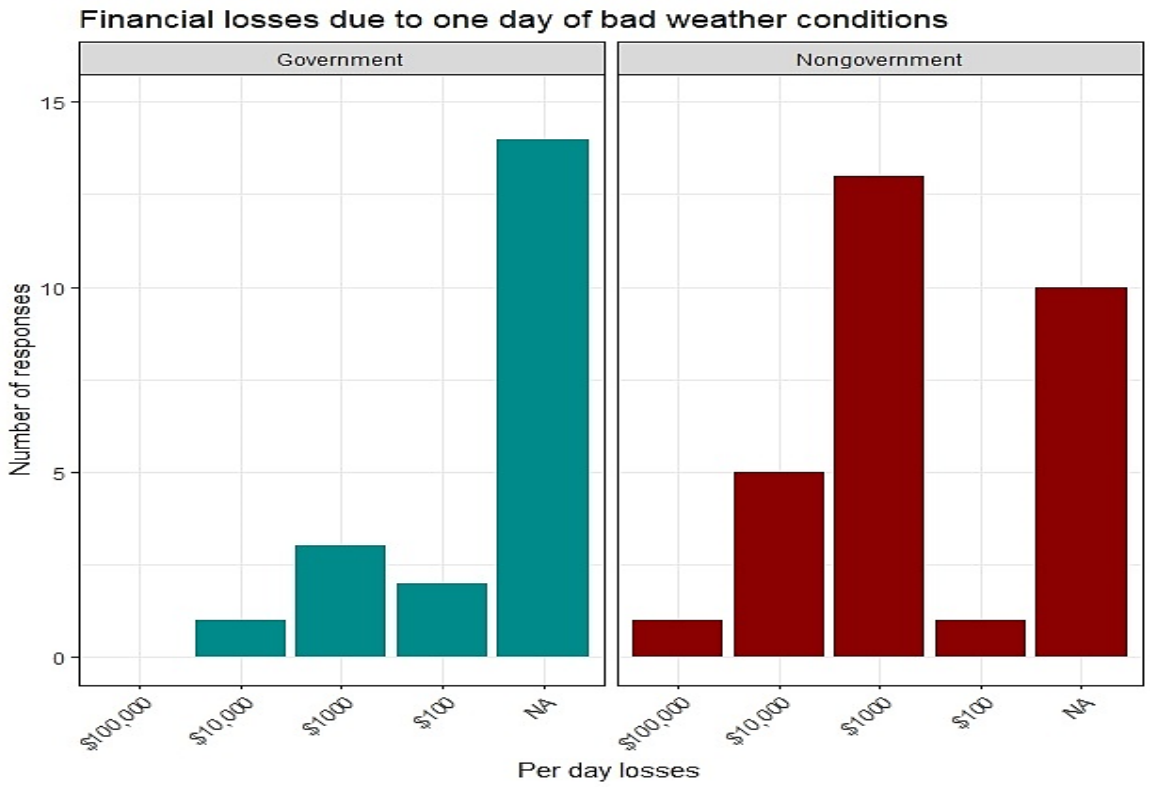

Figure 8: Financial losses of constructions companies due to one day of extreme weather events.

Table 3: Financial losses of construction companies due to one day of bad weather condition. Weighted Averages were estimated as (number of participant responses in each category × $ value of loss per day due to bad weather) / total number of participant response.

Government Sector:

Participant Responses	Loss per Day due to bad weather	Participant Responses X Loss per day due to bad weather
2	$100	$200
3	$1000	$3000
1	$10,000	$10,000
6 (Total)		**$13,200 (Total)**

Non-government Sector:

Participant Responses	Loss per Day due to bad weather	Participant Responses X Loss per day due to bad weather
1	$100	$100
13	$1000	$13,000
5	$10,000	$50,000
1	$100,000	$100,000
20 (Total)		**$163,100 (Total)**

Weighted Average = $13,200 / 6 = $**2,200** per day loss of government sectors
Weighted Average = $163,100/20 = $**8,155** per day loss of non-government sectors.

Table 4: Average annual number of days with snow and precipitation from 1981 to 2010 from 1971 to 2000 (Meteorological Service of Canada, Environment and Climate Change Canada).

ONTARIO CITIES	YEARLY AVERAGE SNOWFALL DAYS	YEARLY AVERAGE PRECIPITATION DAYS
Belleville	41	149
Cornwall	42	150
Kingston	50	159
Ottawa	52	161
Pembroke	70	170
Barrie	46	156
Brantford	24	136
French River	52	149
Hamilton	36	149
Huntsville	53	154
Midland	58	164
Niagara Falls	48	171
Oshawa	27	146
Peterborough	34	147
St. Catharines	43	151
Toronto	41	145
Chatham-Kent	22	137
Guelph	45	167
London	60	168
Owen Sound	60	177
Point Pelee National Park	32	154
Sarnia	41	150
Waterloo	62	166
Windsor	44	150
Chapleau	86	181
Gore Bay	65	159
Kapuskasing	101	191
Moosonee	80	172
North Bay	83	180
Sault Ste Marie	81	176
South Baymouth	48	149
Sudbury	75	167
Timmins	94	184
Wawa	78	170
Atikokan	54	138
Big Trout Lake	96	168
Dryden	69	152
Fort Frances	36	119
Kenora	74	153
Red lake	81	161
Thunder Bay	62	143

Table 5: Average annual losses for bad weather caused due to snowfall and precipitation in Ontario, Canada.

Government sector:

Bad Weather	**Average days per year** X **Average loss per day due to bad weather**	**Loss per year**
Snowfall	57 X $2,200	$125,400
Precipitation	158 X $2,200	$347,600

Non-government sector:

Type of Bad Weather	**Average days per year** X **Average loss per day due to bad weather**	**Annual Losses**
Snowfall	57 X $8,155	$464,835
Precipitation	158 X $8,155	$1,288,490

3.8. Decision making frameworks or protocols to deal with bad weather conditions

A survey question was asked to the construction companies about the existence and use of any decision-making framework or protocol that companies use to deal with bad or extreme weather events. The responses to this question were positive by most companies in both government and non-government construction companies (Figure 9). According to the survey 80% of construction companies in government sectors and 70% of construction companies in non-government sectors had decision making framework in place to deal with bad or extreme weather events. It was quite encouraging to see such as positive response from both sectors. Although common goal of these frameworks would be to reduce bad weather-related risks, however, it is possible that the details of these frameworks might be different in every construction companies.

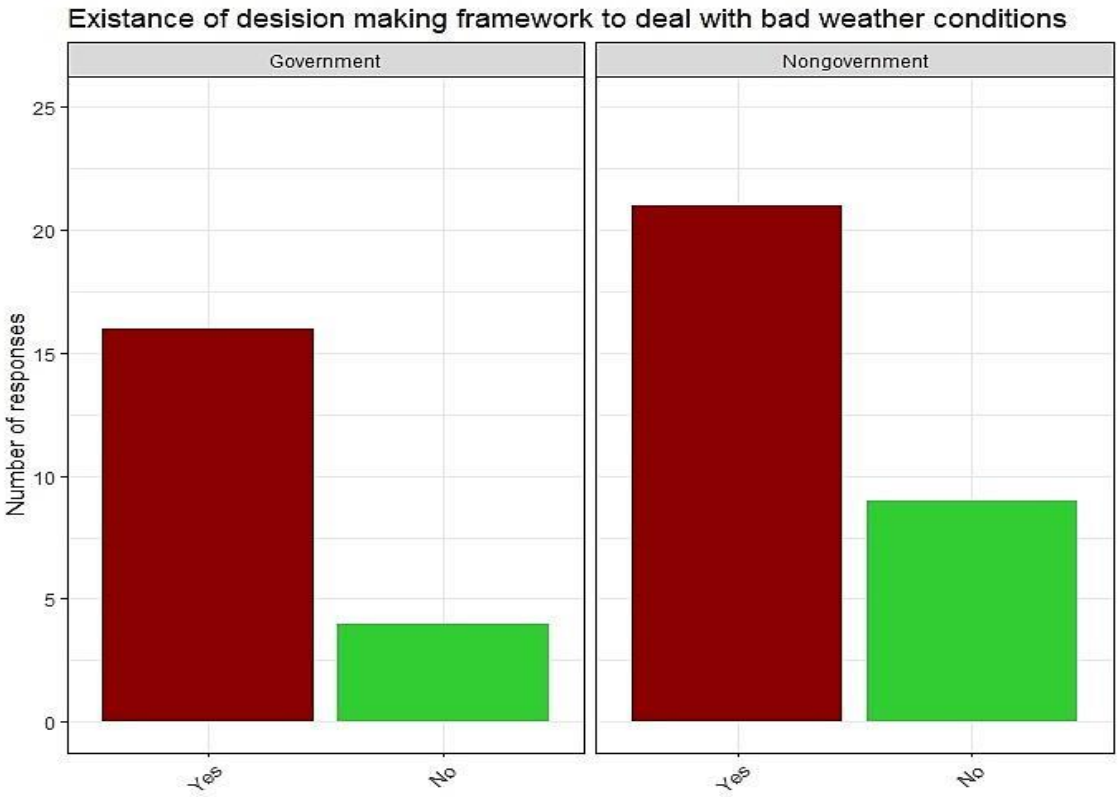

Figure 9: Availability of decision-making framework in construction companies to deal with bad or extreme weather events.

3.9. Adoption of new technologies to deal with bad weather conditions

This study sought information about adoption of new technologies by the construction companies to adapt their operations to weather related risks. Responses from both government and non-government sectors showed that there is very little tendency by these construction companies to use and adopt new technologies deal with bad weather conditions and reduce risk to their operations (Figure 10). Response from both sectors was low for almost always and often categories and it improved for sometimes category for government (35%) and non-government

(40%) companies. Majority of non-government companies suggested that they gave seldom or never adopted new technologies (Figure 10).

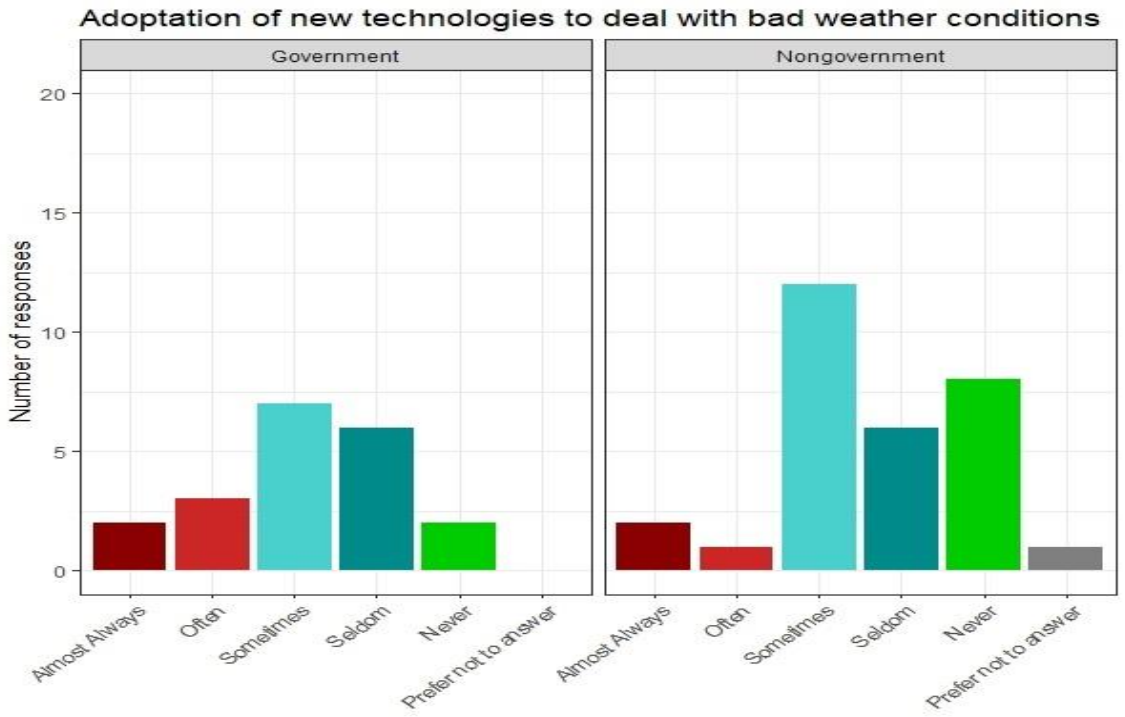

Figure 10: Adoption of new technologies to deal with bad weather conditions.

3.10. Availability of insurance products to deal with bad weather impacts

Construction company's responses for the availability of insurance products to deal with bad weather condition were quite mixed. Majority of companies in both government and non-government sectors opted not to answer this question (Figure 11). Most of the responses from both sectors were either seldom or never (40% to 46%), which indicated that adequate and affordable insurance products are either not available to them or they do not have inclination to use these coverages. Only two companies (10% response) from government and six companies

(20% response) from non-government sector responded positively for always or often having insurance coverage for bad weather-related impacts (Figure 11). It shows lack of insurance products and coverage for most extreme weather events. These responses may also indicate that either the construction company may not have enough information about the availability of insurance products, or they may not be considering the purchase of insurance product due to financial constrains or lake of their interest.

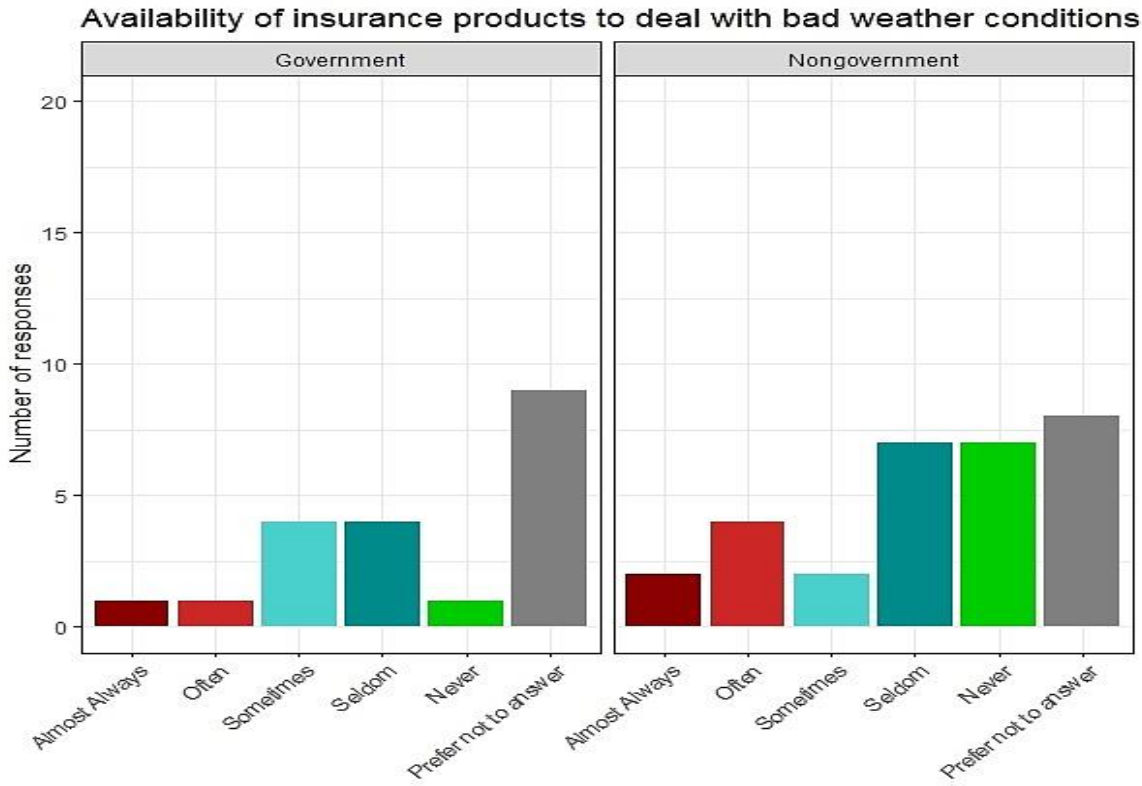

Figure 11: Availability of insurance products for construction companies to deal with bad weather conditions.

3.11. Adoption of bad weather-related guidelines by the government agencies

Survey respondents were asked up to what degree bad or extreme weather-related considerations are being adopted in the guidelines, protocols or standards for infrastructure development projects by the Canadian government agencies (such as municipal, provincial and federal). Most of the construction companies in the non-government sector (60%) responded that weather related considerations are either seldom or never adopted by these agencies (Figure 12). Only 17% non-government companies responded that they were being always or often adopted and this response was similar to the responses from the government sector (20%). There was a minor difference between government and non-government sector companies for the response to these guidelines being adopted sometimes, where 45% government companies responded positively as compared to 17% responses from the non-government sector (Figure 12). It shows the need of developing adequate protocols and guidelines for almost all major environmental impact factors. These guidelines and protocols might be helpful for the construction companies to reduce the impact of extreme weather events on construction projects.

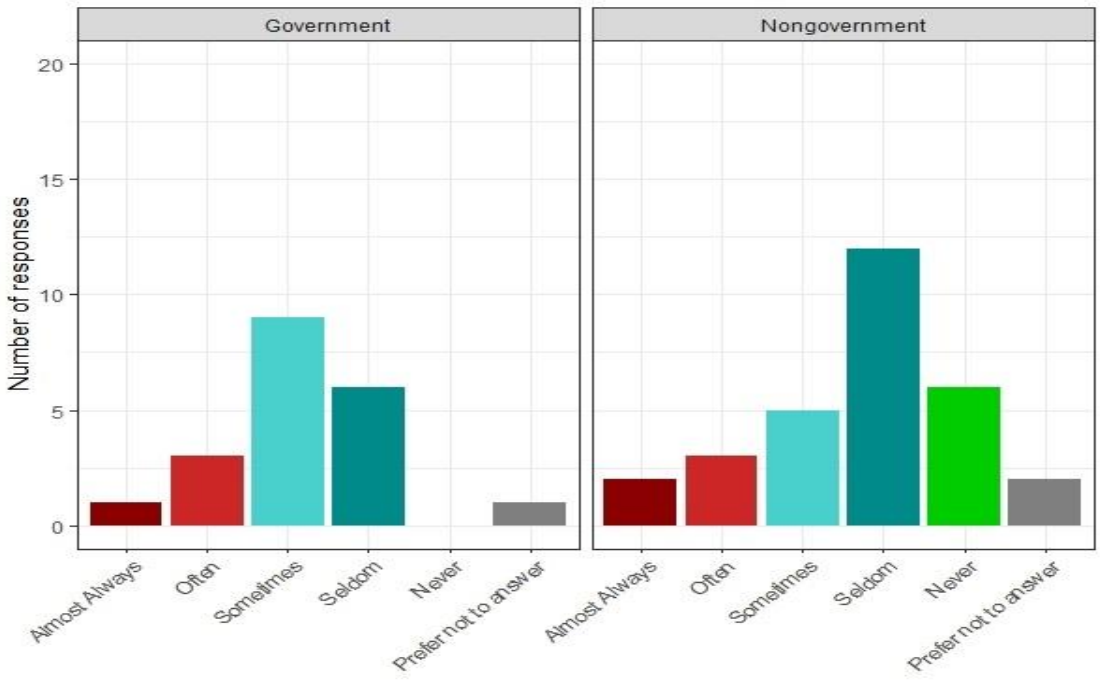

Figure 12: Extreme or bad weather considerations in the guidelines, protocols or standards for the infrastructure development projects by the Canadian government agencies, including municipal, provincial and federal.

3.12. Extreme weather impacts on the operations, workers or profitability

In this study, survey respondents were asked if increase in the frequency, intensity and duration of bad weather conditions have impacted the operations, workers or profitability of their construction companies. This analysis showed that extreme weather events impact company operations, worker's productivity and health and profitability (Figure 13). Warm or cold temperature and heatwaves could reduce the efficiency of workers, high winds or storm and snowfall can make the construction sites difficult for work and could also damage the construction equipment.

There was a very significant contrast between responses from the government sector companies and the non-government companies, which was surprising. Results from government sector companies were very mixed with only 20 to 25% respondents acknowledging that increase in bad weather conditions have always, often or sometimes impacted their construction companies as compared to 17, 30, and 37% positive responses in respective categories from the non-government sector companies. Despite these differences in the frequency of impact, both sectors have acknowledged that increase in the bad weather conditions have impacted almost all major areas of these companies including operation, workers and most importantly their profitability. These results highlight the significance of bad weather condition for these companies.

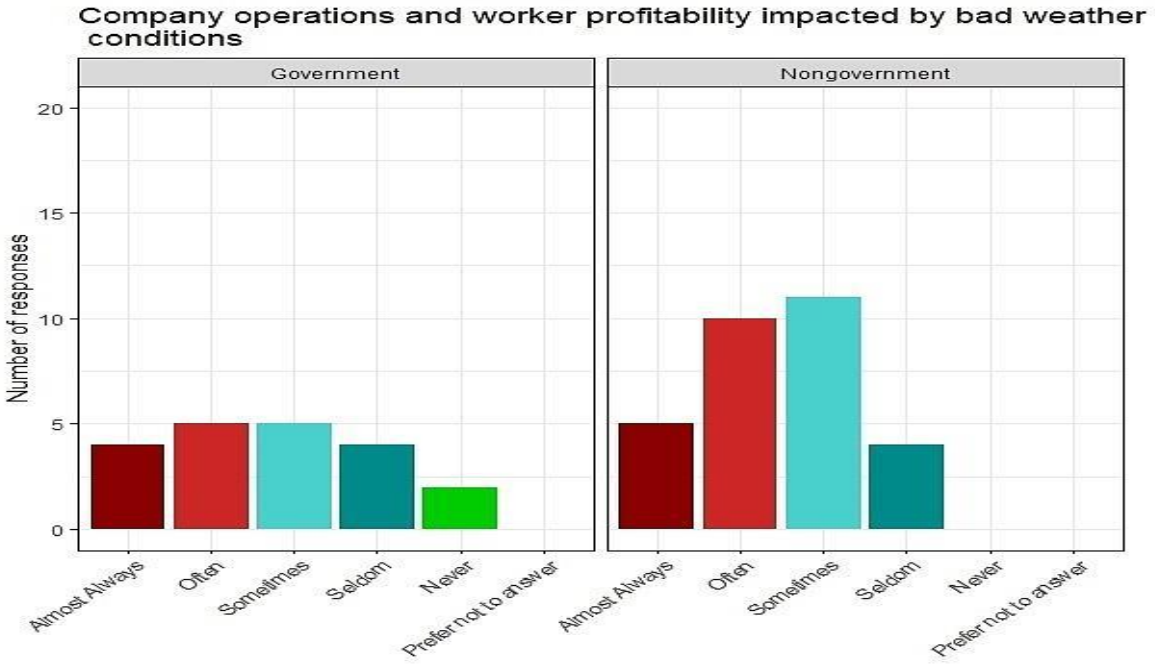

Figure 13: Impacts of increase in the frequency, intensity and duration of bad weather conditions on the operations, workers or profitability of construction companies.

3.13. Importance of planning for bad weather by different departments of the companies

The results from this survey question showed the importance of planning by the different sections or departments of the infrastructure development companies. These departments included design, construction, operations, maintenance, management, planning and investment. The overall distribution of survey responses for each bad or extreme weather category is shown in Figure 15 and the significance of the key sectors inside the construction companies as analyzed using an ordinal logistic regression model is shown in Table 6. Companies indicated that operation, planning and construction were the most or very important departments or areas for the government sectors companies, as suggested by most respondents (Figure 14). It was

followed by management, design and construction areas. Investment was the least important area for the government companies, which is understandable.

For the non-government sector companies, again construction, operations and planning were the most or very important areas as indicated the positive responses of the participants (Figure 14). It was followed by management and maintenance areas. Design and investment were the least important area for the non-government companies. In the non-government sector companies, a significant portion of respondents have considered maintenance and management as moderately or slightly important as well.

Overall, these results showed that operation, planning and construction areas were among the important areas for both government and non-government companies (Table 6). These are the areas where construction companies may have focused to take measures to lessen the effect of bad or extreme weather. However, they have given less important to design and management area which are very important and play a major role for the successful and timely completion of contraction projects. In particular, if steps are taken to include adequate measures to offset bad or extreme weather effects in the design of the project, it would be very helpful not only for the project execution but also afterwards in its maintenance.

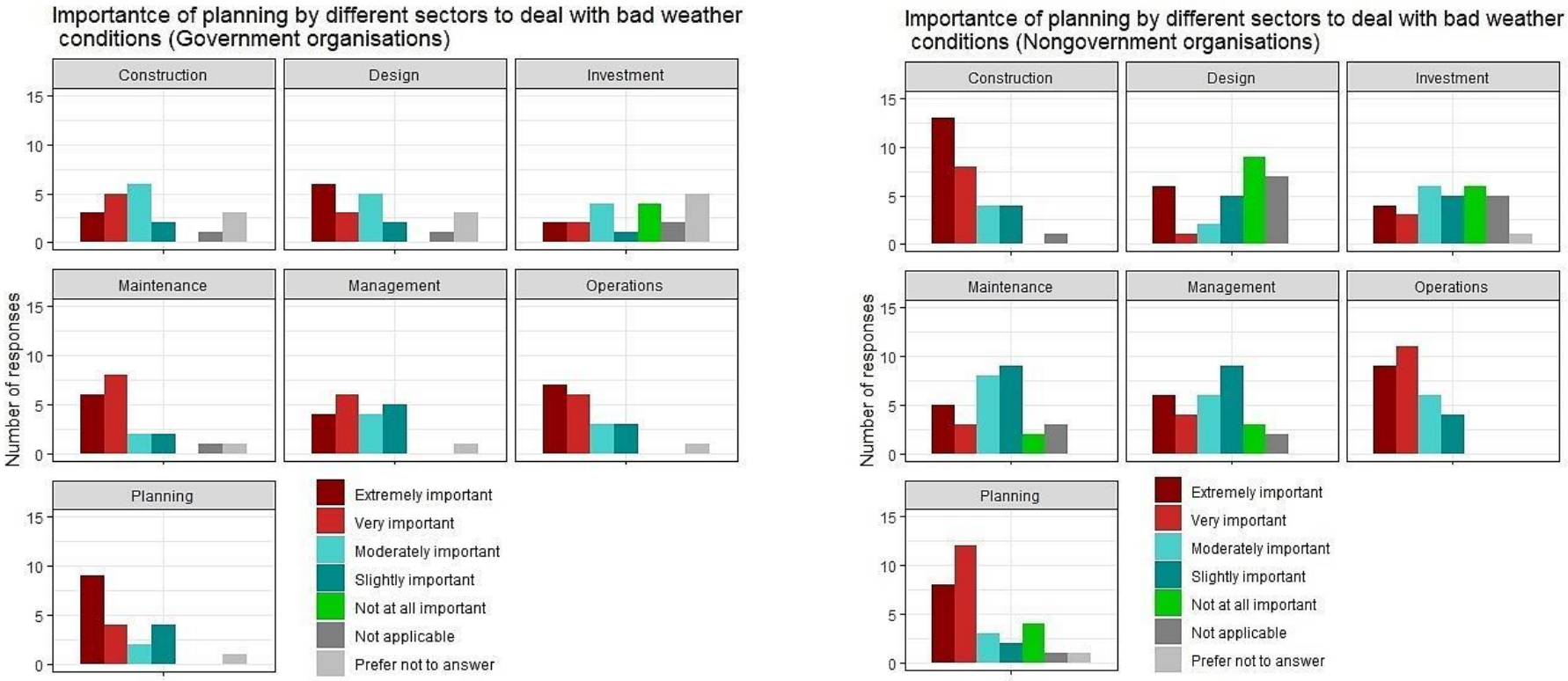

Figure 14: Shows the importance of different sectors in construction companies which are helpful to deal with bad weather condition in government and non-government sectors.

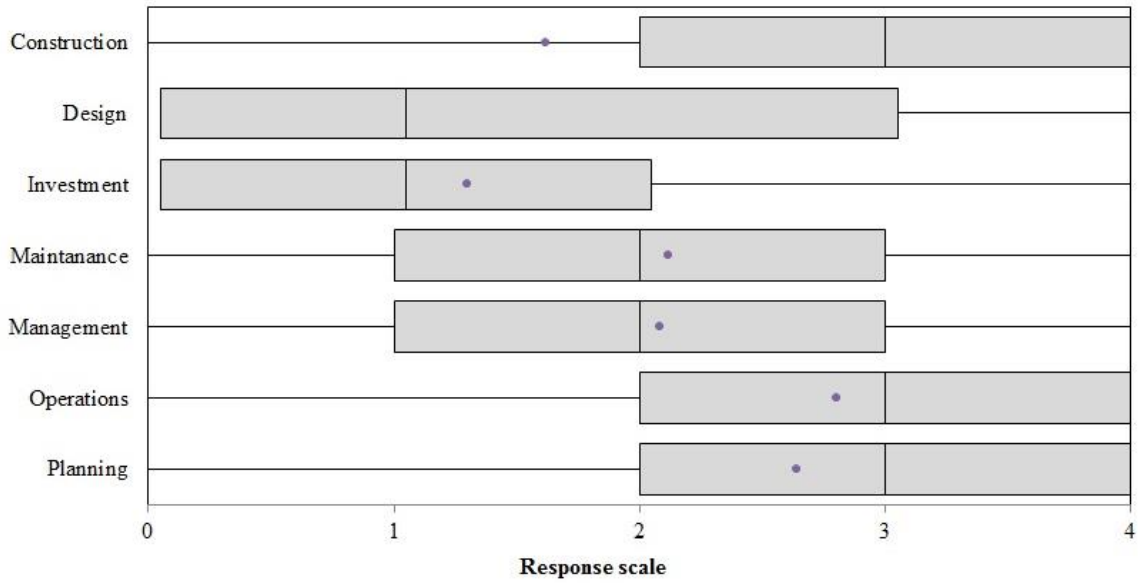

Figure 15: Distribution of survey responses for planning by different sections or departments of the construction companies to deal with bad or extreme weather events.

Table 6: Results of the ordinal logistics regression model of construction company's attributes and different sectors in companies. Statistically significant values are marked by stars (*).

Company's sectors	***Estimate***	***Std. Error***	***z-Value***	***p-Value***
Construction	2.2542	1.1155	2.021	**0.0433 ***
Design	0.2776	0.8261	0.336	0.7368
Investment	1.91678	1.06826	1.794	0.0728.
Maintenance	1.21848	1.08502	1.123	0.2614
Management	2.050	1.208	1.696	0.0898.
Operation	-5.540	2.201	-2.517	**0.0119 ***
Planning	2.468	1.067	2.314	**0.0207 ***

* Significance level <= 0.05 (5% chance of error)
Significance level <= 0.1 (10% chance of error)

Statistical values for model fit	
Number of observations	50
Log likelihood	-63.24
Pseudo R-square (R^2)	0.1256
AIC	153.15

4. Discussions:

The respondents of this survey study included general contractors, specialized contractors, professional civil engineers, developers and conservation authorities. Majority of respondents worked at the top and department level management positions. It means respondents very knowledgeable about company operations, project management, protocols, work security and financial aspects of their organizations. It also shows that top or senior level management of the construction sector has keen interest in finding more about bad weather and extreme events impacts on their organizations and they took time to fill this survey despite their busy schedules.

The result of this study indicated that extreme weather events have significant impacts on the infrastructure development sectors. Flooding and high winds or windstorms had the greatest impact on this sector. Other major factors impacting these companies included snowfall, warm or cold temperature and heatwaves. Overall, non-government construction companies were affected more due to these events as compared to government companies.

In Canada, the flooding is among the most frequently occurring and costliest natural disaster (Sandink et al., 2010; Hoeppe, 2016). In Ontario, flooding was the most commonly occurring (56 events) natural disaster from 1900 to 2013 (Nirupama et al., 2014). Buttle et al. (2016) has described in detail major historic flooding events and various causes of flooding in Canada, including Ontario. Flooding is a significant danger, in particular, in low laying areas and around streams and rivers (Armenakis and Nirupama, 2014). In addition, flooding zones are dynamic and change over time due to developments happening inside the watershed and changes in weather pattern (Pal, 2002). In Ontario flooding associated with Hurricane Hazel in 1954 and a major thunderstorm in Greater Toronto area in July 2013 are well know examples. The

Hurricane Hazel caused 81 deaths and widespread damage to infrastructure with costs exceeding $1 billion. Similarly, July 2013 flooding due to 126 mm of precipitation shut different transportation corridors, caused wide-spread property damage, and disrupted power supply to around 300,000 residents. The Insurance Bureau of Canada estimated that the cost of July 2013 thunderstorm and associated flooding related damages was approximately $1 billion. It was among the most expensive natural disasters in Ontario (Environment and Climate Change Canada). Any future large scale major extreme event such as flooding in Southern Ontario, may have serious consequences for the construction companies or infrastructure development sector. Apart from impacting machinery, material and workers at the construction sites, these events may impact the entire project operations for private sectors companies. Major construction project may also be severely impacted by large scale flooding in the region.

High winds or thunderstorms present danger to rooftops, windows and other parts of infrastructure. Windstorms may also affect tall structures, building heating loads, and trees which may disrupt power supply. In winter, high winds can cause safety challenges for workers on construction sites (Martin et al., 2017). Analysis conducted by Twidle (2018) suggested that thunderstorms, which include high winds are major cause of damage and insurance claims. Nirupama et al. (2014) found thunderstorms and tornados as the seconds most common natural hazard in Ontario, following floods.

Warm and cold temperature and heat waves may diminish the work efficiency and productivity of workers and cause health risks. Although, Environment and Climate Change, Canada has defined a heatwave as "a period with more than three consecutive days of maximum temperatures that is above 32 ^{o}C", however, heatwave severity also depends on humidity, wind

speed and radiant levels. Occurrence of these conditions may cause serious health risks for construction workers, who work outdoors for extended periods of time (Heath Canada, 2012). Moselhi et al (1997) have argued to develop decision support systems for estimating the combined effects and costs of reduced labour productivity and work stoppage caused by bad weather conditions on construction sites.

Snowfall is an important factor for Ontario where presence of Great Lakes and unique wind flow and atmospheric circulation patterns may result in large snow and ice storms. However, apart from freezing rain or ice, major snowfall will be an important factor for construction companies but not a very server constraint on company operations. Most companies and municipalities have measured in place for snow removal and to deal with major snowstorms in Canada.

Various researchers have suggested that frequency, intensity and duration of extreme weather events around the world and in Canada is expected to increase in future (IPCC, 2018; McBean, 2012; Bush et al., 2019; Wazneh et al., 2019). Extreme weather will further increase these risks for construction companies in both private and government sectors. Construction companies can expect extra weather delays from flooding, windstorms, warm and cold temperature, heatwaves and heavy snowfall (Martin et al., 2017). Increased frequency of freeze and thaw may also be a factor as well as freezing rain in areas near Lakes. Construction companies should be well prepared for extreme weather conditions and develop measures to deal with various types of extreme events to avoid delays in their projects.

Apart from these major environmental factors that impact construction companies, there might be indirect impacts which may cause disruptions. On important area is supply chain of constriction companies. Although most of the survey respondents indicated that bad or extreme

weather events did not cause significant delays in supply chain of their companies, however, major extreme events may cause these delays. For example, Chopra and Sodhi (2014) mentioned that a major flood in Thailand in 2011 affected the supply chains of computer parts and hence the Japanese auto sector. In Ontario, a variety of construction materials including raw materials and processed products are imported from other parts of Canada as well as across the world such as lumber, steel products and other building supplies. These supplies may have delays and increased costs due to increase in extreme weather.

In Canada, flooding and disruption of transportation networks in Northern regions due to climate warming and permafrost melt may have serious impacts. Proper time management in construction projects could be helpful to reduce the impact of extreme weather events and timely delivery and completion of projects. Revilla and Saenz (2017) have suggested that business companies who adopted collaborative and integral approaches in their supply chain management faced the lowest level of disruptions. Such collaborations and approaches would also help construction and infrastructure development sector.

Health and safety of workers is a key element of construction sector, which may have huge consequences for the construction companies (Shamsuddin et al., 2015). Ontario Occupational Health and Safety Act (OHSA) suggests that employers have a general obligation to take all reasonable precautions for the protection of the worker (OHSA, 2019). Our study results showed that most construction companies provided accommodations to their workers for bad or extreme weather events, which is very encouraging. It would have positive impact on company workers and their safety. It will also discourage worker from being absent during bad weather conditions, which may have adverse impacts on company operations and planned activities. Wedawatta et al.

(2011) had argued that biggest impact of extreme weather impact on small to medium construction company was due to non-attendance of employees (53%), followed by loss of sale and production, reduction in employee productivity and disruptions to access to premise (33% each) and a decrease in profits (27%) in London, UK.

Weather conditions can influence economic activities, human behaviour and customer's decision making and spending in many ways (Murray et al., 2010). Our study results are in agreement with a significant body of work focusing on weather impacts on customer behaviour and decision making (Murray et al., 2010; Goetzmann and Zhu, 2005; Cawthorne, 1998). Construction companies should consider weather aspects while developing customer services and marketing strategies. Climate and extreme weather-related aspects are becoming an important factor in property and real state decision making by both citizens and government sector. Currently, most government sector projects are being reviewed through climate lens before their approvals (Infrastructure Canada, 2020). In future construction companies would also have to adopt these measures to reduce their greenhouse gas emissions and improve their public relations.

Our study result showed that construction sector may experience large financial losses due to one day of bad weather conditions. Weighted average loss for government sector companies was $2,200 per day of bad weather, while it was much higher at $8,155 per day for non-government companies. Therefore, policies and strategies of non-government construction companies to deal with bad weather conditions is very important. These companies will have to investigate enhancing their capacity and resilience to deal with extreme weather events. Some strategies which they might consider or adopt to overcome weather impacts may include consideration of

extreme events as a hazard in bidding process, accounting them in project planning and cost estimation and provision of accommodations in contract agreements (Wedawatta et al., 2011).

Our study results indicated that most construction companies (70-80%) used decision-making frameworks or protocols to deal with bad or extreme weather events. However, it was not clear, how sophisticated and effective these measures may be in alleviating impacts of bad or extreme weather conditions. Willows et al. (2003) have described in detail the risks, uncertainties and decision-making framework or protocols to deal with environmental and climatic impacts. They argue that the principal elements of the framework include (i) the importance of correctly defining the actual problem, (ii) the need to screen and prioritise risks before detailed quantification (iii) the need to consider all risks at the project appraisal stages and (iv) accounting for the iterative nature of the process involved. Weather forecasts and climate modeling can help to support decision making frameworks of companies. Well-informed decision-making frameworks would help to reduce uncertainty and limiting incorrect decisions, which may have huge consequences for project progress, workers' health and costs (Weaver et al., 2013). Engle et al. (2014) have suggested the use of quantitative factors for risk assessment and developing indicators that can be used for decision making to reduce risks and making development and adaptation choices more resilient. Currently, weather forecasts and climate modelling generated information are under-utilized to make decisions by contraction companies as compared to other businesses such as marine shipping companies and airlines. Construction companies involved in the design and execution of projects may utilize models that can quantify or anticipate weather-related impacts on the project execution and durations. Ballesteros-Pérez et al. (2017) have discussed in detail influence of unforeseen and extreme weather on construction

projects. They have suggested to use models that enable practitioner to use weather data for forecasting project execution, durations and construction productivity. They argue to account for normal weather, its multivariate statistical variability and non-exceptional weather condition in the planning and construction stages of the projects for their timely completion. However, availability of long-term observed weather data would be a major hindrance for such modeling studies. Kim and Augenbroe (2012) has suggested using short-term weather forecasts such as US National Digital Forecast Database to enhance the performance of model-based control strategies for building projects, where historic observed weather data may not be available.

Adoption of new technologies by the construction companies could be very helpful to reduce the risks of extreme weather events. Our study results indicated that most of the government and non-government construction companies have not adopted new technologies deal with bad weather conditions. Majority of non-government construction companies are small and have limited resources, except some large national or international private firms. These small companies work on short term projects with limited capital and markets. It will be understandably difficult for these firms to invest in new technologies to reduce weather related risk. In contrast, large construction companies have different scopes and scales of their operations and they usually have better management plans, guidelines and frameworks for long term strategic planning and adopting new technologies and data products. Sexton et al. (2006) have discussed the need to adopt new technologies by the construction companies, in particular for those operating at smaller sale. The availability and easy access of relevant weather datasets and data products from government organizations such as Environment and Climate Change Canada and Ontario Ministry of Environment, Conservations and Parks will be very helpful to

these companies. These weather-related datasets and products that might be utilized by the construction companies may include current weather observations, weather forecasts, early warnings for extreme events or storms, humid and heat indexes and modelling products such as flood prone areas maps. In addition, new weather-resistant and weather smart technologies may also be adopted to improve the operational aspects of the projects including new machinery, tools, materials, sensors, software, mobile applications and even personal protective equipment and gear for workers.

Our study showed that adequate insurance products and coverages to deal with bad or extreme weather events were not available to most construction companies. This is a very important but not a surprizing finding of this survey. Lack of bad weather insurance coverages might have serious implications for both construction companies and government. Hoeppe (2016) has shown that the frequency of global natural disasters has significantly increased over the last three decades. In the early 1980s the annual numbers of weather-related extreme events or disaster were about 300 and this number has increased to about 900 events in 2014. Hoeppe (2016) further suggested that weather related disaster events account for 78% of the economic losses and 89% of the insured losses and there is high potential that changes in the atmosphere due to climate warming will further impact these economic and insured losses in future. A recent Insurance Bureau of Canada (IBC, 2018) report suggests that business risks are increasing due to increase in severe weather conditions related to climate change. These risks may also include supply chain disruptions and business interruptions caused by disasters. In Canada as well, majority of disasters are related to extreme weather as suggested by an analysis conducted by the Catastrophe Indices & Quantification Inc. for catastrophic events (CATs) causing more than $25

million losses from 2008 to 2018 (Twidle, 2018). These events caused total insured losses of $18 billion. Twidle study further suggests that thunderstorms, which many include high winds, lightning, heavy rainfall, hails and sometimes tornadoes accounted for 60% of total 100 of these major events and 50% of the insured losses in Canada. Severe thunderstorms are also one of the largest contributors to global losses (USD $10 billion per year) in terms of property and agriculture, and causes dozens of fatalities (Hoeppe, 2016). Thunderstorms accounted for 41% of disaster events across the world, followed by floods (36%). However, flooding was the number one hazard in terms of economic and infrastructural damages in Canada (Agrawal and Cox, 2019) and across the world (Wahlstrom and Guha-Sapir, 2015). Actual economic costs of these catastrophic events are much higher than insured losses. In industrial countries such as Canada, only 40% of natural disaster related damages are covered by insurance industry, while a significant portion of these damages are not covered and government disaster relief may not be available or adequate to all affected businesses or sectors (Kelly and Stodolak, 2013). In recent years, the weather-related risks have become so significant that the Canadian Securities Administration is considering introducing requirements for businesses to disclose their exposure to climate risk as part of their annual filings (IBC, 2018). It highlights that bad or extreme weather events can have serious consequences for the construction companies and they must ensure adequate insurance coverages for their projects and operations. It also provides an opportunity to insurance companies to introduce new and affordable weather impacts related insurance coverage products, in particular for small and medium construction companies which form the majority of the construction industry. A recent study by Yiannakoulias et al. (2018) found the overland flood insurance was not generally available in Canada, however, after some major flooding events such 2013 Calgary flood, insurance companies have started to offer

insurance products to households. Construction sector is major part of economy in Canada and Ontario. Therefore, proving bad weather-related insurance products to construction sector would be beneficial to both construction and insurance industry. Insurance companies should work in collaboration with construction companies or their professional organization in developing a range of insurance products for construction sector to deal with extreme weather events. Perhaps government may also consider providing some quidelines or passing legislation to ensure these coverages as it is done for transportation or automobile sector.

Our study also found that there are large gaps, when it comes to adopting bad weather-related policies and guidelines in the infrastructure development sector. Climate change is expected to the increase the frequency and severity of extreme weather events in various parts of the world including eastern Canada (IPCC 2018; Hoeppe, 2016). Therefore, there is an urgent need to develop adoptive and preventive policies to deal with extreme weather impacts as discussed earlier. There is a need to develop ambitious climate protection and adaptation measures to avoid catastrophic increases of losses caused by global warming driven weather extreme (Hoeppe, 2016). Craft et al. (2013) conducted a review of policy capacity of the infrastructure sector to respond and adapt to climate change in Canada. They found that the policy capacity of the Canadian infrastructure sector is not adequate to meet the demands placed upon this sector to respond to the increasing challenges of climate change adaptation. In another study conducted by the Institute for Catastrophic Loss Reduction and Engineers Canada to develop a common understanding of the climate change and extreme weather related adaptations in the infrastructure and buildings sectors found that national construction codes and provincial construction codes have impeded the adoption of measures that serve to reduce the risks structures/infrastructure

due to extreme (Wheeler and CVC, 2017). Main cause of these inadequate policies is lack of funding, inadequate communication between different levels of governments and municipalities and absence of guideline or standards on bad weather risk assessment. Wheeler and CVC (2017) suggested that successfully planning and management of the impacts of climate change and extreme events requires not only the understanding of the risks/opportunities caused by changing climate but also information sharing and collaboration among multiple levels of stakeholders and decision-makers. All levels of governments including municipalities and provincial and federal government as well as private sector stakeholders should urgently join efforts conduct vulnerability assessments and to develop extreme weather and climate change adopted policies and protocols for the growth, suitability and resilience of this sector. Wedawatta et al. (2011) have discussed some strategies that might be adopted by the construction companies to overcome weather changes related impacts including considering extreme events hazard in bidding process, project cost estimations, project planning and contract agreements, where clear quid lines and policies from contract awarding agencies are very necessary for the successful completion of infrastructure projects. These guidelines will be helpful to cut down the costs of extreme events related disasters and help to deliver the projects on time (Weaver et al., 2013). Engle et al. (2014) have suggested the use of quantitative factors for risk assessment and developing indicators that can be used for decision making to reduce extreme weather-related risks. These measures or actions may also help in the developing green construction practices and enhance the and sustainability of the construction and infrastructure development sector (Shurrab et al., 2019).

5. Conclusions

In this study a survey questioner was developed and administered to investigate bad or extreme weather impacts on infrastructure development or construction companies in Ontario, Canada. Major aspects covered in this survey included company operations, employees, supply chain, adoption of new technologies, availability of insurance and protocols, costs and profitability. The participants of the study included owners, managers and engineers form both government and non-government sector companies. In total 450 participants were contacted through e-mails and asked to provide their comments and survey data using an online survey tool (Lime Survey). Survey response rate was 11.11% which is typical response rate for most survey studies. Apart from descriptive evaluations, the survey responses were also analyzed using an ordinal logistic regression model to determine the significance of key determinants for the bad weather impacts on the construction companies. The study results identified major environmental factors that impact the operations and working of the construction companies. They included flooding, high winds or thunderstorms, warm/cold temperature, heatwaves and snow/ice storms. These bad weather impacts were more significant for the non-government construction companies as compared to governmental sector. Effects of extreme weather events on construction companies were not just direct impacts but also indirect such as disruption to their supply chain and changes in customer behaviours, but these impacts were minor as compared to environment factors surveyed in the study such as thunderstorms, heatwaves etc. Study found that both government and non-government sector construction companies granted accommodations to the workers who worked in the bad weather condition. Government sector companies granted more such accommodations to their workers as compared to non-government companies. The study also provided an insight into the financial impacts of extreme weather events on construction

companies. It showed that non-government construction companies faced substantially higher per day financial losses due to bad weather condition as compared to government sector construction companies. Weighted average loss for government sector companies was $2,200 per day of bad weather, while it was $8,155 per day for non-government companies. Study results showed that bad weather can have serious financial consequences for non-government companies, which makes a large contribute to economic activity.

Although overwhelming majority of construction companies in both government and non-government sectors indicated that they use decision making frame works to deal with bad or extreme weather events, however, their responses showed that there were no adequate guidelines, protocols or standards available for construction companies from government to adapt to extreme weather events or alleviate their impacts in company operations. They also highlighted the lack of adequate insurance products for the construction sector to deal with bad weather. There was little tendency by these construction companies to use and adopt new technologies to deal with bad weather conditions and reduce risk to their operations.
Study results highlighted the significance of bad weather condition for the construction companies and lack of capabilities and actions to address them. The increase in extreme events due to future climate change may further aggravate these impacts. Therefore, there is need to develop adaptive and preventive policies, conduct risk assessments studies and develop management practices to deal with these impacts. Climate tailored planning and management by the construction companies will help to reduce impacts of bad or extreme weather conditions on their operations and profitability.

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Appendix A

Business Tool Kit Submitted as Part of the Survey Approval Process

No business is immune to the growing risks presented by climate change. As rising temperatures and extreme weather continue to shape our economy's future, business leaders must consider the vulnerabilities they face and respond with strategic risk management plans.

The most prevalent risks facing businesses across all sectors are:

- Extreme storms and flooding will continue to overwhelm public infrastructure like storm water management systems, roadways and transit routes.
- Floods, fires, and storms will continue to put private property and assets at risk, and cause insurance premiums to rise.
- Longer and more intense heatwaves will increase demand for air condition and refrigeration, potentially driving up energy bills for business.
- Increase in duration and intensity of heatwaves has consequences on worker health, safety and productivity.
- Increasing droughts, seasonal irregularities and pests puts local and global food systems at risk.

Businesses must determine how they will manage these risks. In response to growing extreme weather conditions, businesses might implement work-from-home policies. They might also establish local sourcing practices and find alternate, backup suppliers to limit the risks of supply chain disruption. Ensuring the safety of employees in a warming climate necessitates reviewing and updating health and safety protocols. Understanding insurance policies and creating emergency preparedness plans as it relates to extreme weather are also vitally important for every sector.

These tools and resources equip businesses to better assess their risks of climate change, and find best practices for building a more resilient future-proof business.

Appendix B

Basic Information of the Industry. Check all that apply.

Survey Q-A:

What is the nature of your current industry?

- ☐ Project Management Consultants
- ☐ General Engineering Consultants
- ☐ General Contractors
- ☐ Specialized Contractor (please state specialty field)
- ☐ Prefer not to answer

Survey Q-B:

Which of the following best describes your role in the company?

- ☐ Top Management
- ☐ Department Management
- ☐ Senior Level Engineer
- ☐ Junior Level Engineer
- ☐ Other
- ☐ Prefer not to answer

Survey Q-C:

What is the scale of your company's operation?

- ☐ National
- ☐ Provincial
- ☐ Municipal
- ☐ Local
- ☐ Prefer not to answer

QUESTIONNAIRE OF CLIMATE CHANGES IMPACTS ON INFRASTRUCTURE DEVELOPMENT OR CONSTRUCTION INDUSTRIES:

Survey Q-1:

What kind of weather conditions impact your company's operations? Please rank the level of their importance.

	Extremely important	Very important	Moderately important	Slightly important	Not at all important	Prefer not to answer
Warm or cold temperatures	□	□	□	□	□	□
High humidity	□	□	□	□	□	□
Flooding	□	□	□	□	□	□
Drought	□	□	□	□	□	□
High winds or storms	□	□	□	□	□	□
Heat waves	□	□	□	□	□	□
Frost	□	□	□	□	□	□
Snowfall	□	□	□	□	□	□

Survey Q-2:

How often do bad weather conditions cause delays in your company's operations?

Almost always	Often	Sometime	Seldom	Never	Prefer not to answer
□	□	□	□	□	□

Survey Q-3:

How often do bad weather conditions cause delays in your company's supply chain?

Almost always	Often	Sometime	Seldom	Never	Prefer not to answer

□	□	□	□	□	□

Survey Q-4:

How often does your company make any accommodations for workers who work in bad weather conditions? This could include as paid days off, un-paid days off, rescheduling of work etc.

Almost always	Often	Sometime	Seldom	Never	Prefer not to answer
□	□	□	□	□	□

Survey Q-5:

Does bad weather impact the behavior of your customers/clients?

Almost always	Often	Sometime	Seldom	Never	Prefer not to answer
□	□	□	□	□	□

Survey Q-6:

What are approximate losses for your company caused by one day of bad weather?

- □ $100
- □ $1,000
- □ $10,000
- □ $100,000
- □ >$100,000
- □ Prefer not to answer

Survey Q-7:

Is there a decision making framework or protocol adopted to deal with bad weather conditions when it happens?

- □ Yes
- □ No
- □ Prefer not to answer

Survey Q-8:

How often does your company adopt new technologies to adapt operations to weather related risks?

Almost always	Often	Sometime	Seldom	Never	Prefer not to answer
□	□	□	□	□	□

Survey Q-9:

Does the Canadian insurance industry offer adequate insurance products to deal with bad or extreme weather conditions?

Almost always	Often	Sometime	Seldom	Never	Prefer not to answer
□	□	□	□	□	□

Survey Q-10:

To what degree do you think Canadian government agencies (Municipal, Provincial and Federal) have adopted weather related considerations into their guidelines, protocols or standards for infrastructure development?

Almost always	Often	Sometime	Seldom	Never	Prefer not to answer
□	□	□	□	□	□

Survey Q-11:

Please indicate the level of your agreement or disagreement with the following statement:

"The increase in the frequency, intensity and duration of bad weather conditions would severely impact the operations, workers or profitability of your company."

Almost always	Often	Sometime	Seldom	Never	Prefer not to answer
□	□	□	□	□	□

Survey Q-12:

Rate the importance of planning for bad weather in the different sectors of your company.

	Extremely important	Very important	Moderately important	Slightly important	Not at all	Not applicable	Prefer not to answer
Planning	□	□	□	□	□	□	□
Investment	□	□	□	□	□	□	□
Design	□	□	□	□	□	□	□
Construction	□	□	□	□	□	□	□
Operations	□	□	□	□	□	□	□
Management	□	□	□	□	□	□	□
Maintenance	□	□	□	□	□	□	□

Survey Q-13:

What kind of information or knowledge you may need to improve operations and profitability of your company? Feel free to write your thoughts.