POTENTIAL FOR A VIDEO-BASED SYSTEM TO MONITOR THE TRANSPORT OF DANGEROUS GOODS BY RAIL TO SUPPORT EMERGENCY PLANNING AND PREPAREDNESS

by

Brendan L. McPhee

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Supervisor: Trevor Hanson, PhD, PEng, Department of Civil Engineering

Examining Board: Eric Hildebrand, PhD, PEng, Department of Civil Engineering
James Christie, PhD, PEng, Department of Civil Engineering
Julian Meng, PhD, PEng, Department of Electrical Engineering

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ABSTRACT

The use of video monitoring equipment was explored to determine its effectiveness at collecting open source data from passing rail cars, to provide emergency organizations with an enhanced resolution of data on the movement of dangerous goods (DG) by rail. A camera was installed at a former train station in Sussex, New Brunswick, where it collected video data 24 hours a day from July 2016 until January 2017. The first 3 months of video data were manually transcribed to capture detailed rail car information, obtaining important attributes such as the container code, weight limits, and dangerous good placard. A total of 17,864 rail cars were identified; 94% of container codes and 87% of weight limits were legible from the video data, and only 3 of the 10,339 DG placards were unidentifiable. National accident rates were used due to the absence of local data to obtain estimates of the probability of a rail-related accident occurring anywhere along the Sussex subdivision line.

The use of a video camera was determined to be an effective method of collecting rail cargo data to supplement emergency organizations with detailed historic data in addition to the current data sources provided through railway companies. The manual transcription process has potential to become automated, which could allow real-time rail data to be provided to communities. This study highlighted the lack of rail metrics, such as gross tone miles and number of DG carloads, available at local rail subdivision levels, which are ultimately obtainable through the use of open source data.
DEDICATION

Becky, for the unconditional love and support.
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List of Abbreviations

AAR Association of American Railroads
BNSF Burlington Northern Santa Fe
CANUTEC Canadian Transport Emergency Centre
CN Canadian National Railway
CP Canadian Pacific Railway
CSX Chessie-Seaboard Merger
CTA Canada Transportation Act
CWD Cold Wheel Detector
DED Dragging Equipment Detector
DG Dangerous goods
EB Eastbound
ERAP Emergency Response Assistance Plan
FCM Federation of Canadian Municipalities
FRA Federal Railroad Administration
GPS Global Positioning System
GTM Gross Ton Mile
HBD Hot Box Detector
LPG Liquefied Petroleum Gas
MMA Montreal, Maine and Atlantic Railway
NAS Network Attached Storage
NTSB National Transportation Safety Board
OCR Optical Character Recognition
PD Protective Direction
PHMSA Pipeline and Hazardous Materials Safety Administration
POE Power Over Ethernet
PTC Positive Train Control
RAC Railway Association of Canada
RCIS Rail Crossing Identification System
RFID Radio Frequency Identification
RTM Revenue Ton Mile
TSB Transportation Safety Board of Canada
UN United Nations
US United States
USDOT United States Department of Transportation
WB Westbound
1.0 Introduction

The safe and secure transportation of dangerous goods (DG) throughout Canada has faced increased scrutiny in recent years, due to the increase in DG being transported by rail and high profile derailments. Following the Lac Mégantic tragedy in July 2013, which resulted in 47 fatalities and much of the downtown core destroyed, government agencies reacted by implementing more stringent safety protocols to reduce the possibility of such a devastating accident from occurring in the future. One response by Transport Canada, the regulatory agency for transportation safety in Canada, was to issue Protective Direction (PD) 32 in November of 2013, which has since been replaced by PD 36.

PD32 had required railways to provide registered emergency officials with an annual report summarizing the type and volume of DG transported through their community with the data aggregated quarterly for Class 1, and annually for Class 3 railways (Government of Canada, 2013). This directive was intended to respond to calls for real-time DG rail data, although many community and emergency officials were still calling for real-time information on train activity two years later (CBC, 2015). Following the implementation of PD36, Class 1 railways were required to provide similar summary reports on an increased frequency, and also provide high-level online reports available to the public. Class 3 railways are still only required to provide an annual report, with no additional data required to be released. It is unclear whether the reports provided through PD 36 are at a sufficient detail to fully inform strategic emergency planning, in light of notable changes in the volume of DG being transported by rail.
The number of carloadings of DG transported by rail have been on a general increase in Canada, increasing from 406,425 in 2006, to 491,802 in 2015, with a noticeable spike of 576,226 in 2014 (Railway Association of Canada, 2016). Similar trends have also been observed in the United States, with 9,000 carloadings of crude oil originated by Class 1 railroads in 2008, increasing to 493,146 in 2014 (Association of American Railroads, 2015). The variability in the volume of DG being shipped by rail throughout North America can lead to changes in risk, and the challenge is that current data sources represent a lagging indicator.

Emergency organizations need to have access to a sufficient level of data on DG being transported through their community in order to properly prepare and plan for changes in risk. The challenge is that the two primary sources of data available to emergency officials are reliant on railways to provide the data on rail cargoes. Since railways prefer to keep their shipping information private, another way of obtaining rail cargo data would be through the use of open source data. Open data sources on railway activity that are available to emergency organizations are limited, although rail cargo data can be obtained by monitoring and manually transcribing trains as they travel through public space.

Research recently conducted by Hanson (2014) at the University of New Brunswick has demonstrated that detailed data of rail cargoes can be quantified and collected through the use of video monitoring equipment (Hanson, 2014). By setting up a video camera adjacent to a rail line, it was found that by using open source data, important characteristics regarding the movement of cargoes through a community could be obtained. Rail cargo data, such as type and number of rail cars, and estimated quantities
of cargoes transported, were obtained from transcribing the information posted on the side of the various rail cars. This led to the development of the work completed in this thesis to support emergency organizations by collecting data on the movement of DG by rail through the use of video monitoring equipment.

1.1 Problem statement

The data emergency officials are currently receiving through PD36 provides them with lagging indicators on the movement of cargoes through their communities. The challenge is that it is difficult to determine the effectiveness of this data when received a year later when the volumes in DG can change within a short time period. The resolution of the reports provided by railways is also questionable as to whether the level of detail is sufficient for emergency organizations to carry out their emergency planning. It is unclear whether it would be a greater benefit for emergency officials to receive these summary reports on a more frequent basis, with a shortened period over which the data is aggregated.

Possessing real-time information on rail cargo movements would be the highest level of data emergency organizations could receive. Presently, emergency organizations are reliant on railway companies to provide data which is lagging at a varying frequency. Railways are following the requirements implemented by Transport Canada to supply information to these emergency organizations, although there are no requirements in place for railways to provide additional information. While some railways may willingly share additional data, others may wish to protect their shippers’ proprietary information by not disclosing any data that is not required by law. If emergency organizations were
able to receive a more detailed cargo report at an increased reporting frequency, then they
would be in a better position to adjust their practices in response to changes in DG
movement.

1.2 Hypothesis

The use of video camera technology to monitor train activity could be an effective and
timely open source method to collect data on the transport of DG by rail to support
emergency planning and risk assessment.

1.3 Project significance

Following the Lac Mégantic accident, as well as other accidents involving DG, there has
been increased desire from both community officials and emergency organizations to
enhance rail safety across Canada. Little scientific research has explored the data sharing
policies and practices that support community emergency planning regarding the
movement of DG by rail. There has also been little research exploring the use of open
source data collection methods to understand the movement of DG by rail. The work
completed for this thesis investigated the effectiveness of a standalone video camera to
collect and transcribe all rail cargo activity for three months. This method of data
collection would allow for rail cargo data to be disseminated to emergency organizations
on a more frequent basis, and at an enhanced resolution of data, which would include
data on a per train basis. If the video camera was successful in providing sufficient video
quality to identify various rail cargoes and transcribing related container information,
then this method of open data collection could be implemented elsewhere in Canada to
allow other communities and emergency organizations to collect data on train activity. However, outlets currently in place to provide these organizations with rail cargo data are limited with regard to their timeliness and level of detail.

PD36 is currently the only rule implemented by Transport Canada that requires railway carriers to share train cargo data with emergency officials. This directive requires all railway companies that operate through a community, to provide the nature and volume of DG being transported to an emergency official who must be registered with the Canadian Transport Emergency Centre (CANUTEC). PD36 requires Class 1 railway companies to provide a report to these registered emergency officials on an annual basis, with the volumes of DG aggregated quarterly. Conversely, Class 3 railway companies are required to provide an annual report, with the volumes of DG aggregated annually (Government of Canada, 2013). Since the effectiveness and timeliness of PD36 is unclear, it would be beneficial to emergency organizations to receive data on a more frequent and timely basis to ensure their data needs are met.

In addition to PD36, emergency officials also have access to a mobile phone application named AskRail. This application provides registered emergency responders access to information about what types of DG are being transported in a rail car by keying in the equipment ID. It is envisioned to be a source of DG information in the event of an accident if the train’s manifest or conductor is not immediately available (Association of American Railroads, 2015). It offers first responders a real time ability to understand rail cargo; however, it appears limited to information on train consist for Class 1 railways.
only, and is not accompanied by historical data to aid emergency organizations understand and respond to trends in train movements.

Although emergency officials have access to these sources of data, they do not currently have possession of a historical set of detailed data with respect to the movement of DG through communities. The video data collected as a result of the thesis work highlights the use of open source data and how it can be used to monitor railway activity to gain a better understanding of the type and volume of cargoes being transported. Open source data are data within the public realm that can be obtained by any member of the public simply recording their observations. Open source data for freight rail transportation in North America is quite limited when compared to not only passenger rail services, but all other modes of transport as well. Open source data for highway, air, and marine transport have been extensively collected and distributed in the past, whereas freight rail has been lagging behind. To complement the lagging data provided by railways, an innovative method of collecting data on the movement of DG by rail was investigated through the use of video monitoring equipment.

1.4 Goal and objectives

The goal of the proposed project was to provide an enhanced form of data concerning the movement of DG to emergency organizations and public safety agencies that are transported through their communities. This goal was largely accomplished by completing several main objectives:

- Understand current rail data sharing landscape in Canada
- Evaluate and select suitable video camera equipment and setup location
• Procure, install, and test video equipment to ensure proper setup
• Collect video data using video equipment at selected location for a period of three months
• Transcribe, review, and validate video data
• Analyze video data
• Evaluate potential of approach for use in risk assessment

While the majority of the objectives were completed, the data were unable to be validated due to the railway summary report being unavailable at the time this thesis was completed (February 2016).

1.5 Scope

This research relied on scientific literature and was informed through consultations with municipal and provincial emergency planning officials. A single video camera was procured and installed at the municipally owned train station in Sussex, New Brunswick to monitor passing train activity from July 1, 2016 until January 2017. The video data collected from the camera were manually transcribed by reviewing each of the video recordings of trains, to obtain important attributes associated with each of the rail cars for 3 months ending September 30, 2016. All research activity occurred outside the railway right of way and did not involve any private sector participation.

1.6 Thesis Organization

While Chapter 1 provides some context behind the focus and significance of the project, the remainder of the thesis is organized as follows: Chapter 2 provides background on
high profile accidents motivating this work, primary governing authorities overseeing the transport of DG by rail and the statutes enacted to regulate the industry. Risk assessment methodologies were also explored, which determine the level of risk of transporting DG, as well as safety technologies that reduce the potential of an accident. Chapter 3 contains the methodology used to carry out the described research, which included video camera and setup location evaluation, data collection procedures, and analysis. The results of the analysis are presented in Chapter 4. The primary conclusions drawn through the completion of this work are summarized in Chapter 5, along with recommendations for future work.
2.0 Literature Review

There has been a strong emphasis on improving safety within the rail industry throughout Canada and the United States (US) due to the potential risk associated with transporting DG through communities throughout the country. There has been a general increase in the number of DG carloads shipped by rail in recent years, increasing from 406,425 in 2006, to 491,802 in 2015, with a noticeable spike of 576,226 in 2014 (Railway Association of Canada, 2016). This increase in the number of DG carloads transported has created an even greater need for railway companies to share information with emergency organizations to ensure the safety of communities neighbouring rail lines.

The primary motivation for this work was Transport Canada’s Protective Direction (PD) 32, a response to increased calls for DG data sharing following the Lac Mégantic disaster. PD 32 provided emergency organizations with an annual report that summarized the type and volume of DG transported through their community, with volumes aggregated quarterly. PD 32 was implemented in November of 2013, and then later replaced by PD 36 in April of 2016. This new directive requires Class 1 railways to provide more frequent reports to emergency organizations, incrementally increasing from one report in 2016, two in 2017, three in 2018, to four reports in 2019, as well as provide select information regarding DG movement to the public (Transport Canada- A, 2016). Although improvements were implemented with PD 36, the data are still only required to be aggregated quarterly and provides lagging indicators rather than leading ones.
The aim of the literature review is to provide a detailed analysis of the current government and scientific literature related to the movement of DG in Canada and the US, as well as the relevant data that emergency organizations have access to and its effectiveness.

2.1 Events motivating increasing focus on rail safety in communities

There have been a number of high profile accidents in recent years that have increased awareness in communities of DG being transported by rail. While the probability of an event is quite low, the potential still exists. It is important to then learn from past accidents and enhance the current system to prevent a similar type of event from occurring again.

2.1.1 Lac Mégantic

The train derailment in Lac Mégantic on July 6, 2013 was one of the deadliest rail accidents in Canadian history that resulted in 47 lives lost, 40 buildings and 53 vehicles destroyed. The train involved was loaded with 72 tank cars that contained petroleum crude oil destined for the oil refinery in Saint John, NB. (Transportation Safety Board of Canada, 2014).

The train stopped in Nantes, Quebec for the night, where a series of errors occurred which set the disaster in motion. Previous to the day of the derailment, there had been existing issues with the lead locomotive as it had been seen emitting white and black smoke on several occasions. On the night of the disaster, a fire erupted in the lead locomotive, which required firefighters to shut down the locomotive to extinguish the
fire. Since there were no locomotives running, the air brake pressure throughout the train began to dwindle. Since there were an insufficient number of hand brakes applied to the rail cars and the train was parked on a descending grade, the downward forces began exceeding the braking force. The train began its descent towards Lac Mégantic where it reached a speed of approximately 105 kilometres per hour and derailed around a curve near the center of the town (Transportation Safety Board of Canada, 2014).

The town experienced extensive damage from 63 of the 72 tank cars derailing and spilling approximately 6 million litres of petroleum crude oil, causing extensive environmental contamination throughout the downtown area and nearby water bodies. (Transportation Safety Board of Canada, 2014). Three key safety issues were identified by the Transportation Safety Board of Canada (TSB) that required immediate attention to improve the safety of the Canadian rail system: the Class 111 tank cars vulnerability to damage following a derailment, route planning and analysis for trains carrying DG, and requirements for ERAPs (Transportation Safety Board of Canada, 2014).

A list of 18 causes and contributing factors were discovered by the TSB after the accident, which included factors such as Montreal, Maine & Atlantic (MMA) Railway not clearly identifying and managing potential risks, MMA missing key processes from their safety management system, and Transport Canada not providing a sufficient level of regulatory oversight (Transportation Safety Board of Canada, 2014). Overall, it highlighted a weakness in the understanding of risk associated with the movement of hazardous goods and how a community responds to managing that risk.
2.1.2 Other Notable Accidents

While Lac Mégantic disaster was one of the most devastating rail accidents in Canadian history, there have been several other notable accidents in Canada that resulted in a major release of DG cargo.

In early 2015, two main-track train derailments occurred near Gogama, Ontario. The first train to derail on February 14, 2015 involved a train loaded with 68 petroleum crude oil DOT-111 tank cars and 32 with petroleum distillates. There were 29 tank cars that had derailed, where a number of them released product and ignited a fire (Transportation Safety Board of Canada, 2015). Only a few weeks later on March 7, 2015, a second train derailed, which involved a train carrying 94 DOT-111 tank cars loaded with petroleum crude oil. A total of 39 tank cars had derailed, causing the release of product and igniting a large pool of fire (Transportation Safety Board of Canada, 2016). During the preliminary damage assessment of the derailed tank cars, it was discovered that all of the TC/DOT-111 tank cars were built within the previous 3 years. They were compliant with the industry standard, and also had additional enhancements such as the half-head heat shield, improved top and bottom fitting protection, and normalized steel (Transportation Safety Board of Canada, 2016). It was determined that these tank cars performed similarly to the DOT-111 tank cars involved with the Lac Mégantic disaster, despite the additional protection.

On January 7, 2014, a main-track derailment occurred in northern New Brunswick, near Plaster Rock, involving a train consisting of 122 rail cars. A total of 19 rail cars derailed, including 12 cars loaded with DG, such as petroleum crude oil and butane, as well as
several residue cars. Due to the release of approximately 230,000 litres of DG, 150 residents were evacuated within a 1.6 kilometre radius (Transportation Safety Board of Canada, 2015).

Evident from these accidents highlighted, the potential for trains transporting DG to become compromised and release product is a major concern for emergency organizations and communities adjacent to rail lines. Equipping these emergency organizations with enhanced data derived from open sources would allow for better preparation to enhance response and resilience in the event of a disaster.

2.1.3 Recent trends in volume and safety of DG movement by rail

Since 2009, the number of DG carloadings transported by rail in Canada has been on the rise, increasing from 246,042 carloadings to 333,765 carloadings transported in 2015, with a spike of 407,968 in 2014 (Statistics Canada, 2016). Similarly, in the United States, there were 9,500 tank car loads of crude oil originated by Class 1 railroads in 2008 that increased to 493,146 tank car loads in 2014 (Association of American Railroads, 2015).

While there have been slight increases and decreases in several types of DG by rail, such as gaseous hydrocarbons, gasoline and aviation turbine fuel, and sulphuric acid, the commodity causing the greatest level of concern with regard to rail safety in Canada is petroleum crude oil. The variation in the volume of crude oil being transported is substantially greater than the volumes of other types of DG being moved by rail. The annual total of carloadings of these DG transported by rail are represented in Figure 1.
Figure 1 Rail cars transporting DG annually in Canada (Statistics Canada, 2016)

The large spike in the number of carloads of fuel oils and crude petroleum is evident in 2014, increasing from approximately 68,000 rail cars in 2011 to the peak in 2014 of approximately 186,000. Despite this large increase of nearly three times the number of carloads between 2011 and 2014, there was a decrease realized in 2015 to approximately 158,000 carloads, as well as in 2016 with approximately 110,000 carloads.

Intuitively, it would be assumed that the number of accidents would increase when a system is subject to a greater volume of traffic than it normally experiences. Although the rail industry has experienced a general increase in the total number of DG carloadings transported, the number of railway accidents has been on a general decrease. A comparison of the total number of railway accidents versus the accidents involving DG
can be found in Figure 2. There has been an average of 236 rail accidents involving DG occurring in Canada each year between 2004 and 2016, with a noticeable decline from 2014 to 2016.

![Graph showing rail accidents versus accidents involving DG](image)

**Figure 2 Rail accidents versus accidents involving DG (Transportation Safety Board of Canada, 2017)**

A railway occurrence would include a person being killed or seriously injured by coming in contact with a train, train derailment or collision, unpermitted or uncontrolled movement of a train, or a track switch left in an abnormal position (Transportation Safety Board of Canada, 2016). Although the frequency of accidents has not been increasing along with the volumes of DG transported by rail, the potential for accidents with more severe consequences has increased due to the increased volume of DG being transported.
by rail. Several recent rail accidents, along with the disaster in Lac Mégantic are examples of the level of destruction that a train loaded with DG can have on a community.

2.2 The North American rail industry

The rail industry in Canada generates approximately $10 billion dollars in revenue annually with its 46,000 kilometres of track, which allows the transport of large volumes of cargo throughout the country (Transport Canada, 2012). The rail network between Canada and the United States (US) is largely integrated, which allows for many of the larger railway companies to operate across the border. At this level of integration, both federal governments work in coordination with one another to ensure rail safety policies and practices are aligned.

There are three classes of railway companies in Canada and the US that include both freight and passenger rail: Class 1, Class 2, and Class 3 railways. Class 1 railways in Canada are classified as railways companies whose annual revenue is greater than $250 million in each of the past two years (Transport Canada, 2012), while in the US their annual revenue must exceed $453 million (Association of American Railroads, 2016). Class 1 freight railways in Canada account for approximately 75% of track, or 34,500 km. Class 2 railways in Canada, also known as regional railways, are classified as railway companies whose annual revenue is less than $250 million in each of the past two years (Government of Canada, 2016). Class 3 railways, also known as short-line railways, operate on a much smaller scale than Class 1 railways and account for 22.2% of track, or 10,169 kilometres in Canada. The remaining 2.8% of track is operated by
passenger rail services, which includes intercity rail operators, urban rail transit railways, and VIA Rail (Transport Canada, 2012).

2.3 Roles and responsibilities of rail safety agencies

Canada and the United States have various agencies that have authority over their respective jurisdictions, which range from enforcing regulation to investigating accidents. Transportation agencies such as Transport Canada and the USDOT have been working in coordination with one another to implement new rules and regulation to enhance the safety of the transportation of DG by rail. The close proximity between Canada and the US and the interconnection of each country’s rail network allows for the efficient transport of goods. Since these countries have a shared rail network, many of the trains that originate in Canada travel into the US, as well as vice versa. This would require the regulations and standards pertaining to rail transport and infrastructure to be similar in both countries to allow for the safe and efficient transport of goods by rail.

2.3.1 Canadian Agencies

There are several agencies in Canada that are responsible for various aspects related to the rail industry in Canada, ranging from implementing regulation to investigating accidents. A summary of the Canadian agencies pertinent to the transportation of DG by rail can be found in Table 1.
Table 1 Summary of Canadian agencies pertinent to the transport of DG by rail

<table>
<thead>
<tr>
<th>Agency</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Transport Canada</td>
<td>Transport Canada is a department within the government of Canada that was created in 1935 which deals with the various modes of transportation such as aviation, rail, marine and road. It is responsible for developing regulations, policies, and services to the public with respect to the transportation of goods and persons in Canada. There are several acts related to rail safety that Transport Canada is responsible for enforcing, such as: Transportation of Dangerous Goods Act, Canada Transportation Act, and Railway Safety Act (Transport Canada- A, 2015).</td>
</tr>
<tr>
<td>Transportation Safety Board of Canada (TSB)</td>
<td>The TSB is an independent agency of the government of Canada that is responsible for investigating transportation related accidents and advancing transportation safety in Canada. The TSB carries out investigations for rail, aviation, marine, and pipeline transport accidents, and provides a report along with recommendations to encourage the prevention of similar accidents in the future (Transportation Safety Board of Canada, 2015).</td>
</tr>
<tr>
<td>Railway Association of Canada (RAC)</td>
<td>Initially created under the name of the Canadian Railway War Board, the Railway Association of Canada (RAC) was created in 1917 primarily to coordinate railway activities during World War I. RAC now represents over 50 freight and passenger railway companies that move 75 million people and $250 billion worth of goods in Canada every year (Railway Association of Canada, 2011).</td>
</tr>
<tr>
<td>Canadian Transportation Agency (CTA)</td>
<td>The CTA is an independent, quasi-judicial tribunal and economic regulator. It makes decisions and determinations on a wide range of matters involving air, rail, marine modes of transportation under the authority of Parliament, as set out in the Canada Transportation Act and other legislation. They are responsible for economic regulation, dispute resolution, and accessibility (Canadian Transportation Agency, 2014).</td>
</tr>
<tr>
<td>Canadian Transport Emergency Centre (CANUTEC)</td>
<td>CANUTEC’s mandate is to ensure the safety of the public while transporting DG for all modes of transport. It is operated by the TDG Directorate of Transport Canada, and is one of Transport Canada’s major safety programs to ensure the safe transport of people and goods across the country (Transport Canada- B, 2016).</td>
</tr>
</tbody>
</table>
2.3.2 US Agencies

There are many federal departments within the US that handle various aspects of the rail industry, such as rail safety, policy, and political relations. Many of these agencies are equivalent to the ones operating in Canada. A summary of US departments pertinent to the transport of DG by rail can be found in Table 2.

**Table 2 Summary of US agencies pertinent to the transport of DG by rail**

<table>
<thead>
<tr>
<th>Agency</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>US Department of Transportation (USDOT)</td>
<td>The USDOT is a federal cabinet concerned entirely with transportation. The top priorities of the USDOT are to keep the traveling public safe and secure, increase their mobility, and have its transportation system contribute to the nation's economic growth. There are many agencies within the USDOT, which related to railway activities, such as the Federal Railway Association and the Pipeline and Hazardous Material Safety Administration (United States Department of Transportation, 2015).</td>
</tr>
<tr>
<td>Federal Railway Association (FRA)</td>
<td>The FRA was created to disseminate and enforce rail safety regulations, administer railroad assistance programs, and conduct research and development in support of improved railroad safety and national rail transportation policy (Federal Railroad Administration, 2015).</td>
</tr>
<tr>
<td>Pipeline and Hazardous Material Safety Administration (PHMSA)</td>
<td>The PHMSA is concerned with the transportation of hazardous materials. PHMSA is responsible to establish national policy, set and enforce standards, and educate and conduct research to prevent accidents (Pipeline and Hazardous Materials Safety Administration, 2015).</td>
</tr>
<tr>
<td>National Transportation Safety Board (NTSB)</td>
<td>The NTSB operates as an independent government investigative agency that is responsible for civil transportation accident investigations, involving rail, aviation, marine, pipeline, and particular highway accidents, and providing recommendations from an objective viewpoint (National Transportation Safety Board, 2015).</td>
</tr>
<tr>
<td>Association of American Railroads (AAR)</td>
<td>The AAR, founded in 1934, is concerned with railroad policy, research, standard setting, and technology improvement. The association works on behalf of primarily major freight railroads in North America when coordinating matters with leaders and officials in government (Association of American Railroads, 2015).</td>
</tr>
</tbody>
</table>
These governing agencies in both Canada and the U.S. each play a vital role in the safe and efficient operation of railways on both sides of the border. These agencies are able to operate due to the regulations and acts that have been implemented by both countries’ federal rail transportation regulators.

2.3.3 Recent advances in rail transport of DG safety

The federal departments responsible for overseeing the rail transportation in Canada and the US hold safety as a major priority when it comes to transporting DG over long distances. This prominent safety culture is evident in both Canada and the US whose federal rail agencies, Transport Canada and primarily the FRA, respectively, implement various regulations to ensure the safe and secure transport of DG by rail.

The DOT-111 tank cars were phased out of commission on October 31, 2016 in Canada due to their lack of safety mechanisms. The new TC/DOT-117 tank car design proposed by Transport Canada, the FRA and the PHMSA requires the tank cars to have thicker steel, full head shield protection, a jacket with thermal protection, top-fitting protection, and new bottom outlet requirements (Canada Gazette, 2015). Further efforts by the US Department of Transportation (USDOT) also requires new braking standards, new operational protocols for trains transporting large volumes of flammable liquids, and new testing requirements (U.S. Department of Transportation, 2015).
2.4 Approaches to enact rail safety policy

Following the devastating accident that took place in Lac Mégantic, railway regulatory agencies in Canada and the United States immediately took action to enhance their current regulations and acts to improve the safety of transporting DG by rail.

2.4.1 Canada

The primary governing transportation agency in Canada is Transport Canada, which has jurisdiction over all federally regulated modes of travel. Various rulings are in effect within Canada, such as protective directives, regulations, and acts, to ensure the safe transport of goods by rail.

2.4.1.1 Protective Directions

Protective Directions are implemented by the Minister of Transport when there is sufficient evidence to require the need of temporary regulation to enhance the safety of the public with regard to the transport of DG (Transportation of Dangerous Goods Act, 1992). In November of 2013, Transport Canada implemented four Protective Directions (PD) in response to the Lac Mégantic tragedy. The four directives addressed concerns with regard to the transportation of DG by rail, and are summarized in Table 3.

The primary focus of this research was PD 32, as it created an emphasis on the reporting of the movement of DG through communities, which has since been replaced by PD 36. Reporting of railway movements before the implementation of PD32 did not provide emergency organizations with historical data that aggregated rail cargo volumes on a quarterly basis. PD 32, along with PD 31, 33, and 34, have all expired or been cancelled.
since their implementation, although DG shippers are still required to provide Emergency Response Assistance Plans (ERAP) in the case of an emergency involving DG.

**Table 3 Summary of Protective Directions implemented by Transport Canada**

<table>
<thead>
<tr>
<th>PD</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>31</td>
<td>Directs any person transporting crude oil to immediately test crude oil classified as UN1267, Petroleum crude oil, and UN1993, flammable liquid, if classification testing was completed before July 7, 2013, and to provide the results to Transport Canada’s inspectors upon request. It requires any person who transports the above goods to provide a Safety Data Sheet (SDS) for the tested product to the Director General through CANUTEC. It also requires such materials to be treated as a Class 3 Flammable Liquid Packing Group I, until testing is completed (Government of Canada, 2013).</td>
</tr>
<tr>
<td>32</td>
<td>Directs any railway company who transports DG through a municipality to provide the municipality’s Emergency Planning Official with yearly aggregate information on the nature and volume of DG. Class 1 railway carriers are required to provide an annual report with the volume of goods aggregated quarterly, while Class 3 railways are required to provide an annual report with the volume of goods aggregated annually. CANUTEC is directed to maintain a list of all Emergency Planning Officials and provide it to all railway companies. The railway companies must also submit contact information to Transport Canada, through CANUTEC, of the person who will liaise with a municipality’s Emergency Planning Official (Government of Canada, 2013).</td>
</tr>
<tr>
<td>33</td>
<td>Directs every person who transports DG by rail to have an Emergency Response Assistance Plan (ERAP) approved by Transport Canada. This directive applies to a number of DG listed under this protective direction. (Transport Canada, 2014). ERAPS are used to assist local emergency responders by providing them with additional expertise to manage the scene of an accident. ERAPs describe the specialized response capabilities, equipment and procedures that are to be used in the event of an accident involving DG (Transport Canada- C, 2016).</td>
</tr>
<tr>
<td>34</td>
<td>Directs every tank car owner to identify each of its tank cars which meet the four criteria set out by Transport Canada. If any one of the four criteria are not met, then the owner can no longer transport DG using that tank car and must label it with “Do not load with DG in Canada” (Transport Canada, 2014).</td>
</tr>
</tbody>
</table>
Several new protective directives have been implemented, some of which have expanded upon their scope from the predecessors. A summary of the most recent PD implemented can be found in Table 4.

**Table 4 Summary of recent Protective Directions implemented by Transport Canada**

<table>
<thead>
<tr>
<th>PD</th>
<th>Description</th>
</tr>
</thead>
</table>
| 36  | PD 36 built on the foundation of PD32 and enhanced it in several areas. The directive outlines several timelines that requires a Canadian Class 1 Rail Carrier to provide Emergency Planning Officials of each Jurisdiction with the following type of report:  
  - From implementation to March 16, 2018, an annual report, aggregated by quarter, is to be provided by March 15 each year.  
  - From implementation to September 16 2017, a report representing the first two quarters of the calendar year, aggregated by quarter, is to be provided by September 15 each year.  
  - Beginning on August 1, 2018, a report representing each quarter, aggregated by quarter, is to be provided within 30 days of the end of each quarter.  
Any person who transports DG by railway car are still required to provide an annual report to emergency officials with the type and volume of goods aggregated annually. A standard report format has also been outlined for railways to model their reports. An online report will also be available on the railway carriers’ website by March 15 for each province in which a railway operates. The report will show the breakdown of the top ten DG transported, as well as percentages for the top ten DG and residual DG of the total cargoes transported (Transport Canada- A, 2016). |
| 37  | PD 37 requires top fitting protection in retrofitted TC/DOT-111 tank cars in Canada. This directive aligns Canadian requirements for the retro-fitted tank cars with those in the US (Transport Canada- D, 2016). |
| 38  | PD 38 accelerated the previous plans for the phasing-out of the legacy DOT-111 tank for transporting crude oil. The jacketed and non-jacketed DOT-111 tank cars were previously supposed to be phased-out by February 28, 2018 and April 30, 2017, respectively, were phased-out on October 31, 2016 (Transport Canada- D, 2016). |
The replacement of PD32 to PD36 allowed emergency and community officials to receive reports from Class 1 railway carriers on a more frequent basis, incrementally increasing from one report in 2016, to a report following each quarter in 2018. PD36 was implemented on April 28, 2016, and is expected to remain in effect until it is cancelled or when permanent regulation is implemented. As for “any person who transports DG by railway car”, which includes Class 3 railways, they are still only required to provide an annual report with the type and volume of DG aggregated annually (Transport Canada-A, 2016).

Despite the frequency of reporting being increased for Class 1 railways, the time periods over which the cargo data are aggregated over will remain the same (by quarter). PD36 still only provides emergency organizations with lagging indicators on the movement of DG instead of leading indicators.

2.4.1.2 Acts and Regulations

There are several acts implemented by the federal government of Canada to ensure the safe and economical transport of goods by all modes. The acts described in Table 5 are federally regulated acts related to the TDG by rail.

The Transportation of DG Regulation, permitted by the Transportation of DG Act, establishes specific procedures and rulings for shippers of DG that operate in Canada. This Regulation covers various aspects of transportation such as classification and documentation, training and emergency response plans, rules for the various modes of transport, and expectations for inspectors.
Table 5 Acts implemented in Canada pertinent to rail transportation

<table>
<thead>
<tr>
<th>Act Name</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Canada Transportation Act (CTA)</td>
<td>The rail section of the CTA establishes rules for many aspects of rail transport, such as: regulation for the construction and operation of railways, certificate of fitness required by railway companies, general powers and abilities of railway companies, rail infrastructure required for operation, financial transactions, and rates, tariffs, and services appointed by rail companies. The CTA is the foundation of transportation rulings in Canada, which is regulated and enforced by Transport Canada (Canada Transportation Act, 1996).</td>
</tr>
<tr>
<td>Railway Safety Act</td>
<td>This act provides further guidelines for railways in addition to the CTA. The Railway Safety Act provides regulations for the following: construction and alteration of railway works, operation and maintenance of railway works and equipment, non-railway operations affecting railway safety, and administration and enforcement of the Act. The Minister of Justice may implement emergency directives if they feel there is an immediate threat to rail safety (Railway Safety Act, 1985).</td>
</tr>
<tr>
<td>Canadian Transportation Accident Investigation and Safety Board Act</td>
<td>The Canadian Transportation Accident Investigation and Safety Board Act provide oversight for investigations that are transportation related, as well as regulation for the Safety Board. This Act provides some oversight for the following items: investigations and public inquiries, administration, privilege of information, evidence of investigations, and pertinent offences (Canadian Transportation Accident Investigation and Safety Board Act, 1989).</td>
</tr>
<tr>
<td>Safe and Accountable Rail Act</td>
<td>The Safe and Accountable Rail Act establishes minimum insurance levels for railway companies and an additional shipper-financed compensation fund to cover any damages resulting from an accident involved DG being transported by rail (Government of Canada, 2016).</td>
</tr>
<tr>
<td>Transportation of Dangerous Goods Act</td>
<td>The TDG Act promotes public safety by detailing the operational boundaries for the TDG in Canada. This Act provides oversight for the following items: safety requirements and security protocols, emergency response assistance plans and security plans, financial responsibilities and obligations, monitoring compliance, disclosure of information, and offences and punishment. This act makes it possible for the government to write regulations to elaborate on the requirements established within the act. This act also allows the Minister of Transport to implement protective directions to reduce the danger of transporting DG by rail to public safety (Transportation of Dangerous Goods Act, 1992).</td>
</tr>
</tbody>
</table>
All DG that are transported by all modes, including rail, are separated in various Packing Groups and Classes, depending on the type and level of danger. Packing groups are defined as a grouping system used to include DG depending on their inherent danger. The three packing groups are: Packing Group I, which indicates a great level of danger, Packing Group II, which indicates a medium level of danger, and Packing Group III, which indicates a minor level of danger (Transport Canada- E, 2016). There are nine classes of DG outlined in the Regulation, some of which have several sub-classes called divisions. The nine classes of DG transported within Canada, along with their corresponding classification type, are summarized in Table 6 (Transport Canada- E, 2016).

Table 6 Class structure for DG transport in Canada

<table>
<thead>
<tr>
<th>Class</th>
<th>Type</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Explosives</td>
</tr>
<tr>
<td>2</td>
<td>Gases</td>
</tr>
<tr>
<td>3</td>
<td>Flammable liquids</td>
</tr>
<tr>
<td>4</td>
<td>Flammable solids; substances liable to spontaneous combustion; substances that on contact with water emit flammable gases (water-reactive substances)</td>
</tr>
<tr>
<td>5</td>
<td>Oxidizing substances and organic peroxides</td>
</tr>
<tr>
<td>6</td>
<td>Toxic and infectious substances</td>
</tr>
<tr>
<td>7</td>
<td>Radioactive materials</td>
</tr>
<tr>
<td>8</td>
<td>Corrosives</td>
</tr>
<tr>
<td>9</td>
<td>Miscellaneous products, substances or organisms</td>
</tr>
</tbody>
</table>

To ensure there is consistency for DG transport throughout the world, the United Nations has developed mechanisms for the harmonization of hazard classification criteria and hazard communication tools (United Nations Economic Commission for Europe, 2016). Since the Transport of Dangerous Goods Directorate is currently a member of the United
Nations Committee of Experts on the Transport of Dangerous Goods, United Nation (UN) numbers are used to identify specific DG transported in Canada (Transport Canada, 2011). They are visible on loaded containers on a diamond-shaped placard with the UN number listed across the center, as shown in Figure 3.

![Sample image of UN number on a placard (Massingham, 2015).](image)

Figure 3 Sample image of UN number on a placard (Massingham, 2015).

Schedule 1 within the Regulation has a complete list of every type of DG available for transport including important attributes, such as UN number, shipping name and description, class, Packing Group, special provisions, and several other indices for transportation.

2.4.1.3 Railway Operating Rules

The primary set of rules used to regulate the operations of the rail industry in Canada is through the use of the Canadian Rail Operating Rules (CROR). The CROR provides guidance for the most basic operations including the standardized time used by railway personnel, general signal and track information, and specific rules to ensure the safety of train operations. The Occupancy Control System (OCS) rule, previously referred for
trains operating in “dark territory”, is a clearance based rule that requires trains to have special permission in order to occupy or enter a rail subdivision, or a particular section of track. It is supervised by a rail traffic controller who monitors train movements to determine when a clearance has been fulfilled, superseded or cancelled (Transport Canada- B, 2015).

In addition to the rules outlined in the CROR, Transport Canada has an additional rule named “Rules Respecting Key Trains and Key Routes”, which identifies key trains and key routes that require additional precautions while being transported through high risk routes.

Key trains are defined as an engine with cars that includes one or more loaded tank cars of DG included in Class 2.3, Toxic Gases and toxic by inhalation, as well as 20 or more loaded tank cars or portable tanks on intermodal units that are loaded with DG. These trains are required to travel at a maximum speed of 50 miles per hour, and must reduce speeds to 40 miles per hour when travelling through the core of a Census Metropolitan Areas. Key trains must also reduce their speed to a maximum of 40 miles per hour if carrying more than one DOT-111 loaded tank cars containing one of the DG listed (Transport Canada- F, 2016).
A Key Route is defined as a length of track that over a period of one year has more than 10,000 loaded tank cars or portable tank loaded on intermodal units travelling through. They must have a rail flaw inspection, and an electronic geometry inspection no less than two times a year, as well as an inspection of joint bars, and have procedures in place to repair joint bars. A risk assessment must also be carried out to determine the level of risk associated with operating a key train over a key route, and rail companies must consult with municipal and other government officials to gather their input on concerns with the risk assessment (Transport Canada- F, 2016).

2.4.2 Approach to rail safety policy in the United States

The United States has also introduced several new regulations issued by the USDOT and its associated agencies, including the FRA and the PHMSA, to increase the safety of trains operating in the US.

2.4.2.1 Emergency Orders

Emergency orders are implemented in a similar manner as the PDs in Canada, on the basis as necessary. The most recent additions to these regulations are several emergency orders and rules, which can be found in Table 7.
<table>
<thead>
<tr>
<th>Order Name</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Emergency Order 28</td>
<td>Implemented by the FRA, this order requires railroads operating on the general system to implement additional processes and procedures to ensure that unattended trains and vehicles on mainline track or siding outside of a yard or terminal are properly secured against unanticipated movement (Federal Railroad Administration, 2013).</td>
</tr>
<tr>
<td>Emergency Restriction/Prohibition Order, Docket No. DOT-OST-2014-0067</td>
<td>Implemented by the USDOT, this order requires railroad carriers to provide emergency response officials with notification of expected movement of dangerous. This emergency order applies to all railroad carries which transport a single train which would be transporting 1,000,000 gallons or more of UN1267 (petroleum crude oil, Class 3), which is produced from the Bakken shale formation. The carrier must provide the State Emergency Response Commission (SERC) for each state with notification of its anticipated movement through every county in which the train will operate (U.S. Department of Transportation, 2014).</td>
</tr>
<tr>
<td>Emergency Order 30</td>
<td>Implemented by the FRA, this order requires trains transporting large amounts of Class 3 flammable liquid through particular highly populated areas to adhere to a maximum operating speed of 40 miles per hour. The volume of product considered to be large amounts would be 20 or more loaded tank cars in a continuous block or 35 or more loaded tanked cars. At least one DOT Specification 111 tank car loaded with a Class 3 flammable liquid would be required to adhere to this emergency order as well (Federal Railroad Administration, 2015).</td>
</tr>
<tr>
<td>“Final Rule”</td>
<td>The PHMSA in coordination with the FRA implemented a “final rule”, which brings together several aspects of the emergency orders. The rule requires tank cars to be held to an enhanced standard for both new and existing tank cars, more accurate classification of crude petroleum-based products, new operational protocols, such as routing requirements, speed restrictions, and information for local government agencies, and enhanced braking standards to improve the level of safety of trains (U.S. Department of Transportation, 2015).</td>
</tr>
</tbody>
</table>
2.4.2.2 Other Legislation

The U.S. has been stringent in developing strict regulations and implementing safety technologies to ensure the prevention of any accident involving the TDG by rail. The USDOT has made safety technologies such as Positive Train Control (PTC) mandatory for Class 1 railroads. PTC was originally supposed to be implemented on all Class 1 railways in the US, including both freight and passenger railways, by December 31, 2015; however the deadline has been extended to December 31, 2018. Railway companies must also submit a plan for implementing PTC by the new deadline to ensure they will be compliant with the specified regulations (Positive Train Control Enforcement and Implementation Act of 2015).

2.5 Recent reviews of rail safety policy

Reviews have been conducted by committees, working groups, and third party consultants who carry out an objective analysis of policy to evaluate their effectiveness. Several reviews have been carried out in recent years that have been brought upon by the increased scrutiny of the rail industry and the transport of DG by rail.

The House of Commons Standing Committee on Transport, Infrastructure and Communities was requested by the Minister of Transport on the 18th of November, 2013 to review and report on the Canadian transportation safety regime. The Committee fulfilled this request with the “Interim Report on Rail Safety Review”, for which they focused on the TDG and the use of Safety Management Systems (SMS) (Standing Committee on Transport, 2014). Through discussions the Committee had with several union representatives, from unions such as Unifor, the United Steelworkers and
Teamsters Canada, they were able to gather and project several recommendations the unions felt were necessary. Unifor had recommended that rail mechanics have the authority to prevent trains from travelling if they are deemed unfit, and also that two-person inspections of railcars should be performed more frequently by railways (Standing Committee on Transport, 2014). While the Committee learned from a number of safety experts that it is impossible to reach zero risk when transporting DG by rail, there are several areas within the industry in which risk can be significantly reduced. While there were several concerns mentioned in the report, such as improved tank cars, identifying key routes, and increased liability coverage, they have since been addressed since its publication in 2014. A suggestion was made by the Auditor General at the time to strengthen SMS by requiring railways to provide Transport Canada with data on their financial performance measures, condition reports on the segments of tracks used to transport DG, and their internal risk assessments (Standing Committee on Transport, 2014). While there are concerns of protecting the information of third-parties with the release of information, the additional protection for the general public needs to be weighed in the assessment as well.

The ERAP Working Group of the Transportation of DG, General Policy Advisory Council, also completed a Report and Recommendations of the Transport of DG in January of 2014. The Working Group stated that the safety of the public primarily depends on effective preventative measures implemented in the form of legislation, enforcement, training, and safe operating practices (ERAP Working Group, 2014). The Working Group noted the importance of critical components of the transport of DG
safety system, such as the Emergency Response Guidebook, CANUTEC, and ERAPs that are available to emergency responders in the event of an accident. An example of a critical component would be during the Lac Mégantic accident, a large amount of foam was required to extinguish the fire, which was supplied by a refinery that was approximately 180 kilometres away (ERAP Working Group, 2014). Although it was noted by the Working Group that if this accident were to occur in a location where the foam concentrate or other specialized resources were not available in a timely manner, then the emergency response efforts would not have been as effective (ERAP Working Group, 2014). Concerns were also raised for some crude oil, such as the Bakken crude that is a very light, volatile, and has a lower viscosity, since it behaves more like a refined product like gasoline when involved in a fire, which can put emergency responders at greater risk.

Cairns (2015) investigated the current state of the Canadian freight rail industry and the current policies implemented to regulate their operations. Cairns mentioned that Canadian railways are already heavily regulated by provincial and federal governments as well as by their representative agencies, despite the increased calls for further regulations in response to issues of safety, competition and capacity (Cairns, 2015). Additional regulation on railways could have a detrimental effect on their productivity, which would have a detrimental effect on the transportation industry in Canada as they move large volumes of goods across the country. One of the recommendations Cairns reported was to harmonize regulation for the transportation of DG with the US to ensure efficient operations across the border (Cairns, 2015).
2.6 Technology to monitor rail safety

The safety of the rail industry can be enhanced by implementing changes at the physical level, through the installation of various types of safety and monitoring equipment, as well at the policy level, with the addition of new policy.

2.6.1 Railway Safety Technologies

There has been extensive research completed through the investigation of the effectiveness of safety technologies in the rail industry to promote safety, both using track side equipment and on-board technology. Track-side equipment has been implemented in the rail industry since the 1960s, while newer technology such as Electronically Controlled Pneumatic brakes and Positive Train Control have become more common.

Various types of track side equipment, such as Hot Box Detectors (HBD), Hot and Cold Wheel Detectors (HWD/CWD), and Dragging Equipment Detector (DED), are placed adjacent to the rail line and are used to physically monitor the status of the train. A summary of these types of track side equipment are described in Table 8.
<table>
<thead>
<tr>
<th>Detector Type</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hot Box Detector (HBD)</td>
<td>HBD are used to monitor the temperature of wheel bearings on a train, which if they are heated to excessive temperatures the bearing could fail (Moynihan &amp; English, 2007).</td>
</tr>
<tr>
<td>Hot Wheel Detector (HWD)</td>
<td>HWD are used to monitor the temperature of the wheels of a train as they pass by the equipment by using digital processing of infrared images (Moynihan &amp; English, 2007).</td>
</tr>
<tr>
<td>Cold Wheel Detector (CWD)</td>
<td>A CWD detecting a colder temperature can be indicative of a brake system malfunction at a location where the train is normally braking (Moynihan &amp; English, 2007).</td>
</tr>
<tr>
<td>Dragging Equipment Detectors (DED)</td>
<td>A DED examines the underside of a train to detect abnormalities, and is a form of car body condition monitoring (Moynihan &amp; English, 2007).</td>
</tr>
</tbody>
</table>

Electronically Controlled Pneumatic (ECP) brakes have been implemented in the rail industry since the early 1990’s to address issues such as reducing propagation time of pneumatic brakes, air pressure recharge delays after releasing the brakes, and their inability to provide a graduated brake release (Moynihan & English, 2007). In the new ECP brake system, the air reservoirs are continually recharged since the brake pipe pressure is kept at a constant level throughout the train, and electronic controllers are fitted on each car to regulate the flow of air in and out of the brake cylinder. This system allows for the brakes on each of the cars in a train to be applied simultaneously to allow for a more effective and smooth braking operation. This reduces braking distances between 40% and 60%, as well as wear on the wheels and brake shoes (Moynihan & English, 2007).

One of the more recent technologies to be implemented, Positive Train Control (PTC), takes advantage of several automated processes and technologies that when employed together can enhance the safety of the train network. PTC has the ability to provide
appropriate spacing between trains, ensure speed limits are being followed, track switch positions, and provide protection for repair crews and other equipment operating on the track (Moynihan & English, 2007). The appropriate infrastructure being installed on both the train and wayside equipment can allow for the constant communication between trains and wayside controllers. Communications can be further enhanced through the use of GPS to provide railway personnel with the precise, real time position of trains, especially on segments of rail lines governed by OCS, where communications are limited (Badugu & Movva, 2013).

2.6.2 Rail monitoring technologies

Several technologies have been used in the past to enhance rail safety including a system for Monitoring and Intervention for the Transportation of DG (MITRA), acoustic detectors, an industry supported mobile phone application, and open sources of data.

2.6.2.1 MITRA

A prototype emergency notification system, MITRA, was developed in Europe aimed at providing emergency personnel with real-time data on the position and type of DG being transported within each jurisdiction (Planas, Pastor, Presutto, & Tixier, 2008). This prototype was designed to provide two operational scenarios: one being an alert scenario, which would detect an accident before it occurs, and second a crisis scenario, which would provide information to emergency personnel when an accident does occur (Planas et al., 2008). The MITRA prototype would require several components for the system to function: an on-board terminal, a communication server, data exchange infrastructure, a user monitoring terminal, and a risk-knowledge platform (Planas et al., 2008). The
MITRA prototype was capable of being equipped on both road and rail vehicles transporting DG. Two field studies were carried out to test the functionalities of the prototype, one in Germany and the other in the French/Spain border region. The test had a tractor-trailer loaded with 1 ton of chlorine (actually loaded with water and a small amount of bleach) colliding with a light vehicle to simulate an accident with a passenger vehicle (Planas et al., 2008). When the accident occurred, the driver of the tractor-trailer activated the panic button, which the on-board terminal then transmitted the alert within two minutes to both the Spanish and French fire departments. The MITRA also provided the proposed information to the fire departments, which included the exact location of the accident (address and GPS coordinates), the DGs involved, recommended emergency response, and a map with the worst-case effect distances of contaminant plumes (Planas, et al., 2008). Although the MITRA system was able to detect the release of DG and send the information to emergency personnel as intended, the amount of infrastructure required to make the system functional would require a large capital cost. The number of different components listed to make the system functional would be expensive, and the equipment that would be required on all vehicles transporting DG would also be costly.

2.6.2.2 Acoustic train detection

Another approach to monitoring train activity has been investigated with the development of a Rail Crossing Information System (RCIS) prototype that could be used to identify when an at-grade rail crossing is being blocked by a passing train (Rempel, Ternowetsky, & Reimer, 2015). The RCIS could detect when a train is passing through a crossing in real-time data, and then predict where the next blockage would be using data collected.
simultaneously from crossings down the line. This data could then be used to inform emergency responders on route to an emergency whether rail crossings are blocked by a passing train, and could then be rerouted to ensure time is not wasted (Rempel et al., 2015). A pilot test was conducted on a 2.5 kilometre segment of track in Winnipeg with two data collection points installed at an adjacent intersection nearby two at-grade crossings. Over the 9-week period of the pilot test, over 1,100 blockages were recorded at the data collection stations with the average blockage duration being 6 minutes (Rempel et al., 2015). Although only 2 stations were used to collect data, it was sufficient to predict the duration of a blockage more than 85% of the time, (+/- 2 min), as well as predict when the next crossing would be blocked more than 85% of the time, (+/- 1 min) (Rempel et al., 2015). The RCIS would possess a fully-predictive system that can provide real-time data on the time and location of rail crossing blockages and also be able to predict the time until the next crossing is blocked along with its duration. This type of information system has potential to benefit not only emergency responders, but also traffic management personnel, transportation planners, and the general public (Rempel et al., 2015). This RCIS prototype has since been developed into an application, Trainfo, which can disseminate rail crossing blockage information via several methods, such as Twitter, text message, or simply providing the aggregate data. This application would be able to predict the time and location of rail crossing blockages, which would be beneficial for commuters, emergency responders, and logistic providers (MORR Transportation Consulting Inc., 2017).
2.6.2.3 AskRail

The Canadian Association of Fire Chiefs has recently partnered with railway companies to promote the AskRail application which is available to qualified first responder with proper training (Canadian Association of Fire Chiefs, 2016). AskRail currently only represents Class 1 railways in North America, and can provide single-car data, as well as data for the entire train, that can be provided to first responders if the conductor or train consist is not readily available. This query based application allows the users to search for individual railcar container codes to determine whether it is loaded with DG (Association of American Railroads, 2015). Despite these data being available in real-time, it does not allow for historical data to be retrieved by the users to determine trends in rail activity or variation in cargoes. Although some communities feel as though they have access to sufficient data through the AskRail application, as well as PD36 (CBC, 2015), there are other emergency organizations that would benefit from more detailed historic data, provided on a more frequent basis.

2.6.2.4 Rail container classification methods

There are several types of classification methods used by railway companies to collect data on rail cargo, which can catalogue and manage rail cars within a classification yard. Technologies range from Optical Character Recognition (OCR) to Radio Frequency Identification (RFID) and Global Position System (GPS), which would require additional equipment to be installed on the necessary rail cars.

OCR technology has been widely used in various industries, as it efficiently recognizes text from photographs or videos, and transcribes it automatically (Anderson &
Mühlberger, n.d.). OCR has been used extensively with applications such as license plate readers, which would have similar application in cataloging rail cargo data. A camera can be used to capture a passing rail car, and then using OCR technology, various rail car data could be collected, such as the container code, weight limits, and DG placard. An automatic detection system was investigated by Roth et al. (2010), where OCR technology was used to identify and transcribe DG placards on both trucks and trains (Roth, Kostinger, Wohlhart, & Bischof, 2010). A private company, Intelligent Security Systems, also offers a service for train and cargo recognition, which transcribes video of a passing train in real-time, obtaining container codes and other information posted on rail cars (Intelligent Security Systems, n.d.).

RFID have also been used in the rail industry to catalogue rail cars within a classification yard. RFID requires use of a combination of a tag, comprised of a microchip with an antenna, and a reader with an antenna used in concert to communicate and track goods during their transport (RFID Journal, 2015). With regard to the monitoring of rail cars, a tag would be installed on every train car that requires being tracked, and a reader would be installed in a central location. Chang and Tsang investigated the use of RFID technology to identify and track the position of trains within the light right transit system in Hong Kong. RFID readers were placed in strategic locations along the trackside with tags attached on the underside of each of the rail vehicles to identify where it was within the network (Chang & Tsang, 2008).

GPS is a widely used technology which utilizes satellites orbiting the earth, which receive and transmit signals to receivers on the ground. This can be taken advantage of within the
rail industry since these receivers would be able to be placed on individual rail cars or trains to track their position along their route (Railway Technology, 2011).

2.6.2.5 Open source data for monitoring rail safety

Open source data, which is information that is made available to the public, has become more accessible with the progression of technology. These types of data are collected and disseminated through various groups and can also be collected by a member of the public documenting their observations. While there are limitations associated with some of the current data sources, alternate methods of data collection can be implemented to obtain a higher resolution of data.

There are several forms of open data presently available on rail transportation, including RR Picture Archives, Amtrak, and VIA Rail. RR Picture Archives is a website tailored towards rail enthusiasts who upload their own photos of locomotives and various rail cars. A number of rail cars are documented, including box cars, hoppers, and tank cars, which have the rail cars’ physical photo, container code, and load limit posted if they can be interpreted (RR Pictures Archives, 2016). Two of the primary passenger rail services in North America provide some form of data on the location of their trains. Amtrak, which operates primarily in the US but with stations in neighbouring provinces, has a “Track A Train” function which allows users to identify where a train is within Amtrak’s rail network (Amtrak, 2016). VIA Rail provides a notification based system where you are able to receive updates on the status on a train by email or text message on any disruption to service, or delay to the trains schedule (VIA Rail, 2016).
While the data available on the rail enthusiast website provides information on a number of rail cars, it is not a comprehensive list of data on rail cars, and similarly with the passenger rail services, they do not provide information on freight cargoes. The potential of implementing video monitoring technology to collect data on freight rail cargoes would overcome the limitations associated with these current data sources.

A one-week pilot study performed by Hanson (2014) investigated the use of open source video to catalogue trains passing over a bridge in Saint John, New Brunswick. Various rail cargo data were transcribed from the recorded video to obtain information on the time of day of the train crossing, direction of travel, type of rail car, and whether a DG placard was present (Hanson, 2014). The data collected over the week provided detailed information on the movement of rail cargoes, although the short duration of the study period did not allow for an extensive dataset to be obtained.

The extended study period used in this thesis allowed for several months of data to be collected at an even higher video resolution. This dataset containing daily rail cargo movements would have potential to better support local emergency organizations than the data available through PD36 railway reports and AskRail. Since this data would collect daily rail car data on a per train basis, it would provide a higher resolution of data than the quarterly aggregated reports through PD36, and also with historic data rather than single train-rail car information through AskRail.
2.7 Outstanding community data needs for the transport of DG

The desire for emergency organizations and community officials to have access to real time data with regard to the movement of train cargo through their community has become more apparent in the years following the Lac Mégantic disaster in July 2013. The Federation of Canadian Municipalities (FCM) has since made calls “for urgent and concrete action” to be taken by the federal government, which includes concerns related to “information sharing and Transport Canada’s oversight of federal railways” (Federation of Canadian Municipalities, 2016). The FCM has also created the National Municipal Rail Safety Working Group in response to the serious rail accidents that have occurred recently, whose mandate is to “support and inform FCM’s discussions with the federal government on rail safety” (Federation of Canadian Municipalities, 2016).

The ERAP Working Group had noted that there is a lack of data available on DG movements in Canada that is available for an analysis of any type. This largely limits the ability to determine what communities are at risk across Canada and to what extent. This also limits the ability to determine what resources would be required in the event of an accident and if they are within an acceptable proximity (ERAP Working Group, 2014). There has been no indication since this report was published that the Working Group or Transport Canada has been receiving additional data, other than through PD36 on the type and volumes of DG being transported by rail in Canada.

The data some emergency organizations, such as public safety organizations at the provincial level, are receiving on the movement of DG by rail are limited, whereas registered community officials receive summary reports from railway carriers through
PD36. Although these community officials, including Chief Administrative Officers and senior staff within local fire departments, receive these summary reports, the data presented are aggregated quarterly or annually, depending on the railway class. At this level of aggregation, it is difficult to determine whether these data are useful for day to day planning exercises to be able to make adjustments for variations in rail car loadings.

Also required through PD 36, Class 1 railway carriers in Canada are now required to post a report detailing the proportion of all DG transported in Canada, as well as list of the top ten DG transported along with their proportion for each province they transport DG. Evident from the online 2015 report, 9.7% and 8.7% of the total number rail shipments in Canada were DG shipped by CN and CP, respectively. Petroleum crude oil accounted for 21% (CN, 2016) and 17% (CP, 2016) of the total DG carloadings for CN and CP, respectively. These proportions account for a large number of carloads considering CN transported nearly 800,000 carloads of DG in 2015 (CN, 2016), and CP transported nearly 500,000 (CP, 2016).

2.8 The role for enhanced DG data in risk assessment

Identifying and assessing the risk involved in performing any activity is important to understand to ensure the risk associated with the various components of an activity can be minimized and managed. This is especially true when it comes to the transport of DG by rail since they pose a tremendous risk to not only the shippers, but to the general population and communities neighbouring rail lines where these DG are transported. There are two types of risk assessment that can be conducted for a scenario: a quantitative risk assessment and a qualitative risk assessment. A risk assessment may also
use both types in conjunction with one another to understand all aspects of a scenario. Both of these types of assessments require some form of data in order to conduct them, which can more often than not be difficult to gain access to or collect.

2.8.1 Data Needs

The data required to perform any type of risk modeling is generally quite extensive, since it requires detailed data from a number of sources to be compiled to create models, which would include train consist data, frequency of train movements, and number of DG carloadings. While there are data available to registered emergency officials within communities, it still only provides lagging indicators on the movement of DG, which are presented at a high level of aggregation. The proposed method of data collection would still provide lagging data; however, additional research could be conducted to automate the process to provide near real-time data. In any case, a greater resolution of historical data would be required to conduct a comprehensive risk assessment of any type.

2.8.2 Quantitative risk assessments

A quantitative risk assessment uses data in order to conduct an assessment. Statistics and other forms of numeric modeling are used to evaluate a hypothesis generated for the study in question. The assessments include a control group while a single variable is altered for a simple analysis, while several variables could be altered for a more rigorous analysis (Ostrom & Wilhelmsen, 2012). The assessment should be performed in such a way that if it was replicated, similar results would be achieved. There are four types of quantitative risk assessment commonly used: descriptive, correlational, cause-comparative, and experimental (Ostrom & Wilhelmsen, 2012).
Verma (2011) developed a risk assessment methodology that incorporated various characteristics of a train accident scenario, such as train length, train-decile position of the DG cars, sequence of events leading to DG release, and impact from ruptured cars (Verma, 2011). Through analysis of the framework developed and FRA derailment statistics from 1995 to 2009, it was concluded that it is riskier to transport DG cars near the front of a train, and that the 7-9\textsuperscript{th} train-decile are the most appropriate sections to position DG cars within a train (Verma, 2011). The case study examined in the analysis was performed on two alternate segments of track between Philadelphia, Pennsylvania and Columbus, Ohio and used national derailment statistics for these segments. While the FRA does not have derailment statistics available publicly for individual track corridors, this type of quantitative data would be useful in supporting risk assessment procedures.

Gheorghe et al. developed a model that uses a complementary cumulative distribution function to determine the level of risk for various traffic segments. The risk can be integrated with a decision support system software that can use GIS data processing and intelligent maps to produce a visual representation of the potential risk to sensitive infrastructure and population centres (Gheorghe, Birchmeier, Vamanu, Papazoglou, & Kroger, 2005). The paper notes that a major disadvantage to this type of modeling technique is that is extremely data intensive, which can be problematic when the data is inaccessible or non-existent.

In the Transportation Research Board’s report on \textit{Surface Transportation Security}, it is noted that staffing levels should be correlated to the number of crimes occurring by breaking down the number of emergency calls by location, and time of day and week
A similar comparison can be made for staffing levels at local emergency departments neighbouring rail lines that have DG transported. If emergency organizations are given the time of day a train is expected to travel through their community, then they could better prepare by adjusting their staff levels to ensure personnel are available in the event of an accident.

The lack of data for quantitative studies can be attributed to the costs and availability of data, which in some cases a qualitative risk assessment may also be conducted instead in order to understand a portion of the risk.

### 2.8.3 Qualitative risk assessments

A qualitative risk assessment is generally less expensive than a quantitative risk assessment as it does not involve the collection of extensive amounts of data. Qualitative risk assessments investigate subjects in greater depth and detail through the use of tools such as focus groups and individual interviews to gather the perspective of various groups and individual persons (Ostrom & Wilhelmsen, 2012).

This assessment also investigates the type of potential accidents that could occur and the consequences that would result from the accident (Erkut, Tjandra, & Verter, 2007). This form of assessment is required because there is lack of data to estimate accident probabilities. Their objective was to focus on the highest risk scenarios, such as identifying the type of accidents that occur more frequently and the type of accidents that would have the most severe consequence (Erkut et al., 2007). Ultimately, a qualitative risk assessment depends on the capabilities of the analyst performing the assessment.
since it can be greatly subjective due to the lack of data available to support the required assumptions (Transportation Research Board, 2009).

The level of risk that trains transporting DG pose to the environment and communities are much greater than other land transportation modes, such as trucks, since they often travel through a number of communities and have longer haul lengths. A rail tank car has roughly three times the volume of a regular truck tanker, and cannot be diverted to other routes to reduce the associated risk unlike a truck (Erkut et al., 2007). Trains are unique as they transport various types of DG in a single train, and if an accident were to occur it would involve multiple rail cars, rather than a single tank car (Erkut et al., 2007). Therefore, it is important to consider all the aspects associated with transporting large volumes of DG over long distance to minimize the risk.

2.9 Summary

There has been much effort put into enhancing the safety of transporting DG by rail by safety agencies, such as Transport Canada and the USDOT, since the Lac Mégantic derailment. These agencies, along with several others, work in combination to implement various rules and regulation to ensure trains are able to safely transport their cargo.

The probability of these accidents occurring can be reduced through the implementation of various safety technologies, with older devices such as the various track side equipment, and newer technologies such as ECP brakes and PTC. Monitoring technologies can also be utilized to gather additional data on the movement of rail cars and to know when a train may be blocking an at-grade crossing using real-time data.
These technologies can be used to increase the level of communication between trains, railway controllers, and rail infrastructure to identify any potential issues that can be addressed before an accident has an opportunity to occur.

Better understanding the level of risk transporting DG by rail imposes on a community can be achieved through a better understanding of probability and consequence of occurrences. Achieving this understanding requires data at an enhanced resolution than what is currently available through existing sources. Although communities do have access to lagging data on the movement of DG through their community, they do not receive data at a resolution capable of detecting changes in DG volumes per day, week or month. To better prepare emergency organizations for an emergency response it is essential have adequate data on the transport of rail commodities, especially DG.

Understanding the potential damage an accident could create, as well as possessing all the data needed to fully conduct an assessment of risk, could greatly aid emergency organizations with their emergency planning and preparedness. The use of video equipment to monitor and catalog rail cars transporting DG through a municipality has yet to be explored in the current scientific literature available at the time this thesis was published.
3.0 Methodology

This research aims to define the procedures implemented to assess the usefulness of video equipment to collect video data on rail movements through a community to provide data to emergency organizations to support their emergency preparedness and planning.

3.1 Video recording equipment selection

Two camera vendors were consulted to determine which video camera product would be the most appropriate for the project. The camera products available from the two companies contacted, ACTi Corporation and Axis Communications, were researched to obtain information on available cameras that would be suitable for the project. Through extensive discussion with representatives from both companies, three devices were recommended to be considered in the evaluation for the project: the ACTi I45, the ACTi KCM7411, and the Axis Q3505VE.

3.1.1 Criteria for potential cameras

The technical specifications for each of the cameras were compared to determine which device would best suit the environment the camera would be recording video. Various attributes possessed by each of the recommended cameras were compared, such as: size of lens, horizontal viewing angle, resolution and frame rate, price, and several others. Each of the cameras evaluated had day and night recording capabilities, as well as motion detection, which were the absolute minimum requirements for a camera to be used for the project. Each camera was given a rank of 1, 2, and 3 for each attribute, depending on its ability to capture train video. A camera that received a rank of 1 would be given a score
of 3, alternatively, a rank of 3 would translate to a score of 1. Each of the attributes were assumed to have equal weighting to ensure the evaluation was kept objective. The scores for the three cameras were then summed and ranked based on their total score, for which the greatest score was deemed the best alternative. The score and rank for each of the cameras, as well as the attributes used in the evaluation, are summarized in Table 9.

**Table 9 Evaluation of the recommended cameras**

<table>
<thead>
<tr>
<th>Attributes</th>
<th>Camera</th>
<th>Description</th>
<th>Score</th>
<th>Description</th>
<th>Score</th>
<th>Description</th>
<th>Score</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lens</td>
<td>AXIS Q3505VE</td>
<td>F1.3</td>
<td>3</td>
<td>F1.6- F5.0</td>
<td>2</td>
<td>F2.0</td>
<td>1</td>
</tr>
<tr>
<td></td>
<td>ACTi I45</td>
<td>F1.6- F5.0</td>
<td>2</td>
<td>F2.0</td>
<td>1</td>
<td>F1.3</td>
<td>3</td>
</tr>
<tr>
<td></td>
<td>ACTi KCM7411</td>
<td>F2.0</td>
<td>1</td>
<td>F1.3</td>
<td>3</td>
<td>F1.6- F5.0</td>
<td>2</td>
</tr>
<tr>
<td>Horizontal viewing angle</td>
<td>105°/35°</td>
<td>3</td>
<td>65-2.34 degree</td>
<td>1</td>
<td>82.6°</td>
<td>2</td>
<td></td>
</tr>
<tr>
<td>Minimum illumination</td>
<td>Colour: 0.18 lux; B/W: 0.04 lux</td>
<td>1</td>
<td>Colour: 0.1 lux; B/W: 0 lux</td>
<td>2</td>
<td>Colour: 0.1 lux; B/W: 0.05 lux</td>
<td>3</td>
<td></td>
</tr>
<tr>
<td>Resolution and frame rate</td>
<td>1920x1080 30 fps</td>
<td>3</td>
<td>1920x1080 30 fps</td>
<td>2</td>
<td>1920x1080 15 fps</td>
<td>1</td>
<td></td>
</tr>
<tr>
<td>Wide dynamic range</td>
<td>120dB</td>
<td>2</td>
<td>145dB</td>
<td>3</td>
<td>Basic</td>
<td>1</td>
<td></td>
</tr>
<tr>
<td>Price (excluding tax)</td>
<td>$915</td>
<td>3</td>
<td>$2,000</td>
<td>1</td>
<td>$870</td>
<td>2</td>
<td></td>
</tr>
<tr>
<td>Total score</td>
<td>15</td>
<td>11</td>
<td>10</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Rank</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
3.1.3 Selected video camera

The Q3505VE video camera from Axis Communications had the highest overall comparative score and was ultimately chosen for installation. The camera also supported an image stabilization function, which was useful in an environment with excessive vibrations, such as near a railway track. The selected camera from the evaluation can be found in Figure 4 (Axis Communications, 2016).

![Video camera procured for the project](image)

**Figure 4 Video camera procured for the project**

The representative from Axis Communications also gave a large reduction in the price of the camera from approximately $2,400 to $915, which was a large saving for the project. The camera was procured from Chandler Sales, a vendor for Axis camera products in New Brunswick.
3.2 Location selection

The video equipment was to be located on public property with a vantage point of a rail line that would experience regular train activity. Several municipalities within New Brunswick were considered as potential candidates with a rail line with trains operating through them on a daily basis, including the City of Saint John, with the Saint John Fire Department being an early supporter of the project.

3.2.1 Candidate locations

Each of the municipalities considered had various advantages associated with them of hosting the monitoring station, but the primary challenge was finding public property where a camera could be installed without needing external housing or power supply. The Town of Sussex, with the support of the Sussex Fire Department, agreed to work with the research team. The Town granted permission for the installation of the selected video camera on a municipal structure, a former train station, which presently serves as a visitor centre.

3.2.2 Selected setup location

The train station in Sussex provided access to electricity to power and internet, at no cost to the project. Perimeter lighting surrounding the building provided a source of light to help view trains during the night time. There were also existing security cameras placed around the train station, though none with the resolution of the candidate camera.
3.3 Camera equipment and installation

Several pieces of equipment were required in addition to the camera itself to record and store the video data on a storage device. The equipment required for the installation and operation of the camera were:

- Network Attached Storage (NAS) device
- 5-port Power Over Ethernet (POE) switch
- Ethernet cables (typical cables)

The NAS device procured needed to provide sufficient storage capacity for the camera to store the video data for the duration of the study period. A preliminary calculation determined that each video would take up approximately 16 Mb/second of data; therefore, if the camera were recording for 4 hours a day, for 100 days, then approximately 3 TB would be required to store three months of video data. It was not expected that the video camera would be recording video for 4 hours a day since it would only be activated on motion; however, a conservative estimate was used to ensure sufficient storage space was available. The NAS drive procured for the project was a 4 TB Western Digital MyCloud, pictured in Figure 5, to allow ample storage space for the video data to be stored over the 3-month study period.
A 5-port Power Over Ethernet (POE) switch was required to connect the camera and the NAS drive to the modem in the building. This connection would allow the video data to be accessible from the NAS drive anywhere there is an internet connection. The POE switch, shown in Figure 6, was procured by Chandler Sales.
The entire installation and programming process took three days in total to ensure the network was functioning properly and recording video data. A picture of the camera installed at the train station in Sussex can be found in Figure 7.

![Camera Installation](image)

**Figure 7** Picture of the camera installed on the train station, facing toward Moncton

### 3.4 Video data collection procedure

Video data were collected for a 3-month period, beginning on July 1, 2016 and running until January 2017. The video data were collected 24 hours a day to ensure all railway activity was recorded for the duration of the study period. There were also video data collected from the installation of the camera on June 27, 2016 until the study period began, which was used for a pilot test to ensure the camera was operating properly.
The collected data was easily managed using the Axis Companion software that allowed the recordings for each day to be viewed individually. The software allowed for the user to pan through a timeline bar for each day, and since the camera only recorded video on motion, there were a series of red lines indicative of any movement captured. The size of the red line was also representative of the length of the recording, which made identifying several minute video segments of trains passing through clear to identify. A screenshot of the Axis Companion software interface can be found in Figure 8.

![Screenshot of the Axis Companion software interface](image)

**Figure 8 Screenshot of the Axis Companion software interface**

There were many instances where there were videos recorded that did not contain a train, but other activity triggered the recording, such as an animal passing through, people trespassing, or wind blowing tall vegetation. This took some time to sort through every
video recording, but once the videos containing trains were identified, they were saved to the computer as well as an external hard drive as a backup.

The video data was retrieved by direct download from the NAS drive using the Axis Companion software at the train station. This provided the quickest way to collect the data since the internet upload speed at the train station was limited, and did not allow for the large video files to be downloaded quickly over the internet. A test was performed to determine the time to download a video over the internet from the NAS drive, and it took approximately 4 hours to download a 3.5-minute video over the internet (approximately 400Mb) compared to 30 seconds to download at the train station. Therefore, several trips were to the train station, approximately one a month, to retrieve the video data to be transcribed.

3.5 Video data transcription

A pilot test for the transcription process was carried out after the camera began recording train activity when it was installed on June 27. The four days of data collected before the actual study period were used as a test-period, where the videos were transcribed to ensure the video quality was sufficient to view the text on the side of the rail cars. This test-period was also used to determine the types of attributes required to be recorded for the data collection period.

The transcription process began as soon as the first couple weeks of data were retrieved from the train station, and was completed for the first 3 months of video collected. The video files were individually reviewed and all the important attributes required for
analysis were transcribed to a spreadsheet. An example of the quality of video footage captured by the video monitoring station can be found in Figure 9 and 10. Evident from these figures, there is a great deal of information available just by reading the text on the side of tank cars. Since the primary focus of this project was to collect data on the movement of DG, the text on the tank cars provided the capacity, commodity type transported, and the tank car design type.

![Figure 9 Screenshot of camera video showing the container code and weight limits](image)

Figure 9 Screenshot of camera video showing the container code and weight limits
The breadth of information posted on the side of these rail cars allowed for the make-up of an entire train to be determined.

As the train videos were analyzed and transcribed, various important attributes were recorded in a spreadsheet, including train number, date, time, direction, car type, cargo, weight limits, placard number, plate code, and tank type. This process was completed for every instance of rail activity within the 3-month study period. An example of the spreadsheet used to transcribe the video data, as well as where information was obtained from each rail car, can be found in Figure 11.
Figure 11 Example of spreadsheet used to transcribe data with callouts from video

3.5.1 Rail car differentiation

The various types of rail cars that were transported through the observed section of rail line were differentiated through the use of several online sources. These sources, which included CN (CN, 2016) and Railroad Picture Archives (RR Pictures Archives, 2016), listed each type of rail car used to transport goods across North America. These sources depicted and described each type of rail car, which allowed the rail cars identified on the observed video to be easily differentiated and assigned the correct rail car type.

There were several instances when non-typical trains and maintenance vehicles travelled past the monitoring station. These non-typical trains included trains transporting unidentifiable rail cars, and trains transporting oversized tank cars. The maintenance
vehicles included passenger-trucks, trucks equipped with a crane, tractor-like vehicles, and other rail maintenance vehicles.

There was one instance later in the study period when it got dark earlier in the evening, which caused a reduction in the clarity of the video. The perimeter lighting in the area provided some light on the side of the rail cars, which allowed the container codes and placards to be transcribed. Although the weight limits and tank car type could not be distinguished at times, the container code was referenced through the previously transcribed data to find the missing data.

3.6 Assumptions

If a tank car had a placard posted on the side, it was assumed to be loaded with the commodity associated with the placard number. This was assumed for all tank cars carrying DG, as well as for those transporting molten sulphur (UN2448). These tank cars were not observed to have a placard posted on the tank car, however, the UN number was painted on the side of the car, adjacent to where the placard would have been. These tank cars carrying molten sulphur were still assumed to be loaded. Tank cars that did not have a placard posted were assumed to be empty.

Several assumptions were made for the determination of the Gross Ton Mile (GTM) and number of DG carloadings observed on the subdivision line. A GTM is the total weight of a train, including the weight of the locomotives, empty rail car weight, and the weight of cargo transported (Railway Association of Canada, 2016). Several of the rail cars observed during the study period were enclosed, which did not allow them to be
categorized as loaded or empty. The enclosed rail cars included box cars, cylindrical hopper, hopper, gondolas, and tank cars. Since their content was hidden from plain view, various load factors were applied to these rail cars to determine a lower and upper bound of the actual value. A separate assumption was made for tank carrying placards designated for petroleum crude oil and Liquefied Petroleum Gas (LPG). It was assumed that the petroleum crude tank cars were loaded if they were headed westbound towards the oil refinery and empty if they were travelling eastbound away from the refinery. This assumption was made since the raw crude oil would be transported to the refinery to be processed, as no raw crude would be expected to be transported away from the refinery. A similar assumption was made for the finished product, LPG, which would be coming out of the refinery. LPG tank cars were assumed to be loaded if they were travelling eastbound away from the refinery and empty if they were headed westbound towards the refinery.

3.7 Installation process and equipment issues

On June 27, the video camera was installed at the Sussex train station by two technicians from Chandler Sales. They were able to install the camera, run wires from the building’s modem to the 5-port POE switch, program the NAS drive, and partially configure the camera all in the first day. The next day on June 28, the camera was finished being configured by one technician, but an issue was encountered when the Axis Companion Software could not recognize the installed camera. The Companion Software was the software provided by Axis which would allow the user to search and sort through the video recordings saved on the NAS drive to distinguish between videos with trains and
other recordings. It was determined that the camera was defective since it could not connect with the provided software and a replacement was ordered, although it was still able to record video to the NAS drive until the replacement camera was installed. The replacement camera was installed and configured on July 5 by the technician. Fortunately, the camera was recognizable by the software, which allowed the remaining camera and software setup to be complete.

The video data recorded from June 28 until July 5 had to be extracted directly from the NAS drive, without the use of the companion software. This required every video file to be opened individually to determine if there was train activity, or if the recording was triggered by other activity.

Another notable occurrence was on August 9th when the camera came slightly out of focus. The camera was originally zoomed in to focus more closely on the rail cars as they passed through, and also to exclude private residents from the view of the camera’s frame. The issue was not noticed until August 30th when a trip was made to collect data, but Chandler Sales were notified immediately and they quickly resolved the issue within the next few days. Despite the camera coming out of focus and causing 23 days of video data to be slightly more difficult to interpret, the video data collected over this time period still allowed for sufficient quality to be transcribed.

3.8 Analysis

The data transcribed from the video data was analyzed using pivot tables in Microsoft Excel. As there were over 18,000 entries in the spreadsheet, the data were managed and
sorted to develop results using various sort functions. A series of analyses were conducted using the transcribed data, which were divided into four primary sections: effectiveness of method, descriptive statistics, comparison to existing data sources, and application to risk assessment.

3.7.1 Effectiveness of method, descriptive statistics, and comparison

The effectiveness of the method was initially analyzed to determine how accurate the method was in identifying and categorizing the information posted on the outside of the observed rail cars. In order to quickly sort the data into a pivot table to obtain the number of container codes and weight limits that were legible, the transcribed data required additional coding. Where the container code or weight limits were not identifiable, a “XX” was put in its place to allow the code to be searched to determine the number of instances where the weight limits were not legible. Other values, such as DG confirmed, and maintenance vehicles, were obtained directly from pivot tables created from the transcribed data that were already coded during the original transcription process.

The rail cars were further categorized to distinguish the rail cars arriving during day and night-time hours, therefore, average day and night-time hours were determined. The average sunset and sunrise times were obtained from the National Research Council Canada to provide the time range for day and night-time hours (National Research Council Canada, 2017). The data available for major cities east and west of Sussex, Moncton and Saint John, respectively, were averaged to determine the sunrise and sunset times since they were not available for the Sussex area.
Descriptive statistics, such as the proportion of rail car type, proportion of DG, train arrivals, train lengths, and directionality of trains, as well as representing DG carloading data at the monthly, weekly and daily level, were again developed using pivot tables. The necessary data were obtained to develop tables and graphs to represent the rail activity monitored over the study period.

The collected data were then compared to current data sources available on the transport of DG through PD36. Although the annual report could not be obtained for comparison, the online report representative of provincial DG movements was used in place.

### 3.7.2 Risk assessment

The two components involved in the determination of risk are the probability of an event occurring and the magnitude of the resulting consequence. The probability of an event can be determined by calculating the frequency of the event from historical data, whereas the consequence could be determined from the quantity of harmful substances involved in the event.

The probability of a train accident occurring was determined by analyzing various railway data sources, including data obtained from the Transportation Safety Board of Canada (TSB) and the Railway Association of Canada (RAC). Railway occurrence data, made available by the TSB, were manipulated using pivot tables for both the observed subdivision and national figures. The frequency of train accidents were determined for both, along with additional event frequencies such as main-track derailments, DG released, fire, and explosion (Transportation Safety Board of Canada, 2017).
Additionally, data provided by the RAC in their *Rail Trends 2015* report was used to obtain performance metrics, such as GTM travelled, number of accidents involving DG, as well as accidents rates per GTM travelled and per 1,000 DG carloads transported (Railway Association of Canada, 2016). These two data sources were used in combination, along with the observed data, to develop a coarse estimate of the probability of a railway-related accident occurring along the observed railway subdivision.

The consequence of a train accident would be primarily a function of the number of DG carloadings involved in the accident for the purpose of this research. The number of DG carloadings could be determined from the summation of the DG carloadings observed over the study period.
4.0 Analysis and Results

The key findings and results obtained through the analysis of the collected data are described in the following chapter. Descriptive statistics were developed to represent the movement of cargo along the observed rail subdivision line. The collected data were then compared to existing data sources to validate its accuracy. Historic rail data sources were then analyzed to determine the probability component of rail risk in Canada, which were then translated to estimate the rail accident rate from the transcribed data.

4.1 Effectiveness of the method

The use of video monitoring equipment provided an innovative method of collecting data on the movement of cargo by rail. The video camera selected was effective for the required task, and was able to collect video of the trains at a sufficient quality to allow the various cargo data to be transcribed.

A total of 17,864 rail cars were observed over the study period. They were classified according to the procedure outlined in the methodology section, with the researcher using technical judgment to classify the various types of rail cars. The video camera was able to collect video of trains at a more than sufficient quality to transcribe the vast majority of the information posted on the side of the observed rail cars. However, there were instances when the container code, weight limits, or placard were not legible from the video. A summary of the effectiveness of the video camera can be found in Table 10.
Table 10 Effectiveness of the video camera

<table>
<thead>
<tr>
<th></th>
<th>Count</th>
<th>Dangerous good</th>
<th></th>
<th>Non-dangerous good</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Day</td>
<td>Night</td>
<td>Day</td>
<td>Night</td>
</tr>
<tr>
<td>Total railcars observed</td>
<td>17,864</td>
<td>10,274</td>
<td>62</td>
<td>6,432</td>
<td>1,096</td>
</tr>
<tr>
<td>Container code legible</td>
<td>16,832</td>
<td>10,273</td>
<td>62</td>
<td>6,254</td>
<td>243</td>
</tr>
<tr>
<td>Weight limits legible</td>
<td>15,845</td>
<td>10,236</td>
<td>62</td>
<td>5,531</td>
<td>16</td>
</tr>
<tr>
<td>DG confirmed by placard</td>
<td>10,313</td>
<td>10,251</td>
<td>62</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>DG confirmed by secondary source</td>
<td>23</td>
<td>23</td>
<td>0</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>DG unconfirmed</td>
<td>3</td>
<td>3</td>
<td>0</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Maintenance Vehicles</td>
<td>62</td>
<td>-</td>
<td>-</td>
<td>48</td>
<td>14</td>
</tr>
</tbody>
</table>

Table 10 was divided into DG and non-DG observed during both the day and night to distinguish the effectiveness of the camera during both times of day. Day-time was defined as the time between the average sunrise and sunset times during the study period, which was found to be from 6:00AM and 9:00PM (National Research Council Canada, 2017). Night-time was then defined as the opposite, which was from 9:00PM until 6:00AM.

The container code was legible from the video data 94% of the time. There were two specific types of rail cars that made transcribing the container code difficult: hoppers and intermodal flatbed cars. Unit trains composed of hoppers travelling during the middle of the night accounted for 853 of these instances, and 133 were flatbed intermodal rail cars. The intermodal rail cars were the most difficult type of rail car to collect information from since the container code and weight limits were approximately 1 metre off the ground. The video camera being mounted on the eave of the building at approximately 3.3 metres off the ground made it difficult to clearly capture the information on the side of the flatbed intermodal cars.
The weight limits were legible from the video data 87% of the time. Hoppers and intermodal flatbed cars again accounted for the largest proportion of unread weight limits, with 1,029 and 565 instances, respectively.

There were a few instances when there was inadequate lighting in the video data to transcribe the weight limits on the cars during the night time, although the container code on these cars were legible. In these cases, the container code was referenced through the spreadsheet to obtain the weight limits from the same rail car previously transcribed. If the rail car had not been transcribed previously, then the average weight for that type of rail was used in its place. Fortunately, the majority of rail cars travelled past the monitoring station at least once, which allowed the weight limits to be referenced and transcribed.

There were several instances when the container code or weight limits were unidentifiable due to a factor not attributable to the video camera. There were several instances when the container code and weight limits had been partially or fully covered by graffiti or rust.

Of the 10,366 carloadings identified as DG, there were 23 instances when there was some uncertainty involved with identifying a placard on the side of a tank car, but there was strong evidence provided to identify the placard. During some of these instances there was a partial read on the placard, and by referencing the container code, the placard previously posted on the same tank car matched with the partial read on the questionable placard. The other instances were placards that were marked with “1075”, or LPG. While
there was also a partial read on these placards posted with “1075”, tank cars carrying LPG had “Liquefied Petroleum Gas Non-odorized” posted on the side in white letters. Since these letters were identified, along with the partial read on the placard, it was assumed that the tank car was identified as transporting LPG.

Unfortunately, there were 3 instances when a tank car’s placard was entirely unidentifiable. This included one placard that was folded over, blocking the placard number, and two that were unidentifiable due to low light during the night. There were also two occasions when an irregular train had travelled through, each time carrying three over-sized tank cars with no observable placard posted. The first instance occurred at 5:21AM and the train was travelling westbound, followed by the second instance a day later occurring at 3:59AM with the train travelling eastbound. Since there was a single trip in each direction, it was assumed that the same train was observed both times.

There was a great level of effort required to transcribe all the video data that was captured during the 3-month study period. A summary of the video data and the time required to transcribe the data can be found in Table 11.

<table>
<thead>
<tr>
<th>Table 11 Level of effort required for video transcription process</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Value</strong></td>
</tr>
<tr>
<td>Total files</td>
</tr>
<tr>
<td>Total hours of video</td>
</tr>
<tr>
<td>Video transcription rate</td>
</tr>
<tr>
<td>Estimated person-hours</td>
</tr>
</tbody>
</table>
Although this method of data collection required considerable time to transcribe the video data, it could be simplified through the use of computer software that could automatically transcribe the video data, potentially making the analysis in real-time.

4.2 **Descriptive statistics**

The data collected from the 3-month study period were transcribed to obtain descriptive statistics with regard to the movement of goods along the observed rail line. The collected data could be represented by a number of aggregation levels, ranging from a per train or daily basis to a quarterly basis, which is what emergency officials currently receive.

4.2.1 **Overview**

Over the study period, there were 199 regular trains transporting nearly 18,000 different rail cars through the rail line. A summary of the number of rail cars observed throughout the study period, separated by Eastbound (EB) and Westbound (WB), can be found in Table 12.
Table 12 Total of rail cars observed during study period with direction

<table>
<thead>
<tr>
<th>Car Type</th>
<th>EB</th>
<th>WB</th>
<th>Grand Total</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Jul</td>
<td>Aug</td>
<td>Sep</td>
</tr>
<tr>
<td>Box car</td>
<td>221</td>
<td>263</td>
<td>214</td>
</tr>
<tr>
<td>Bulkhead</td>
<td>1</td>
<td>4</td>
<td>4</td>
</tr>
<tr>
<td>Center beam car</td>
<td>25</td>
<td>33</td>
<td>7</td>
</tr>
<tr>
<td>Cylindrical hopper</td>
<td>11</td>
<td>14</td>
<td>28</td>
</tr>
<tr>
<td>Flatbed</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Flatbed intermodal</td>
<td>154</td>
<td>161</td>
<td>181</td>
</tr>
<tr>
<td>Gondola</td>
<td>313</td>
<td>271</td>
<td>264</td>
</tr>
<tr>
<td>Hopper</td>
<td>508</td>
<td>55</td>
<td>305</td>
</tr>
<tr>
<td>Locomotive</td>
<td>91</td>
<td>82</td>
<td>93</td>
</tr>
<tr>
<td>Log car</td>
<td>3</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Tanker</td>
<td>1,843</td>
<td>1,760</td>
<td>1,930</td>
</tr>
</tbody>
</table>

The EB and WB traffic were generally well balanced, aside from the flatbeds, center beam cars, and hoppers. There were a greater number of center beam cars travelling westbound, that would be in the direction of a wood and lumber manufacturing plant. Since this type of rail car typically carries wood or lumber products, the cars could have been returning to the plant to be processed or loaded with product.

There were two occurrences when a train composed solely of flatbeds loaded with steel beams was being transported in a westbound direction. This direction would also be the location of a steel manufacturing plant where the flatbeds could be destined to deliver product. Lastly, the monthly volumes for the hopper cars were quite consistent over the study period, with the exception of the final observed month in September. The 79-car discrepancy could be explained by the limitations of the study period. It would be reasonable to assume that the next shipment of hoppers travelling eastbound would have
been after the study period concluded in October. Another possible reason for the
difference, as well as the decline in the number of hoppers transported, would be due to
the closure of the nearby potash mine. This closure would have substantially reduced the
volume of potash and other mined materials being shipped, since the mining operations
had ceased at the facility.

The proportion of tank cars transported is nearly two-thirds of all rail traffic observed,
though not all tank cars were marked as transporting DG. There were a number of tank
cars that were not loaded with DG, which were either marked with “calcium carbonate or
clay slurry only” or others that did not have a placard posted. These non-DG loadings
accounted for 7.7% of the total number of tank cars transported. A breakdown of the tank
cars carrying DG versus non-DG can be found in Table 13.

<table>
<thead>
<tr>
<th>Count</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Total Tank cars</td>
<td>11,093</td>
</tr>
<tr>
<td>Identified as DG</td>
<td>10,233</td>
</tr>
<tr>
<td>Non-DG</td>
<td>851</td>
</tr>
<tr>
<td>Unknown</td>
<td>3</td>
</tr>
<tr>
<td>Special</td>
<td>6</td>
</tr>
</tbody>
</table>

4.2.2 Train length and arrivals

The arrival times of the trains were consistent over the study period. On a typical day
during the observation period, there would be at least two trains: one during the
afternoon, and one during the evening. Very few days were observed to have three or
four trains travelling through. The frequency of the number of trains arriving each day
can be found in Figure 12.
A graphical representation of all train arrival times can be found in Figure 13. As the figure would suggest, the afternoon train would typically arrive between 2:00PM and 3:00PM, while the evening train would arrive between 6:30PM and 7:30PM. There were several instances when trains would arrive outside the typical arrival time. Unit trains, loaded with hopper cars, were observed to travel through in the early morning, between the times of 12:00AM and 7:00AM. DG were typically observed to travel on the trains passing through either during the afternoon or evening.
Train lengths varied over the duration of the study period. The train lengths were measured by the total number of locomotives and rail cars comprising a single train. The lengths varied from a train composed of 25 units to one composed of 160. The average train length was determined to be 90 units, while the median was 88 units. The various train length statistics for each month of the study period can be found in Table 14.

Table 14 Summary statistics on the observed train lengths

<table>
<thead>
<tr>
<th></th>
<th>July</th>
<th>August</th>
<th>September</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>Average</td>
<td>88</td>
<td>87</td>
<td>94</td>
<td>90</td>
</tr>
<tr>
<td>Minimum</td>
<td>25</td>
<td>30</td>
<td>36</td>
<td>25</td>
</tr>
<tr>
<td>Maximum</td>
<td>157</td>
<td>143</td>
<td>160</td>
<td>160</td>
</tr>
<tr>
<td>Median</td>
<td>84</td>
<td>86</td>
<td>100</td>
<td>88</td>
</tr>
</tbody>
</table>
The frequencies of the observed train lengths were examined, and plotted in a histogram as seen in Figure 14. The figure resembles a bimodal distribution, as it is evident there are two distinct peaks in the train lengths. The two train length bins with the most frequent number of trains are between [70,75] and [105,110].

![Figure 14 Histogram of the frequency of train lengths observed](image)
The direction of carloadings identified as DG transported throughout the day were also examined, as seen in Figure 15. The DG transported westbound (WB) were observed entirely during the afternoon, whereas the DG transported eastbound (EB) were observed almost entirely in the evening, with only a few carloadings transported in the afternoon.

**Figure 15 Direction of DG carloadings by time of day**

### 4.2.3 Carloadings of DG transported

The observed rail line experienced a large proportion of DG carloadings compared to the total number of carloadings transported through the line. Carloadings identified as DG accounted for 57.8% of all rail shipments during the study period, which is much greater than the national proportion of DG transported, 10.2%, in 2015 (Railway Association of Canada, 2016). The proportion of each type of DG compared to the total DG transported during the study period can be found in Figure 16.
Carloadings identified as transporting petroleum crude oil (crude oil) and Liquefied Petroleum Gas (LPG) accounted for nearly 80% of the total DG shipped, with crude oil accounting for nearly half (47.6%) and LPG accounting for 30.0%.

More than half (58.6%) of the observed carloadings on an average train were identified as transporting DG. There were many trains observed that were comprised of primarily carloadings identified as transporting DG, which for some trains would account for 93% of the total number of carloadings. There were also several trains that were not identified to be transporting any DG. The various statistics on the proportion of DG transported on a per train basis can be found in Table 15.
### Table 15 Proportion of DG transported on an average train

<table>
<thead>
<tr>
<th></th>
<th>July</th>
<th>August</th>
<th>September</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Carloads per train</td>
<td>Percent of train length</td>
<td>Carloads per train</td>
</tr>
<tr>
<td>Average</td>
<td>47</td>
<td>54.2%</td>
<td>54</td>
</tr>
<tr>
<td>Max</td>
<td>108</td>
<td>93.0%</td>
<td>114</td>
</tr>
<tr>
<td>Min</td>
<td>0</td>
<td>0.0%</td>
<td>0</td>
</tr>
<tr>
<td>Median</td>
<td>48.5</td>
<td></td>
<td>57</td>
</tr>
</tbody>
</table>

Emergency officials currently receive quarterly carloading totals from Class 1 railway companies, whereas Class 3 railways provide annual carloading totals. Since the data collected allowed for a range of aggregation levels, the data were represented at monthly, weekly, and daily levels to explicitly show the difference between the varying resolutions of data.

#### 4.2.3.1 Aggregation level: Monthly

Examining the transcribed data at a monthly level of aggregation can provide an overall indication of the total number of carloadings marked as transporting DG each month, as well as the variability between month-to-month carloadings. Table 16 summarizes the identified DG types and their carloadings for each month in descending order, along with the monthly average each type of DG transported over the three-month period.
Table 16 Summary of DG placards identified over three months

<table>
<thead>
<tr>
<th>DG type identified</th>
<th>July</th>
<th>August</th>
<th>September</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>Petroleum Crude Oil</td>
<td>1,601</td>
<td>1,666</td>
<td>1,650</td>
<td>4,917</td>
</tr>
<tr>
<td>LPG</td>
<td>992</td>
<td>895</td>
<td>1,209</td>
<td>3,096</td>
</tr>
<tr>
<td>Sulphuric acid</td>
<td>91</td>
<td>218</td>
<td>167</td>
<td>476</td>
</tr>
<tr>
<td>Elevated temperature liquid</td>
<td>194</td>
<td>112</td>
<td>136</td>
<td>442</td>
</tr>
<tr>
<td>Molten Sulphur</td>
<td>132</td>
<td>164</td>
<td>126</td>
<td>422</td>
</tr>
<tr>
<td>Sulphuric acid, spent</td>
<td>112</td>
<td>164</td>
<td>116</td>
<td>392</td>
</tr>
<tr>
<td>Others</td>
<td>169</td>
<td>199</td>
<td>223</td>
<td>591</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>3,291</strong></td>
<td><strong>3,418</strong></td>
<td><strong>3,627</strong></td>
<td><strong>10,336</strong></td>
</tr>
</tbody>
</table>

The monthly carloadings totals identified as transporting DG were consistent over the study period. Several types of DG carloadings, such as LPG and the DGs with a lower number of carloadings transported, had greater variability. The percent difference in DG carloadings between each consecutive month can be found in Table 17.

Table 17 Percent difference between months of DG carloadings

<table>
<thead>
<tr>
<th>DG Type</th>
<th>July/August</th>
<th>August/September</th>
</tr>
</thead>
<tbody>
<tr>
<td>Petroleum Crude Oil</td>
<td>4%</td>
<td>-1%</td>
</tr>
<tr>
<td>LPG</td>
<td>-10%</td>
<td>35%</td>
</tr>
<tr>
<td>Sulphuric acid</td>
<td>140%</td>
<td>-23%</td>
</tr>
<tr>
<td>Elevated temperature liquid</td>
<td>-42%</td>
<td>21%</td>
</tr>
<tr>
<td>Molten Sulphur</td>
<td>24%</td>
<td>-23%</td>
</tr>
<tr>
<td>Sulphuric acid, spent</td>
<td>46%</td>
<td>-29%</td>
</tr>
<tr>
<td>Others</td>
<td>18%</td>
<td>12%</td>
</tr>
</tbody>
</table>

Monthly carloading totals were consistent between months, although at this level of aggregation it is unclear whether there is variability within weekly or daily DG carloading totals.
4.2.3.2 Aggregation level: Weekly

The data aggregated by week were sectioned as beginning on the first day of data collection, which was July 1 (Friday), and ending on the seventh day of data collection, which was July 7th (Thursday). This grouping of weeks was done for the entire study period, excluding the final week, which only included one day (Friday, September 30th). The weekly carloadings totals of the identified DG transported are depicted in Figure 17.

![Figure 17 Weekly carloadings of DG](image)

**Figure 17 Weekly carloadings of DG**

The weekly identified DG carloading totals appear to have greater variability than compared to the monthly totals, especially for crude oil and LPG carloadings. There are several weeks when there are distinct increases in the carloadings for both DGs. The increase in carloadings for crude oil can be found between week 4-5, 8-9, and 11-12, and between 2-3, and 10-11 for LPG. These large increases in the number of carloadings
between weeks would be worth identifying since they can be an increase of 100+ carloadings.

All the other identified DG carloadings appear to be consistent between weeks, although variability does exist between several DG. The full weekly identified DG carloading totals can be found in Appendix A.

The largest positive and negative changes between successive weeks, as well as the maximum and minimum weekly carloading totals can be found in Table 18. Due to the partial week of data during the final week being representative only one day, the final week of data are excluded from the percent difference calculation to avoid skewing the results.

**Table 18 Variability in weekly identified DG carloadings**

<table>
<thead>
<tr>
<th></th>
<th>Largest change from previous week</th>
<th>Carloadings during week</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Positive</td>
<td>Negative</td>
</tr>
<tr>
<td>Petroleum crude oil</td>
<td>25%</td>
<td>-20%</td>
</tr>
<tr>
<td>LPG</td>
<td>46%</td>
<td>-22%</td>
</tr>
<tr>
<td>Sulphuric acid</td>
<td>130%</td>
<td>-78%</td>
</tr>
<tr>
<td>Elevated temperature liquid</td>
<td>38%</td>
<td>-36%</td>
</tr>
<tr>
<td>Molten sulphur</td>
<td>156%</td>
<td>-40%</td>
</tr>
<tr>
<td>Sulphuric acid, spent</td>
<td>55%</td>
<td>-34%</td>
</tr>
<tr>
<td>Others</td>
<td>74%</td>
<td>-39%</td>
</tr>
</tbody>
</table>

More variability exists between the weekly percent differences for each DG than compared to the monthly percent difference. This is evident when comparing the weekly
percent difference for crude oil ranging from -20% to 25%, while at a monthly level of aggregation ranges between -1% and 4%.

4.2.3.3 Aggregation level: Daily

Examining the data at a daily level of aggregation can reveal any noticeable trends in the transport of DG at an even greater data resolution. The daily carloadings of each type of identified DG are separated by month, depicted in Figures 18, 19, and 20.

Figure 18 DG carloadings transported in July
Figure 19 DG carloadings transported in August

Figure 20 DG carloadings transported in September
An even greater degree of variability is noticeable at the daily level of identified DG carloadings compared to both the weekly and monthly levels of aggregation. Examining carloadings of crude oil specifically, there were several days that experienced large fluctuations in the number of carloadings between two days, with increases and decreases as large as 78 and 67, respectively. It is worth noting there were five days where several other types of identified DG surpassed or were equal to the number of carloadings of LPG: elevated temperature liquid (1 day), molten sulphur (1 day), and sulphuric acid (3 days). There were also several days where the carloadings of sulphuric acid had noticeable spikes in the number of their carloadings.

A summary of the percent change between successive weeks and the minimum and maximum carloadings in a single day can be found in Table 19.

**Table 19 Variability in daily DG carloadings**

<table>
<thead>
<tr>
<th></th>
<th>Largest change from previous day</th>
<th>Carloadings during day</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Positive</td>
<td>Negative</td>
</tr>
<tr>
<td>Petroleum crude oil</td>
<td>1,560%</td>
<td>-95%</td>
</tr>
<tr>
<td>LPG</td>
<td>360%</td>
<td>-82%</td>
</tr>
<tr>
<td>Sulphuric acid</td>
<td>1,200%</td>
<td>N/A</td>
</tr>
<tr>
<td>Elevated temperature liquid</td>
<td>500%</td>
<td>N/A</td>
</tr>
<tr>
<td>Molten sulphur</td>
<td>900%</td>
<td>N/A</td>
</tr>
<tr>
<td>Sulphuric acid, spent</td>
<td>1,400%</td>
<td>N/A</td>
</tr>
<tr>
<td>Others</td>
<td>550%</td>
<td>N/A</td>
</tr>
</tbody>
</table>

It is apparent that the greatest variability with the identified DG carloadings can be seen at the daily level of aggregation. Again, examining crude oil more closely, there are major fluctuations in the number of carloadings ranging from an increase of 1,560% to a
decrease of -95% between two days. The percent difference for several of the DG transported could not be determined since there were days when 0 carloadings were observed.

4.3 Comparison to existing data

Existing sources of data that are available to emergency organizations include an annual summary report and an online report from railway carriers, both required through Protective Direction 36 (PD36). The summary report was not available for comparison, although the online report was obtained and used in a coarse comparison.

4.3.1 Protective Direction 36

Since the implementation of PD 36 in April 2016, Class 1 railways have been required to provide additional data on the movement of DG in addition to the summary reports communities have been receiving since PD 32 was implemented. Railways are now required to provide online reports that contain: the proportion of DG shipments in Canada, the proportion of each type of DG, and the top ten DG shipments through each province in which they operate.

4.3.1.1 Annual summary report

The annual summary report of DG carloadings given to the community officials was not available at the time of completing this thesis (February 2017), though it is hoped that the report, when available to emergency organizations, can be shared to finalize validation.
4.3.1.2 Online railway reports

The only Class 1 railway that transports freight in New Brunswick is Canadian National Railway (CN). Since they are required to adhere to PD 36, access to their online report was obtained by visiting their website (CN, 2016).

Although the data is representative of 2015 railway data, the proportions of DG shipped in New Brunswick were assumed to be approximately similar to the proportion of DG shipped in 2016 for the sake of a coarse comparison. The section of CN’s online report pertinent to the comparison can be found in Figure 21.

![Figure 21 Top ten DG transported in New Brunswick by CN in 2015](image)

The total proportion of DG carloadings to the total number of carloadings was 11% for CN in 2015, while the proportion of identified DG carloadings determined from the video data were found to be 57.8%. When DG are transported, the percentage breakdown when compared to the observed video data can be found in Table 20.
Table 20 Comparison between collected data and online report

<table>
<thead>
<tr>
<th>DG Type</th>
<th>Video data</th>
<th>CN</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Carloads (3 months)</td>
<td>%</td>
<td>%</td>
</tr>
<tr>
<td>Petroleum crude oil</td>
<td>4,917</td>
<td>48</td>
<td>52</td>
</tr>
<tr>
<td>LPG</td>
<td>3,096</td>
<td>30</td>
<td>23</td>
</tr>
<tr>
<td>Gasoline</td>
<td>1</td>
<td>0</td>
<td>4</td>
</tr>
<tr>
<td>Diesel fuel</td>
<td>0</td>
<td>0</td>
<td>4</td>
</tr>
<tr>
<td>Sulphuric acid</td>
<td>476</td>
<td>4.6</td>
<td>3</td>
</tr>
<tr>
<td>Environmentally hazardous substances, solid, n.o.s.</td>
<td>0</td>
<td>0</td>
<td>2</td>
</tr>
<tr>
<td>Sodium hydroxide solution</td>
<td>0</td>
<td>0</td>
<td>2</td>
</tr>
<tr>
<td>Molten sulphur</td>
<td>422</td>
<td>4.1</td>
<td>1</td>
</tr>
<tr>
<td>Sulphuric acid, spent</td>
<td>392</td>
<td>3.8</td>
<td>1</td>
</tr>
<tr>
<td>Ethanol and gasoline mixture</td>
<td>134</td>
<td>1.3</td>
<td>1</td>
</tr>
<tr>
<td>Others</td>
<td>897</td>
<td>8.7</td>
<td>6</td>
</tr>
</tbody>
</table>

While the data are similar in some respects, several comparisons can be made between the two data sets. The most notable difference would be that several DG were not observed being transported that were reported by CN in 2015, which included DG such as diesel fuel, environmentally hazardous substances, solid, n.o.s, and sodium hydroxide solution.

The proportions of DG that were both observed during the study and reported by CN generally fell within the same order of magnitude, although some carloadings identified as transporting DG were observed at a proportion greater than what was reported by CN, and vice versa.
The difference in the proportions of DG between the collected data and CN’s report could be attributed to several aspects. The collected data is only representative of 3 months, and not the entire year like CN’s report. A portion of the DG reported may only be required at times of the year that were not captured within the study period. Another cause for the discrepancies could also be attributed to CN’s report lagging by a full year. Although it is possible for shipments to alter drastically within a year, it is reasonable to assume the carloadings would be within similar magnitudes. Lastly, only one route was observed throughout the duration of the project, where CN has multiple rail lines in New Brunswick. It is possible that the DG not observed during the study period were transported on another route in the province, which could account for the difference in the proportion of DG transported.

4.4 Applicability to risk assessment

The assessment of risk requires the determination of two parameters: the probability and consequence of an event. The data collected was used primarily in determining the probability of an event, more specifically the probability of a train-related occurrence. A railway occurrence is reported if either a railway related accident or incident occurs, which are both summarized in Table 21.
Table 21 Distinction between railway related accidents and incidents

(Transportation Safety Board of Canada, 2017)

<table>
<thead>
<tr>
<th>Accident</th>
<th>Incident</th>
</tr>
</thead>
<tbody>
<tr>
<td>• A person is killed or injured as a result of contact with rolling stock</td>
<td>• Rolling stock is involved in minor collision or derailment</td>
</tr>
<tr>
<td>• The rolling stock is involved in a collision or derailment, sustains</td>
<td>• Track switch left in abnormal position, or unplanned movement of rolling stock</td>
</tr>
<tr>
<td>damage that affects safe operation</td>
<td>• Railway signal display is less restrictive than required, or stop signal is not followed</td>
</tr>
<tr>
<td>• Accidental release of DG or emission of radiation</td>
<td>• Crew member is incapacitated and cannot ensure safe operation of train</td>
</tr>
</tbody>
</table>

Due to the lack of local subdivision data, national rail occurrence data were obtained from the TSB’s railway occurrence data, as well as the RAC’s Rail Trends 2016 report. These sources of data were used in combination to determine the number of accidents estimated to occur on the observed rail subdivision line, as well as the probability of an explosion. Railway occurrences are hereon referred to as railway accidents, to ensure similar terminology is used between the TSB and the RAC data.

4.4.1 Observed rail subdivision

In order to determine the risk associated with transporting DG on the observed Sussex subdivision line, each of the two parameters of risk assessment would be required. To estimate the probability of an accident or incident occurring along the observed rail line, the TSB railway occurrence data was used to determine the historical number of accidents that have occurred on the observed rail line. A summary of the railway accidents on the Sussex subdivision rail line can be found in Table 22.
Table 22 Summary of railway accident data on observed rail line (Transportation Safety Board of Canada, 2017)

<table>
<thead>
<tr>
<th>Year</th>
<th>All Reportable Accidents</th>
<th>Main-track Derailment</th>
<th>DG involved</th>
<th>DG Released</th>
<th>Fire</th>
<th>Explosion</th>
</tr>
</thead>
<tbody>
<tr>
<td>2005</td>
<td>6</td>
<td>1</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>2006</td>
<td>6</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>2007</td>
<td>5</td>
<td>1</td>
<td>1</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>2008</td>
<td>10</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>2009</td>
<td>3</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>2010</td>
<td>6</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>2011</td>
<td>3</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>2012</td>
<td>4</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>2013</td>
<td>4</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>2014</td>
<td>5</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>2015</td>
<td>7</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>2016</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Total</td>
<td>59</td>
<td>2</td>
<td>1</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
</tbody>
</table>

There were low frequencies for all reportable accidents, especially for main-track derailments and other resulting events. The most frequent accidents occurring on the observed rail line were non-main-track derailments (56%) and crossing accidents (14%). Non-main-track derailments typically occur during switching maneuvers within a sorting yard at low speeds, whereas crossing accidents typically include a vehicle or passenger being struck by a train at a grade crossing.

While these data are representative of the accidents that have occurred along the observed line, it does not provide a complete measure of the probability of each individual event occurring. Although there have been zero accidents involving DG being released, fire, or an explosion, the probability of each of these events occurring may not be equal zero.
Since these events are rarely observed, to obtain estimates for the frequency of these events, historic rail accident data were examined at the national level.

4.4.2 National railway accident data

The frequencies of various historic railway accidents that had occurred in Canada were determined after analyzing the historical rail data retrieved from both the TSB and the RAC. Since there is a single Class 1 freight railway company that operates on the observed rail line, the accident data from the TSB was sorted to include only the number of accidents that involved Class 1 freight railways, including CN and CP, as well as BNSF and CSX. The railway accident data were obtained from the TSB, which contained historical frequencies of various rail-related events, as seen in Table 23.

Table 23 Summary of Class 1 freight railway accident data in Canada

(Transportation Safety Board of Canada, 2017)

<table>
<thead>
<tr>
<th>Year</th>
<th>Reportable Accidents</th>
<th>Main-track derailment</th>
<th>DG involved</th>
<th>DG released</th>
<th>Fire</th>
<th>Explosion</th>
</tr>
</thead>
<tbody>
<tr>
<td>2005</td>
<td>1,586</td>
<td>173</td>
<td>30</td>
<td>3</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>2006</td>
<td>1,459</td>
<td>128</td>
<td>17</td>
<td>2</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>2007</td>
<td>1,427</td>
<td>148</td>
<td>35</td>
<td>1</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>2008</td>
<td>1,285</td>
<td>112</td>
<td>22</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>2009</td>
<td>1,173</td>
<td>59</td>
<td>9</td>
<td>1</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>2010</td>
<td>1,200</td>
<td>71</td>
<td>13</td>
<td>1</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>2011</td>
<td>1,191</td>
<td>88</td>
<td>20</td>
<td>1</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>2012</td>
<td>1,188</td>
<td>58</td>
<td>5</td>
<td>1</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>2013</td>
<td>1,221</td>
<td>77</td>
<td>9</td>
<td>2</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>2014</td>
<td>1,338</td>
<td>91</td>
<td>23</td>
<td>3</td>
<td>2</td>
<td>1</td>
</tr>
<tr>
<td>2015</td>
<td>1,269</td>
<td>73</td>
<td>12</td>
<td>3</td>
<td>2</td>
<td>0</td>
</tr>
<tr>
<td>2016</td>
<td>978</td>
<td>50</td>
<td>8</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Total</td>
<td>15,315</td>
<td>1,128</td>
<td>203</td>
<td>18</td>
<td>5</td>
<td>2</td>
</tr>
</tbody>
</table>
The total of these data over the twelve-year period were used to develop approximate values for the probability of each type of occurrence, based on their historic frequency. The approximate probability of each event occurring, as well as the compounded probability of each event occurring in succession, can be found in Table 24.

**Table 24 Probability of Class 1 freight railway related accidents occurring**

<table>
<thead>
<tr>
<th>Year</th>
<th>Reportable Accidents</th>
<th>Main-track derailment</th>
<th>DG involved</th>
<th>DG released</th>
<th>Fire</th>
<th>Explosion</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total</td>
<td>15,315</td>
<td>1,128</td>
<td>203</td>
<td>18</td>
<td>5</td>
<td>2</td>
</tr>
<tr>
<td>Probability of reportable accident being of type</td>
<td>-</td>
<td>7.4%</td>
<td>18%</td>
<td>8.9%</td>
<td>28%</td>
<td>40%</td>
</tr>
<tr>
<td>Compounded probability of reportable accident being of type</td>
<td>-</td>
<td>7.4%</td>
<td>1.3%</td>
<td>0.12%</td>
<td>0.033%</td>
<td>0.013%</td>
</tr>
</tbody>
</table>

The probabilities of a main-track derailment, as well as each successive consequence, are quite low compared to the total number of reportable accidents. The TSB accident data does not have exposure metrics, such as number of DG carloadings or GTM travelled; therefore, external estimates of these were sourced from the RAC’s *Rail Trends 2016*.

The RAC report contains various metrics on freight rail data for both Class 1 and 3 railways, such as the GTM travelled, number of total carloadings originated, number of DG carloadings, as well as accident rates, such as the number of accidents per billion
GTM and per 1,000 DG carloadings. A summary of the metrics available from the RAC can be found in Table 25.

Table 25 Summary of national rail accident data (Railway Association of Canada, 2016)

<table>
<thead>
<tr>
<th>Year</th>
<th>Gross Ton-Miles (billion)</th>
<th>DG carloads</th>
<th>Accident rate per billion GTM</th>
<th>Accident rate (per 1000 DG carloads)</th>
</tr>
</thead>
<tbody>
<tr>
<td>2005</td>
<td>457.95</td>
<td>414,752</td>
<td>3.60</td>
<td>0.55</td>
</tr>
<tr>
<td>2006</td>
<td>459.63</td>
<td>406,425</td>
<td>3.43</td>
<td>0.48</td>
</tr>
<tr>
<td>2007</td>
<td>463.36</td>
<td>426,789</td>
<td>3.23</td>
<td>0.48</td>
</tr>
<tr>
<td>2008</td>
<td>449.92</td>
<td>422,764</td>
<td>2.90</td>
<td>0.40</td>
</tr>
<tr>
<td>2009</td>
<td>397.29</td>
<td>379,650</td>
<td>2.78</td>
<td>0.38</td>
</tr>
<tr>
<td>2010</td>
<td>455.05</td>
<td>400,318</td>
<td>2.58</td>
<td>0.37</td>
</tr>
<tr>
<td>2011</td>
<td>473.31</td>
<td>425,124</td>
<td>2.23</td>
<td>0.30</td>
</tr>
<tr>
<td>2012</td>
<td>503.88</td>
<td>428,660</td>
<td>2.10</td>
<td>0.29</td>
</tr>
<tr>
<td>2013</td>
<td>529.38</td>
<td>493,360</td>
<td>2.17</td>
<td>0.32</td>
</tr>
<tr>
<td>2014</td>
<td>564.31</td>
<td>576,226</td>
<td>2.11</td>
<td>0.31</td>
</tr>
<tr>
<td>2015</td>
<td>544.79</td>
<td>491,802</td>
<td>2.18</td>
<td>0.30</td>
</tr>
</tbody>
</table>

Despite an increase in both the total GTM and DG carloadings over the past ten years, the accident rate per billion GTM and the accident rate per 1,000 DG carloads have been on a general decline, with a slight increase in 2013 and 2015.

While the RAC data provides valuable information on railways at the national level, it does not provide any local data on railway subdivision lines. The data collected for this thesis would allow for the determination of total DG carloadings transported, as well as estimates for the total GTM travelled along the observed subdivision line.
4.4.3 Estimating rail line accident rate from transcribed data

The national data obtained through the RAC and TSB were applied to the data collected from the observed rail line to estimate the probability of a rail-related accident somewhere along the observed line, and not at a single point along the line, such as a population centre. These rail accident estimates were then used in combination with the accident frequency data obtained from the TSB to determine the probability of an explosion occurring on the observed subdivision.

4.4.3.1 Exposure based accident rate estimates

To determine the probability of an accident occurring using the national exposure-based accident rate per billion GTM travelled, the estimated GTM observed on the rail line would be required. The observed GTM was determined by summing the total weight of all locomotives, empty rail cars, and cargoes transported during the study period. To account for an entire year of GTM travelled, the estimated GTM was then multiplied by a factor of four. Since the rail accident rate for 2016 was not available at the time, the 2015 accident rate of 2.18 accidents per billion GTM was used in place to serve as an exposure metric.

Due to the uncertainty surrounding the capacity of the enclosed rail cars, including both DG and non-DG rail cars, a sensitivity analysis of varying loading estimates were used to determine the lower, middle, and upper bounds of the GTM travelled. The DG and non-DG carloadings were subjected to three different load cases to determine the magnitude of effect on the GTM travelled, with the exception of crude oil and LPG being 100% loaded if travelling westbound and eastbound, respectively.
The first load case was used to determine the lower bound of GTM travelled over the observed subdivision, assigning a load factor of 0% to all unknown DG and non-DG rail cars. Although, this lower bound would be an extreme load casing, it would provide the minimum GTM travelled on the observed rail line. The second load case was used to determine a middle bound of the GTM travelled, assigning a load factor of 50% to all unknown DG and non-DG rail cars. The third load case was used to determine an upper bound of the GTM travelled, assigning a load factor of 100% to all unknown DG and non-DG rail cars. Although, this upper bound would also be an extreme load casing, it would provide the maximum GTM travelled on the rail line. The estimated GTM and reportable accidents for all three load factor estimates can be found in Table 26.

**Table 26 Estimated number of GTM for each load factor**

<table>
<thead>
<tr>
<th>Load Factor (%)</th>
<th>Scenario 1</th>
<th>Scenario 2</th>
<th>Scenario 3</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total GTM (billion) per year</td>
<td>0.412</td>
<td>0.565</td>
<td>0.718</td>
</tr>
<tr>
<td>Estimated accidents per year</td>
<td>0.90</td>
<td>1.2</td>
<td>1.6</td>
</tr>
<tr>
<td>Return Period (years)</td>
<td>1.1</td>
<td>0.81</td>
<td>0.64</td>
</tr>
</tbody>
</table>

Increasing the load factor from 0-100% appeared to only increase the estimated number of accidents from 0.90 to 1.57 accidents per year. The Sussex subdivision had historically experienced between 0 and 10 accidents each year, with 4.9 accidents occurring per year on average over the past twelve years, according to the subdivision data from the TSB. While the estimated number of exposure-based accidents was less than the historical average, the estimate still fell within the range of accidents observed on this line. The low
estimate could be due to the observed GTM being increased by a factor of a four to account for an entire year of GTM travelled. Due to seasonal transportation demands, it is difficult to determine if the three-month study was representative of one-quarter of the total GTM travelled for the year.

4.4.3.2 Carloading-based accident rate estimate

To determine the probability of an accident occurring based on the number of DG carloadings, the accident rate per 1,000 DG carloads was used along with the total number of DG carloadings observed. The total DG carloadings observed over the study period was determined by the summation of all DG transported from the transcribed data, while considering some tank cars were empty. The number of DG carloadings observed were multiplied by a factor of 4 to estimate the number of DG carloadings in a year. Since the 2016 carloading-based accident rate was unavailable, the 2015 accident rate of 0.30 accidents per 1,000 DG was used in place.

A sensitivity analysis was conducted for the number of DG carloads observed over the study period, similar to the sensitivity analysis implemented for the exposure-based estimate. Due to the uncertainty surrounding the number of DG carloadings observed over the study period, they were also subjected to three load case scenarios to determine the lower, middle, and upper bounds for the estimated number of loaded DG carloads, again with the exception for crude oil and LPG.

The first load case was used to determine the lower bound of the number of DG rail cars transported over the observed subdivision, assigning a load factor of 0% to all unknown
DG carloads. The second load case was used to determine a middle bound of the number of DG carloads transported, assigning a load factor of 50% to all unknown DG carloads. The third load case was used to determine an upper bound of the number of DG carloads transported, assigning a load factor of 100% to all unknown DG carloads. A summary of the estimated number of DG carloadings and reportable accidents for each of the load factor estimates can be found in Table 27.

Table 27 Estimated number of DG carloads for each load factor

<table>
<thead>
<tr>
<th>Load Factor (%)</th>
<th>Scenario 1</th>
<th>Scenario 2</th>
<th>Scenario 3</th>
</tr>
</thead>
<tbody>
<tr>
<td>DG carloads per year</td>
<td>15,612</td>
<td>20,258</td>
<td>24,904</td>
</tr>
<tr>
<td>Estimated accident rate per year</td>
<td>4.68</td>
<td>6.08</td>
<td>7.47</td>
</tr>
<tr>
<td>Return period (year)</td>
<td>0.21</td>
<td>0.16</td>
<td>0.13</td>
</tr>
</tbody>
</table>

The carloading-based accident estimate range of 4.68 to 7.47 is closer to the historical accident average of 4.92 for the observed subdivision line. While the estimated range for carloading-based accidents is greater than the historical average for the observed line, it again falls within the historic range of 0 to 10 accidents per year.

Since between 22% to 35% of the total observed rail cars were assumed to be loaded with DG, it could explain why the accident rate per 1,000 DG carloadings estimated a larger number of accidents than the exposure based accident rate. The national proportion of DG carloadings in Canada for 2015 was calculated to be 10.2%, using the total carloads originated and DG carloadings totals obtained from the RAC data. Since a greater proportion of DG carloadings were observed during the study compared to the national
proportion, it would be reasonable to also expect a greater number of accidents from the DG carloading-based estimate compared to the exposure based estimate.

4.4.3.3 Probability of explosion for exposure and carloading-based estimates

One of the greatest risks the transport of DG poses is the possibility they are involved in a derailment scenario, where the contents are lost and a fire has the potential to ignite, which would ultimately cause an explosion. The potential of an explosion occurring anywhere along the observed rail line was investigated using the national accident data from the TSB, as well as the exposure and carloading-based accident rate estimates.

The probability of an explosion occurring, after some type of rail accident had previously occurred, was determined to be 0.01306% using the historic national accident database obtained from the TSB. The rail car loading case of 50% was chosen as a reasonable case scenario to be used for the purpose of an explosion scenario. The estimated probability of an explosion occurring using both the exposure and carloading-based accident rates, assuming a loading case of 50%, can be found in Table 28.

Due to the extremely low frequency of an explosion occurring from the historical data source, the estimate explosion rate was also found to be very low. The return period of an explosion occurring anywhere along the observed division with the 50% loading case scenario assumed, was estimated to be 6,200 and 1,300 years for the exposure and carloading-based type, respectively.
Table 28 Estimating the probability of experiencing an explosion anywhere along subdivision based on exposure and carloading-based accident rates

<table>
<thead>
<tr>
<th>Estimate type</th>
<th>Exposure-based</th>
<th>Carloading-based</th>
</tr>
</thead>
<tbody>
<tr>
<td>Probability of explosion after accident occurs</td>
<td>0.013%</td>
<td></td>
</tr>
<tr>
<td>GTM (billion)</td>
<td>0.565</td>
<td>-</td>
</tr>
<tr>
<td>DG carloads</td>
<td>-</td>
<td>5,065</td>
</tr>
<tr>
<td>Accident rate</td>
<td>2.18 per billion GTM</td>
<td>0.30 per 1,000 DG</td>
</tr>
<tr>
<td>Accidents per year</td>
<td>1.2</td>
<td>6.1</td>
</tr>
<tr>
<td>Explosions per year</td>
<td>0.00016</td>
<td>0.00079</td>
</tr>
<tr>
<td>Return period (years)</td>
<td>6,200</td>
<td>1,300</td>
</tr>
</tbody>
</table>

Further use of these data in risk analysis could be to use the probability distributions of train arrivals, direction and cargo compositions to further evaluate risk. For example, a westbound train arriving at the observation point at 2:30PM, and carrying 150 rail cars with 70% of the cars transporting DG would have probability distributions associated with each of these attributes. Using this, in concert with estimates of an explosion occurrence could assist with understanding the consequences of a worst-case scenario.
5.0 Conclusions and Recommendations

This research aimed to assess the usefulness of monitoring train activity using off-the-shelf video camera technology to collect data on the movement of DG by rail to support emergency organizations with their planning and preparedness. A video camera was setup within a community neighbouring a Class 1 railway line, and was used to monitor all train activity 24 hours a day for a period of 3 months. There were 199 trains observed over the course of the study period, all of which were manually transcribed from the video data. The data were then analyzed to develop descriptive statistics on the movement of cargoes by rail, especially those with DG placards, to better understand the transport of these goods through the community. The following section highlights the major conclusions derived from the study, as well as several recommendations for future work.

5.1 Conclusions

Several conclusions were drawn from the results interpreted during the analysis, pertaining to the effectiveness of the video camera data and its usefulness compared to current data sources. Conclusions were also drawn with respect to identifying gaps in the availability of data at local levels and validating the transcribed video data.

1. The video camera was able to provide sufficient video quality to allow the majority of the rail car data to be transcribed. The types of data extracted from video data included: rail car type, container code, cargo, weight limits, tank car type, and placard. The data transcribed from the video are summarized below:
• A total of 17,864 rail cars were observed throughout the duration of the study period, with 94% of the rail cars having legible container codes, and 87% having legible weight limits.

• A total of 10,339 DG carloadings identified, accounting for 57.8% of total rail cargoes, with only three DG placards unidentifiable.

2. The transcribed video data has the ability to provide more timely summary reports than currently provided through PD36, with the data being presented on a per train basis rather than aggregated quarterly for the Class 1 railways. While AskRail does provide data on a per train basis, it does not support the ability to archive the data to be used for future emergency planning, which is a major limitation of the application. The transcribed video data provided information on the number of rail cars, number of DG carloadings, length of train, and frequency of train arrivals, which are common inputs among several risk assessment methodologies. This enhanced data would allow risk assessments to be conducted at various resolutions, including daily, weekly, monthly, and annual levels. Comparing these varying levels of data resolution would determine if the results at each level would be similar, or differ enough for alternate conclusions to be drawn at each level.

3. Video monitoring technology also allows for various railway performance metrics to be estimated, such as GTM and number of DG carloadings transported. Since the video camera is able to capture and identify the type of rail car, weight limits posted, and the DG placard, the GTM and number of DG carloadings can be estimated using load factors to determine the lower and upper bounds. These
metrics can be used in combination with the national historic rail accident data to estimate the number of accidents expected to occur along the line. Although these national accident rates would provide some context with respect to the number of potential accidents, it is unable to exactly represent the accident rate at the rail subdivision or even provincial level. The Sussex subdivision line studied had not experienced a DG explosion within the 10 year TSB dataset, therefore national occurrence data were used to provide some estimate of probability for risk assessment purposes. National rail accident rates from the Railways Association of Canada (RAC) were obtained to apply to the Sussex subdivision line, due to the absence of local data. These accident rates were applied to the metrics gathered from the data collected, such as the number of DG carloadings and estimated Gross Ton Miles (GTM) travelled, to calculate an estimate for the probability of an accident occurring somewhere along the rail line.

4. The proportion of DG carloadings transported by rail differs between the observed subdivision line and the national proportion. This would suggest the need for additional data to be available at provincial or subdivision levels. Since the national proportion of DG (10.2% in 2015) would not be representative of the proportion of DG transported through the observed rail line (57.8%), the national proportion would not provide much value to a risk assessment for a specific subdivision line in Canada. If this type of data was provided for each province, or even for each subdivision, then these proportions could be used more accurately in these types of assessment, rather than a generalized value representative for all of Canada.
5. While the annual report summarizing the DG transported through the community was not available at the time of writing this thesis, CN’s online report summary of DG transported in NB was available for 2015, which was used as a coarse comparison with the collected data. The proportions of LPG, crude oil, and sulphuric acid from the collected data were quite similar to the aggregate proportions from the online report.

Although the data collected through the methodology outlined for this research would still be considered lagging in nature, summary reports generated using the method followed would be more readily available than reports provided by railways. These reports would have potential to not only be provided to emergency personnel more frequently, but also at a greater resolution of data, that can detail historic rail cargo movements on a per train basis. This research also has potential to be further explored to use OCR technology to automate the transcription process, which would allow the rail video data to be processed in a timelier manner. A further step would be to use this automated process downstream of a community to allow the train data to be transcribed and processed, and then provided to the emergency organization within the downstream community. This would provide said emergency organization with the approximate arrival time of a train, as well the rail car composition before the train enters the community.

5.2 Recommendations

The usefulness of implementing video monitoring equipment to collect data on the movement of rail cargoes was explored, and was found to be an effective method of
obtaining detailed train data at an enhanced resolution. Since this type of data collection had yet to be explored in the scientific literature, an original methodology was developed to carry out the prescribed work. While the methodology outlined allowed for the completion of the primary objectives of this work, additional research would be required to further improve the methodology as well as the accuracy of the results. Several recommendations to improve future research are presented below.

1. Enhancements to PD36 data resolution and Class 3 railway reporting requirements. Major variability was observed in the number of DG carloadings transported by day and week, which would not be noticeable with the currently reporting being aggregated quarterly. While Class 3 railways are currently held to less stringent reporting regulation, they also transport DG through Canadian communities where a similar level of risk would be present. It would be beneficial for emergency organizations to have enhanced data on the movement of DG through their communities to support day-to-day operations.

2. Enhancements to AskRail application. The data provided through AskRail currently only provides data in rail-time to support emergency organizations during an emergency situation involving a Class 1 railway. The application does not allow for a historic dataset to be obtained to be used for future emergency planning. A historic dataset would be attainable through this application if emergency organizations were able to download data on trains passing through their communities. AskRail should also be extended to include Class 3 railways.
3. Extend the study period to encapsulate an entire year of rail cargo data. An entire year of data would provide an even greater dataset to analyze. Annual trends in DG carloadings would be noticeable; petroleum crude oil carloadings may increase in the winter time; determine effectiveness of method during inclement weather (snow).

4. Gain access to annual DG carloading report from corresponding railways to validate the transcribed video data. An agreement of understanding between all parties involved, including the pertinent railway, community official, and Transport Canada, could allow future researchers to validate DG carloadings observed.

5. Additional lighting could be installed adjacent to the video camera to enhance the level of illumination in the area. Fortunately during the study period there were few trains that arrived outside of day light hours, partially due to the fact sunset occurring later in the evening. Although, if another iteration of this work were to be completed during a time of year when sunset is earlier in the evening, additional lighting would be required to ensure the rail car information could be transcribed.

6. Mount video camera at lower height. Due to a physical limitation at the train station, the camera was required to be mounted on the eave of a building, approximately 3.3 metres from the ground. This high elevation made it difficult in some instances to read the information from one type of rail car. In future work, it would be recommended to install the camera at a lower height of
approximately 1.8 metres off the ground to ensure sufficient field of view for all rail car types.

7. Monitor a Class 3, or short-line, railway. Class 1 railways have sufficient organizational infrastructure to support the sharing of real-time cargo information and are partly doing so through the AskRail application. The ability of Class 3 railways to provide the same level of data sharing is not clear. Video data collection would return more information than currently available from any data source if performed on a Class 3 railway line since these companies are not required to provide data to communities at the same level of sophistication as Class 1 railways.

8. Explore data set further to determine various probability scenarios. There was a great amount of data collected from the information posted on the rail cars travelling through. Due to a time constraint, various types of analysis were not explored, such as the probability of train per day, train arrival time, length of train, and even examine tank car type observed.
References


An Act to amend the Canada Transportation Act and the Railway Safety Act. (S.C. 2015, c. 31)


Association of American Railroads. 2015. Moving Crude Oil Safely by Rail.


Canada Transportation Act. (S.C. 1996, c. 10)

Canadian Transportation Accident Investigation and Safety Board Act. (S.C. 1989, c. 3)


Hanson, T. 2014. Estimating the supply chain impacts of disruptions to critical transportation infrastructure in NB.


Standing Committee on Transport. 2014. Interim Report on Rail Safety Review.


Statistics Canada. 2016. Table 404-0002 - Railway carloadings statistics, by commodity, monthly, CANSIM. Available from


Transportation Information Regulations. (SOR/96-334).


### Appendix A: Weekly DG carloadings

<table>
<thead>
<tr>
<th>Week</th>
<th>Beginning on</th>
<th>Petroleum Crude Oil</th>
<th>LPG</th>
<th>Sulphuric acid</th>
<th>Elevated temp. liquid</th>
<th>Molten Sulfur</th>
<th>Others</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>1-Jul</td>
<td>363</td>
<td>233</td>
<td>25</td>
<td>57</td>
<td>39</td>
<td>87</td>
</tr>
<tr>
<td>2</td>
<td>8-Jul</td>
<td>353</td>
<td>181</td>
<td>14</td>
<td>46</td>
<td>28</td>
<td>62</td>
</tr>
<tr>
<td>3</td>
<td>15-Jul</td>
<td>342</td>
<td>265</td>
<td>12</td>
<td>33</td>
<td>25</td>
<td>43</td>
</tr>
<tr>
<td>4</td>
<td>22-Jul</td>
<td>330</td>
<td>233</td>
<td>20</td>
<td>41</td>
<td>18</td>
<td>59</td>
</tr>
<tr>
<td>5</td>
<td>29-Jul</td>
<td>412</td>
<td>187</td>
<td>46</td>
<td>39</td>
<td>46</td>
<td>65</td>
</tr>
<tr>
<td>6</td>
<td>5-Aug</td>
<td>390</td>
<td>217</td>
<td>47</td>
<td>25</td>
<td>29</td>
<td>103</td>
</tr>
<tr>
<td>7</td>
<td>12-Aug</td>
<td>382</td>
<td>217</td>
<td>64</td>
<td>27</td>
<td>34</td>
<td>78</td>
</tr>
<tr>
<td>8</td>
<td>19-Aug</td>
<td>338</td>
<td>177</td>
<td>53</td>
<td>21</td>
<td>34</td>
<td>97</td>
</tr>
<tr>
<td>9</td>
<td>26-Aug</td>
<td>406</td>
<td>210</td>
<td>30</td>
<td>29</td>
<td>53</td>
<td>66</td>
</tr>
<tr>
<td>10</td>
<td>2-Sep</td>
<td>357</td>
<td>233</td>
<td>54</td>
<td>40</td>
<td>32</td>
<td>90</td>
</tr>
<tr>
<td>11</td>
<td>9-Sep</td>
<td>381</td>
<td>309</td>
<td>54</td>
<td>29</td>
<td>29</td>
<td>84</td>
</tr>
<tr>
<td>12</td>
<td>16-Sep</td>
<td>458</td>
<td>316</td>
<td>45</td>
<td>22</td>
<td>25</td>
<td>77</td>
</tr>
<tr>
<td>13</td>
<td>23-Sep</td>
<td>368</td>
<td>265</td>
<td>10</td>
<td>29</td>
<td>29</td>
<td>65</td>
</tr>
<tr>
<td>14*</td>
<td>30-Sep</td>
<td>37</td>
<td>53</td>
<td>2</td>
<td>4</td>
<td>1</td>
<td>7</td>
</tr>
<tr>
<td></td>
<td>Total</td>
<td>4,917</td>
<td>3,096</td>
<td>476</td>
<td>442</td>
<td>422</td>
<td>983</td>
</tr>
</tbody>
</table>

*Week 14 includes one day of rail observation data
Curriculum Vitae

Candidate’s full name: Brendan Larry McPhee

Universities attended: University of New Brunswick (2011- 2015); BScE

Publications:


Conference Presentations:

1. Hanson, T., McPhee, B. 2016. Monitoring hazardous goods movement by rail: What we know and what we need to know. Presented at the Canadian Institute of Transportation Engineers Atlantic Provinces Section 2016 Fall Meeting, Fredericton, NB, 17 November 2016.