RISK ANALYSES IN THE RAIL TRANSPORT OF DANGEROUS GOODS: HOW TO BEST AVOID RELEASES

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INTRODUCTION

Each year, products identified as dangerous goods are transported across Canada by road, rail, water and air. Shipments of dangerous goods range from industrial chemicals to manufactured goods and, while indispensable to our modern way of life, can pose a threat to life, property and the environment if not handled safely.

This paper provides examples of the type of activities addressed in the area of risk management at the Transport Dangerous Goods (TDG) Directorate of Transport Canada. The quantities of dangerous goods freight transported in Canada and the corresponding number of dangerous goods accidents are gathered, as they need to be monitored to reduce the risk. A survey of the coupling speeds of tank cars and reliability analyses of equipment are provided as examples where safety measures are considered. The knowledge brought by these analyses helps adjust policies, regulations and standards and leads to the continuous improvement of the Transportation of Dangerous Goods program and therefore public safety.

TRANSPORTATION OF GOODS: EXPOSURE DATA ON DANGEROUS GOODS

Dangerous goods arrive and depart on highways, at airports, harbours and rail yards. Shipments of these goods are numerous and number in the tens of millions each year. These dangerous goods are necessary to maintain Canadians' quality of life: we need gasoline for our cars, chlorine for our swimming pools to name but a few examples. With large movements of these goods however, lies the potential for endangering human life and damaging property and the environment. It is therefore important to increase our knowledge of the dangerous goods transport.

Some of the information has good coverage, as is the case for the Air, Marine and Rail modes. They represent a census of the information available from airports, ports and rail carriers.[1] For the road mode, sample surveys are done and only for-hire carriers are surveyed. The numbers presented are gathered from different sources[2], mostly through Statistics Canada. Table 1 represents the total traffic of freight for the year 2006. The information was gathered for each mode not accounting for potential overlap i.e. freight carried in one mode and then in another.

Table 1: 2006 Freight Transportation in Canada
(in thousand tonnes)

Mode	Total Freight	Dangerous Goods (DG) Freight	% DG within category	% DG from total DG
Air	696			
Marine*	398 197	15 088	3.8%	11.5%
Rail**	315 566	31 225	9.9%	23.7%
Road	601 191	85 326	14.2%	64.8%
Total	1 315 651	131 638	10.0%	100.0%

*DG statistics do not include bulk DG
** DG statistics are for Canadian National & Canadian Pacific Railway's extended network

Besides coverage, another problem resides with the collection of the appropriate information. Freight and freight movement can be measured in various ways by: the number of shipments, the weight (tonne), the weight-distance product (tonne-km), and the distance

[1] Attention should be paid nevertheless to the actual coverage of the census.
[2] For rail, Transport Canada gathers origin and destination statistics directly from Canadian National and Canadian Pacific Railway. This information is complemented through Statistics Canada for other rail carriers.

(vehicle-km). However, for dangerous goods, one could argue that the measures are not as important as the properties of the goods: some dangerous goods are more dangerous than others.

There are over 2200 categories of dangerous goods covered under the Transportation of Dangerous Goods Regulations. They are classified by their United Nations (UN) number, a 4-digit code. When UN numbers are not collected, as they are most often not gathered through the current data capture mechanisms, descriptions of the freight can sometimes be used.

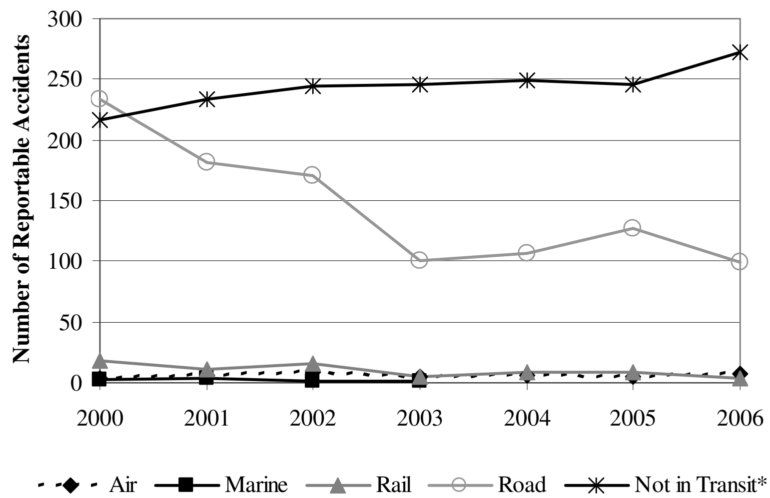
Another important distinction is that between bulk and non-bulk goods transported by ship: dangerous goods in bulk are not regulated by the *Transportation of Dangerous Goods Act, 1992* (TDG Act), for which this Directorate is responsible, but by the Canada Shipping Act.

Table 1 reflects the overall information available on freight dangerous goods transportation. From a TDG perspective however i.e. excluding marine bulk dangerous goods, the marine mode represents 11% of DG transport while the rail and road mode represent 24% and 65% respectively.

ACCIDENTS INVOLVING DANGEROUS GOODS

Within its mandate, TDG administers an accident-reporting requirement. An accidental release of dangerous goods is reportable if it consists of a quantity of dangerous goods or emission of radiation that is greater than the quantity or emission level set out in Part 8 of the Transportation of Dangerous Goods Regulations. These reports are captured into a system called the Dangerous Goods Accident Information System (DGAIS).

TDG accidents can occur while dangerous goods are being transported, while they are handled, or during temporary storage pending transport. The dangerous goods themselves, however, cause very few accidents. Dangerous goods accidents are divided between the handling stage and the transportation stage. Figure 1 shows that in recent years most reportable accidents involving dangerous goods did not occur during transport but rather during the loading or unloading phase at transportation facilities.



* Handling, loading, unloading, rail yard operations, temporary storage, etc.

Figure 1: TDG Reportable Accidents by Mode in Canada 2000-2006

In order to reduce the risk in the transportation of dangerous goods, different measures, often related to the containment of the dangerous goods, are monitored. Examples of such measures are presented below.

COUPLING SPEEDS INVOLVING RAILWAY TANK CARS IN CANADIAN HUMP YARDS

In the mid 1990s, a project was initiated by Transport Canada with the National Research Council of Canada to develop a basis for regulations with respect to the structural integrity of railway tank cars and to refine allowable impact speeds for railcars in switchyards. The results of this project [Tong and Dong, 1998; Xu and Dong, 1998] were used to establish that 7.5 mph (12 km/h) should be the maximum speed when coupling railway tank cars so as not to exceed a 1 M lb (454 metric tonnes) force, the design tolerance in some rail cars.

To evaluate changes that may be required due to imposing a 7.5 mph limit on the coupling speed of railway tank cars, Transport Canada requested that a survey of coupling speeds be conducted in six hump yards at Canadian National (CN) and Canadian Pacific Railway (CPR) in the fall of 2000. From October 23 to December 7, rail car coupling speeds were measured at the six hump yards. Measurements were taken at different times (day, evening, or night) and on varied tracks at each hump yard. For a given coupling event, one or several cars (referred to as a "cut") would be sent down the hump to a given track to build a train. A coupling speed is targeted, say 4 mph (6.4 km/h), the retarders are adjusted accordingly through the hump yard control system, the cut is sent down the hump and the coupling speed is measured using a radar device in the immediate vicinity of the impact location.

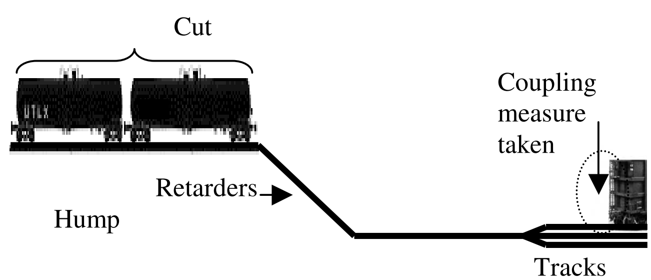


Figure 2: Simple scheme of hump yard surveys

From the data collected, some records were not useable. For some events, no coupling took place and these events were handled separately. For others, the coupling speed reading was unreliable. In the latter case this happened because a second cut was sent down the hump too soon after the first cut, allowing the cuts to run into one another before the first cut could couple with the cars waiting in the track. Out of 1 766 observed events, 287 were not usable, no coupling occurred for 210, and 1 269 coupling speeds were measured.

Event	Total
Coupling Reading Unreliable	287
No Coupling	210
Coupling Reading Measured	1 269
Total	1 766

In calculating the difference between the measured coupling speed and the projected coupling speed for all events where coupling occurred, we find that the mean absolute difference is 0.03 mph with a standard error on the mean of 0.05 mph and a median of 0. A test that the mean is null cannot be rejected. So for one, we know that the measured coupling speed is on target, it oscillates around the projected coupling speed, but that does not mean that there is precision.

Then what is the variability of the difference between the measured coupling speed and the targeted coupling speed? The standard deviation is 1.61 mph (2.6 km/h). Figure 3 illustrates the distribution of the differences.

The distribution looks close to the Normal. Under the Cramer-von-Mises goodness-of-fit test for the Normal distribution, we cannot reject the hypothesis of Normality (the test is based on the difference between the empirical distribution function and the Normal distribution function, the p-value is 0.15, a p-value ≤ 0.05 would lead to the rejection of the hypothesis).

During the survey the median projected coupling speed over all events was 4 mph and resulted in a proportion of no coupling events of 12% (210/1766). For the industry these events where no coupling occurs are inconvenient because they require the intervention of a locomotive to push cars and couple the delinquent car(s) to the train being formed.

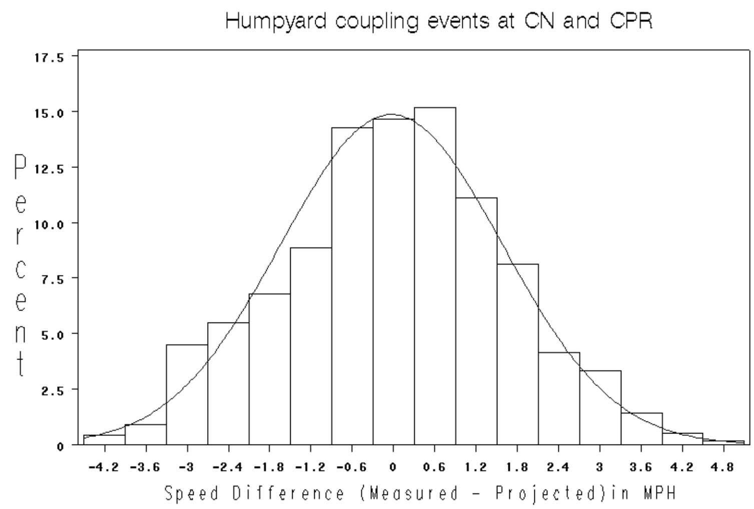


Figure 3: Distribution of the speed difference between measured and projected coupling speeds (mph)

Given the observed Normal distribution, the probability of exceeding 7.5 mph when coupling occurs for a projected coupling speed of 4 mph is 1.4%.

The establishment of a maximum coupling speed of 7.5 mph would be realistic in consideration for the probability of exceeding that speed and the proportion of no coupling events and would preserve the structural integrity of railway tank cars.

Regulations that came in force on August 15 2002 restricted the coupling speed of railway tank cars to 7.5 mph (12 km/h) when the ambient temperature is above -13° F (-25° C) and to 6 mph (9.6 km/h) when the ambient temperature is at or below -13° F (-25° C)[3] i.e. when the steel is cold. With all the measurements used by the hump yard control systems e.g. targeted speed, speeds measured at

[3] Department of Transport. *Transportation of Dangerous Goods Regulations*. Supplement, *Canada Gazette*, Part II, August 15, 2001 (SOR/DORS/2001-286), Section 10.7

various points during the descent, weather conditions, these systems' precision should have the potential to improve.

GIRTH SEAMS AND PRESSURE RELIEF VALVES ON RAILWAY TANK CARS: HOW RELIABLE ARE THEY?

Girth Seams

One aspect of the safe transport of dangerous goods is the continuing qualification and maintenance of tank cars. The requirements for periodic qualification of tank cars can be found in the National Standard of Canada CAN/CGSB-43.147-2002[4]. It states that for cars transporting materials not corrosive to the tank, a qualification inspection and test should take place at least every 10 years for the tank and service equipment.

An interest with girth seam welds and their reliability was identified following the request for a permit for equivalent level of safety by a company. The company provided the ultrasonic inspection data of its tank cars, a sample of 1543 tank cars, to propose an alternate qualification interval based on accumulated mileage or age instead of periodic time intervals.

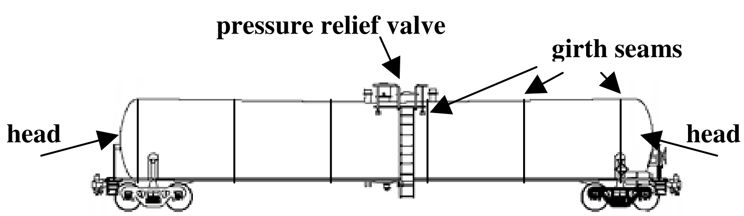


Figure 4: Tank car with girth seams

A tank car can be compared to an assembly of "cans", without tops or bottoms, plus the "heads". This assembly is done through welding.

[4] A National Standard of Canada publication entitled "Construction, Modification, Qualification, Maintenance, and Selection and Use of Means of Containment for the Handling, Offering for Transport, or Transporting of Dangerous Goods by Rail", March 2002, published by the Canadian General Standards Board.

These welds or attachment points are called girth seams or girth seam welds.

Tank cars are inspected for structural integrity through several methods (dye penetrant test, radiography test, magnetic particle test, ultrasonic test, optically aided visual inspection or acoustic emission), all of which can be time consuming and costly, leading to question the inspection frequency in areas where very few significant defects, if any, can be found.

Although life testing of components during the period of useful life is generally based on the exponential model, the failure rate of a component may not be constant throughout the period under investigation [Miller and Freund, 1977].

In the Weibull distribution, the failure rate $\lambda(t)$ is defined as a function of time t, by

$$\lambda(t) = \alpha\beta t^{\beta-1}$$

where α and β are respectively the scale and shape parameters of the distribution. For $\beta = 1$, it is the exponential distribution $\lambda(t) = \alpha$, a constant. If $\beta < 1$, the failure rate diminishes with time (initial period of failure). If $\beta > 1$, the failure rate increases with time (wear-out period).

Not surprisingly, this distribution is used extensively to deal with such problems as reliability and life testing. It can model a large number of observed failure time distributions [Blischke and Prabhakar Murthy, 2000].

The Weibull failure time probability density function is

$$f(t) = \alpha\beta t^{\beta-1} e^{-\alpha t^{\beta}} \qquad t>0,\ \alpha>0,\ \beta>0$$

and the reliability, the probability that the item will not fail before it reaches time t, is

$$R(t) = e^{-\alpha t^{\beta}} .$$

Using as time variables the age or mileage distribution of the tank cars inspected together with the cumulative frequency of defects, one can determine the best Weibull fit and possible thresholds of accumulated mileage or age for acceptable levels of risk. The data showed a total of 24 indications of defects.

Using a fitted Weibull based on mileage and acceptable probabilities of defect, one can determine the threshold mileage (Figure 5). Using this model and a cumulative probability of defect of 5%, then one would start inspecting the tank cars for girth seam weld defects at 570 000 miles (916 000 km).

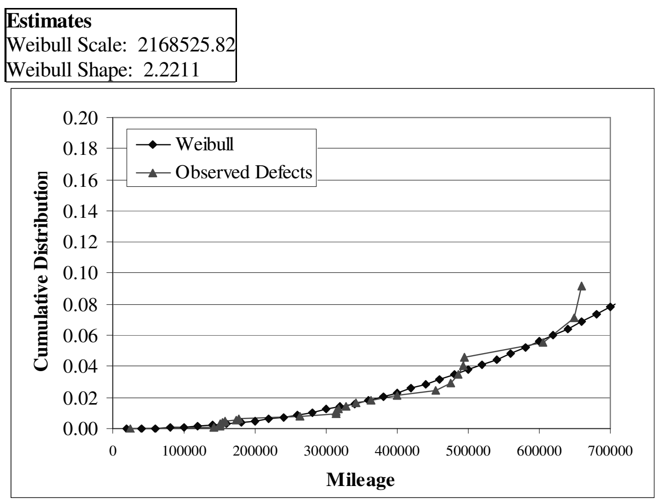


Figure 5: Cumulative failure distribution for girth seams defects

The following table (Table 2) provides a summary of all results obtained using weld defects as failures and age or mileage as time variables. A 1% risk corresponds to a likelihood of 1% defects amongst all tanks 24.6 years old or younger (or a likelihood of 1% defects amongst all tank cars with mileages of 273 332 or less). Note that as in any model fit, in this case the Weibull distribution, the use of the model is less reliable where there are few observations.

Table 2: Summary results of all Weibull analyses

	Defects	
	Analysis for Mileage	**Analysis for Age**
Number of failures	24	24
Scale α	1/2168526	1/48
Shape β	2.22	6.86
Percentile at 1% risk	273 332 miles	24.6 years
Percentile at 5% risk	569 375 miles	31.2 years
Percentile at 10% risk	787 313 miles	34.7 years

This analysis is useful to determine when girth seams start deteriorating. It seems to indicate that girth seams are more reliable than the current qualification interval of 10 years maximum implies. These results led to a permit for equivalent level of safety for this company. Additional information from a number of companies would be required to modify the general requirements.

Pressure Relief valves

While for girth seams there are indications that the standard's requirement might be too stringent, it is a very different story with pressure relief valves. Pressure relief valves (PRV) are designed to open automatically at a predetermined pressure (the start-to-discharge pressure) and to re-close themselves when the pressure lowers to an acceptable level. Most of the valves in this study generally had features corresponding to Figure 6.

Following the 1999 sudden and catastrophic rupture that propelled the tank of a tank car an estimated 750 feet (228 m) in Clymers, Indiana, the adequacy of inspection and testing requirements for pressure relief devices became a safety issue.

A task force composed of representatives from the Federal Railroad Administration (FRA), the Association of American Railroads (AAR) of which Canadian National Railway (CN), Canadian Pacific Railway (CPR) and the Railway Association of Canada (RAC) are members, the Research and Special Programs Administration (RSPA),

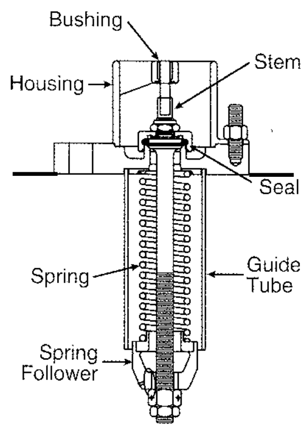


Figure 6: PRV - Internal Spring Design

Transport Canada (TC), valve and tank car owners and manufacturers, and the Railway Supply Institute (RSI), was formed to develop a protocol to determine the condition of pressure relief valves. A pilot run was performed to test the use of a new inspection test protocol and report form applicable to these pressure relief valves (PRV). The tests were performed at various RSI tank car facilities. A total of 1785 forms were analysed.

For the pressure relief devices to conform to the Standard's test requirements:

i. The tolerance for the start-to-discharge pressure for a reclosing pressure-relief device is ± 21 kPa (± 3 psi) for devices with a start-to-discharge pressure equal to or less than 690 kPa (100 psi) and ± 3% of the start-to-discharge pressure for devices with a start-to-discharge pressure greater than 690 kPa (100 psi); and

ii. The vapor-tight pressure of a reclosing pressure-relief device must be equal to or greater than 80% of the start-to-discharge pressure.

Table 3: Test Results for STD and VTP 1st Readings on Low and High Pressure Valves

Start-to-discharge (STD) Test				
Measure: 1st Reading	# failed	# passed	Proportion of success	Margin of error 95% confidence
Low Pressure Valves	233	924	0.80	0.02
High Pressure Valves	135	372	0.73	0.04
Vapor-tight-pressure (VTP) Test				
Measure: 1st Reading	# failed	# passed	Proportion of success	Margin of error 95% confidence
Low Pressure Valves	122	969	0.89	0.02
High Pressure Valves	69	370	0.84	0.03

The first reading is the most crucial reading. These valves should all be functioning as required at the moment of the first reading in order to be in compliance with the Federal (TC/DOT) Regulations. The estimated probability of success (see Table 3) is around 80% for the start-to-discharge (STD) pressure and higher for the vapour-tight-pressure (VTP). The probabilities were estimated separately by valve type and showed to be significantly different.

Using the time elapsed since the last qualification of a PRV along with the cumulative frequency of not passing the qualification test, one can determine the best Weibull fit and possible thresholds of time elapsed since the last PRV qualification for acceptable levels of risk. The age of the PRV (the date of manufacture) was not systematically provided and therefore could not be used in the analysis. Figure 7 illustrates the modeled cumulative distributions for the 1st Reading of STD pressure. This can be used to determine the best time interval for qualification tests. For the current upper limit of 10 years, the probability of a PRV failing the test at or before 10 years is 73% when the last commodity is Ammonia or LPG, 66% for high-pressure valves, 31% for low-pressure valves and 38% without specific information[5]. Using an upper limit of 5 years instead, the probability of a PRV failing the test at or before 5 years is 18% when the last

[5] The R^2, the percentage of the variance in the observations that is explained by the model is at or above 91% for all groupings considered.

commodity is Ammonia or LPG, 17% for high pressure valves, 9% for low pressure valves and 11% without specific information i.e. much lower probabilities of failure.

Having analysed 1785 forms on pressure relief valves condition and performance, it was found that 20% of the valves did not pass the start-to-discharge pressure test under the current tolerance levels. These percentages are large considering that all of the valves should be operating within the limits specified in Federal Regulations. Analyses of the cumulative probability of failing the test as a function of the time elapsed since the last PRV qualification reveals that 5-year time intervals as opposed to the current upper limit of 10 years would go from 38% to 11%.

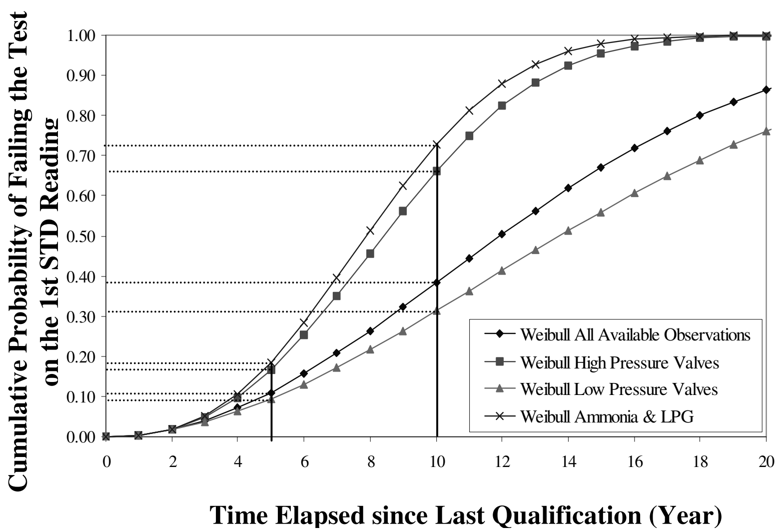


Figure 7: Cumulative Probability of Failing the Test on the 1st STD Reading for Different Groupings

CONCLUSION

An overview of the quantities of dangerous goods transported in Canada and the corresponding number of accidents was presented.

Examples of risk analyses applied to specific issues were also presented:

- the coupling speeds of railway tank cars in hump yards – an upper limit was adopted in the TDG Regulations
- the reliability of girth seam welds – a permit for equivalent level of safety was delivered
- the reliability of pressure relief valves – indications are that either the time interval between re-qualifications should be shorter or the tolerance levels of the pressure tests need to be reviewed – this is still under study.

Risk analyses are an inherent part of the transportation of dangerous goods program and the conclusions we draw from these analyses are key to the decision process leading to safer transportation.

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