

## ENHANCEMENTS AND UPDATES TO THE RISKMOD RISK ANALYSIS MODEL

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### ABSTRACT

The computer model RISKMOD was developed to provide assistance in the evaluation of policies for the movement of dangerous goods, by estimating objective risk. The model represents individual vehicle shipments of dangerous goods on the truck and rail networks for which the associated risks are estimated in a series of steps. The first step involves an accident rate prediction, followed by a spill rate prediction, given an accident. In subsequent steps, the damages are evaluated of an accident alone, and of an accident followed by a spill of goods. The final tables provide link by link risk estimates and a summary of the total risk for the entire route. A novel feature of the RISKMOD model is the valuation of consequences, which provides a common denominator in terms of expressing risk, so that all risks may be summed on a route.

This paper describes recent modifications to the model which have been made, based on new data. Specifically, the risk associated with the mechanical aspects of an accident are included separately from the risk due to the release of the dangerous cargo. In addition, more detailed truck release data have been included to better reflect the range of consequences which follow a release event. Both modifications assist in providing a more accurate and representative account of the risks associated with transporting dangerous goods.

### 1. INTRODUCTION

Risk analysis was developed to provide objective estimates of the risks associated with engineered systems for subsequent use by both engineers and political decision makers. Prior to formal objective risk calculations, policy was driven by expert opinions regarding risk, or the public perception of the riskiness of an activity. However, both experts and the public have certain biases, making this process generally unsatisfactory. In addition, in today's society there is a preference for systematic planning, forecasting, and early warnings rather than crisis management (1), which makes risk analysis very attractive.

In order to assist in these risk management tasks in the transportation field, the RISKMOD computer model was developed to provide estimates of the risk associated with the transportation of dangerous goods by road and rail. An initial risk model was designed in a project completed for Transport Canada by the Institute of Risk Research (2), where the qualitative and quantitative aspects of the transport of dangerous goods by rail and by road were studied. Since then, the model has been developed further at Queen's University (3).

Further modifications have been made recently at Queen's University, including the addition of a routine which estimates accident related damages. The significance of this routine is that damages, that occur virtually every time there is an accident, can be compared to the more infrequently occurring damages caused by actual dangerous goods spills. This balanced analysis helps to keep spill-related risks in perspective with accident-related risks, which are perhaps better understood. Another recent update is the inclusion of recent truck data that have been collected by Transport Canada (TC) in accordance with the Transport of Dangerous Goods Regulations, which require the reporting of any dangerous occurrence involving dangerous goods. These data have improved the default input values on release size distribution for the truck risk estimation routines.

This paper describes the most recent version of the RISKMOD model. It starts out with a description of the RISKMOD modelling approach in Section 2. Subsequent sections of the paper closely follow the structure of the model, namely, its input routines, risk calculations, and summaries. These are described in Sections 3 and 4, respectively. Section 5 shows a sample application of the model to two hypothetical links, which illustrates the level of detail in the input files and the calculations performed by the RISKMOD model. Section 6 presents the conclusions of the paper.

## 2. MODELLING APPROACH

The RISKMOD computer model is comprehensive in its representation of the process that causes transportation risk, yet it is simple in its structure. Its complexity derives from the level of detail in the input files, which can represent diverse situations. Its simplicity results from the use of a spreadsheet type of computer program, which easily manipulates the numerous large data arrays which are generated from the various input files.

There are a number of advantages to a simple, spreadsheet approach to risk analysis programming, as this approach facilitates checking and validating of model inputs, as well as the intermediate and final results. In addition, the approach is useful for "what if" types of analyses in a decision making process. By changing the input values, the model results can be compared to a base case to evaluate the trade-offs for numerous policies in terms of risk.

### 2.1 Risk Modelling

It is generally accepted that risk can be evaluated for analysis purposes with the simple formula:

$$[1] \quad \text{risk} = \text{frequency} \times \text{consequence}$$

Whyte (4) has suggested that for particularly abhorred consequences (for example, multiple death accidents), the consequence in equation [1] can be raised to the power  $n$ , where  $n$  is greater than one and reflects societal values. Although application of a value for  $n$  is possible in the RISKMOD model, at present the model considers a power of  $n = 1$  for all consequences.

The model represents the sequence of events that takes place when dangerous goods incidents occur during transportation and at shipping terminals. The event sequence begins with an analysis of accident frequencies, followed by an analysis of release frequencies per accident and release magnitude per release, which combine to form the frequency aspect of risk. Subsequently, estimates of the area impacted by a spill and the density of sensitive characteristics within this area are used to estimate the consequence aspect for each link of a transportation route. These links are formulated to be relatively homogeneous in terms of accident rates and other characteristics that are used in the consequence analysis.

To aggregate all risks (e.g., fatality risk, property damage risk) to a single risk estimate per link, each consequence considered by the model is assigned a cost. The final summary provides the risk attributed to a shipment of dangerous goods on each link of a route and for the entire transportation route. Given annual shipments of goods, the annual risk can be estimated.

### 2.2 RISKMOD Structure

The structure of the RISKMOD model is shown in Figure 1. The first four routines are used for input data selection and to set initial parameters. The next 3 routines (nos. 5 to 7) are the computational routines that

produce the actual risk estimate. The final routine (no. 8) provides the summaries for the entire route in terms of risk and risk costs (the term risk cost is used when the consequence components of the risk estimate have been assigned a cost). Sections 3 and 4 describe the input routines, risk calculations, and summaries, respectively, while Section 5 shows a 2 link example application of the RISKMOD model.

### 3. INPUT ROUTINES

The information needed to perform the risk analysis is provided to the RISKMOD model in six input files. These data are read in four routines and various subroutines which are shown in Figure 2. The following paragraphs describe these input routines and the contents of the six input files.

Routine 1 is an organizational routine in which array dimensions are established and input ASCII file names are assigned Turbo Basic file names. This routine provides for a dynamic memory allocation for all the arrays, efficiently managing memory usage for RISKMOD.

In Routine 2, the first two input files are read, which are used in the frequency calculations of RISKMOD. The first file contains information regarding how often an accident can be expected to occur (5). The maximum level of disaggregation currently used within RISKMOD for accident rates includes for each mode:

$$4 \text{ accident types} \times 2 \text{ track/road types} \times 4 \text{ accident causes} \times 3 \text{ speed classes} \times 4 \text{ volume classes} \\ = 384 \text{ accident rate entries}$$

The second input file read in this routine describes how often a release of dangerous goods takes place, given an accident has occurred (faulrate). The file contains the probability of the occurrence of discrete release sizes which have been selected from TC dangerous occurrence data (6). These are chosen for each commodity to model the continuum of possible release sizes. In the subsequent consequence analysis, these same discrete release sizes are used to provide a link between the frequency and the consequence data. The maximum level of disaggregation for release rates, which are constant over track type, speed classes, and volume classes, includes:

$$4 \text{ accident types} \times 2 \text{ release types} \times 4 \text{ release levels} = 32 \text{ release rates.}$$

In Routine 3, the data required to complete the consequence analysis of accidents and of spills are read into RISKMOD in three subroutines:

- 3.a) reads the results of the spill impact analysis (damcon);
- 3.b) reads the cost of damages (damcost); and
- 3.c) reads accident related damages (accdam).

In routine 3.a, areas that are expected to experience various types of damages caused by each of the discrete spill sizes are read into RISKMOD. These data have been generated by separate commodity-specific spill propagation and damage models which are described in Van Aerde et al. (7 and 8). Damage costs are constant over accident causes, speed classes, and volume classes, but are disaggregated to include:

$$4 \text{ accident types} \times 8 \text{ damage types} \times 4 \text{ exposure types} \times 3 \text{ damage levels} = 384 \text{ costs.}$$

Data read in subroutines 3.b and 3.c have been derived from the literature. The first 3 types of spill damage costs (3.b) are described in Needleman (9), and accident related costs are described in Stewart (10). The cost data file in subroutine 3.b has been structured so that it contains costs for both spill related damages (damcon) and accident related damages (accdam). These costs are used to sum fatality-risks, injury-risks, property

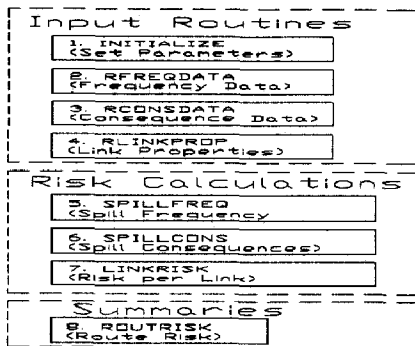


Figure 1: Flowchart of RISKMOD Structure

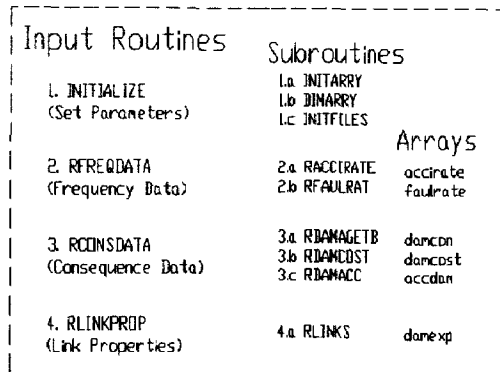


Figure 2: Flowchart of RISKMOD Input Routines

damage risks, and other risks. Damage costs are constant over accident causes, speed classes, and volume classes but are disaggregated to include:

$$4 \text{ accident types} \times 8 \text{ damage types} \times 4 \text{ exposure types} \times 3 \text{ damage levels} = 384 \text{ costs.}$$

Routine 4 provides an analysis based on link-specific densities (damexp) of sensitive features, such as population density, property density, and environmental features. A separate density is entered for each damage type, which allows separate population densities to be used for fatality-risk, evacuation-risk and other risks that affect the population. In addition, it is possible to distinguish among the persons at risk, for example, employees and residents. Other important characteristics of the link are input using this file, for example, link type, speed, and volume. This link-specific information is used to select appropriate values from the accident rate file (accirate), the accident related damages file (accdam), and the spill related damages file (damcon) as shown in Figure 3. Figure 3 also shows the relationship between the input files and the intermediate and output arrays generated by RISKMOD. The following section contains a description of the calculations performed within the model to produce this output.

#### 4. RISK CALCULATIONS

After the input routines have read all the required data, three routines are used to perform the risk calculations. These routines, their subroutines, and the arrays generated are shown in Figure 4.

Routine 5 generates two intermediate arrays, which are used in the frequency analysis. The first contains link-specific accident rates (accid), which have been selected to match link type characteristics given in the link file. The second array contains the probability of a spill (splpro), which is the result of multiplying these link-specific accident rates with the corresponding fault rates, which have been input for each accident type.

Routine 6 produces intermediate arrays that are used in the consequence analysis. Subroutine 6.a generates an array (spldam) that contains damages resulting from each spill size (the continuum of possible spills has been reduced to 8 spill sizes ranging from a multiple car release scenario to small continuous releases). This is accomplished by multiplying the areas damaged by each spill size (damcon) by link characteristics,

such as population density (damexp). The result is a set of link-specific damages for each of the discrete spill sizes (spldam). Subroutine 6.b generates the costs related to these spills (splcost). This is accomplished by multiplying link specific damages (spldam) by the cost of these damages (damcost).

The values in these intermediate arrays (spldam and splcost) are relatively large as these are the actual damages expected following each spill, not probabilistic damages. The advantage of displaying these actual damages per spill is that damages for a single spill can be verified with historical data, establishing the credibility of the consequence aspect of the model, and also providing a partial check on the risk values which are produced by the RISKMOD model. However, the disadvantage is that these intermediate arrays may focus attention on the damages of the worst case scenario, without accounting for the likelihood of the event. This may be of considerable concern as in the past some technologies have not gained acceptance due to worst case scenario studies. For example, Kunruether and Linnerooth (11) point out that liquefied nitrogen gas facilities in California never were built, partially due to a risk study that focussed on the worst case failure, without evaluating the probability of the event.

Routine 7 produces the final arrays that contain the estimates of the risk values per shipment. In subroutine 7.a, the spill damages calculated in Routine 6 (spldam) are multiplied with the probability of that spill occurring (splpro), to produce spill risks (riskdam). The accident risks (non-spill related) are also calculated in this routine (riskdama). The fatality, injury, property damage and other damage type risks are given for each link. Risk costs are calculated in subroutine 7.b. The risk arrays calculated in subroutine 7.a (riskdam and riskdama) are multiplied at this stage by the damage cost file (damcost) to produce risk cost arrays for spill and accident occurrences (riskcost and riskcosta, respectively). A total risk cost for each link is then produced, as risk costs can be summed.

Routine 8 displays risk and risk costs values for each link in a tabular format to provide the analyst with concise summary data. There are two subroutines to do this, as shown in Figure 5. One routine for estimating risk damage values and one for estimating risk cost values. Since risk cost values can be summed, a grand total risk cost for the link and for the route is calculated (triskc shown in Figure 5). In the final output, spill risk costs and accident risk costs are displayed separately and the grand total is also given. The execution of a single iteration of the risk analysis is now completed.

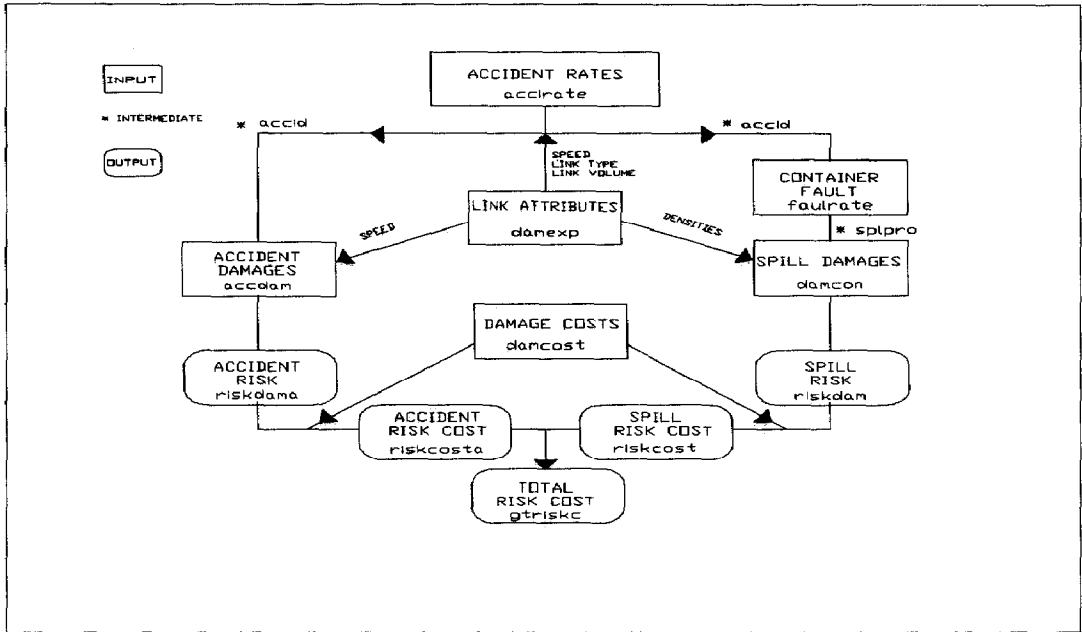
## 5. DEMONSTRATION EXAMPLE

In order to illustrate the calculations and results of each of the routines described in this paper, a simple demonstration run of the model using two links is described in this section. The output shown is condensed from the RISKMOD model computer output and annotated to illustrate the example. To simplify the example, only one table is shown for each routine, although other dimensions of these tables are identified. Note that the table number corresponds to the routine in which it was produced, as discussed earlier in this paper.

The demonstration example is based on an analysis of 2 hypothetical links. However, the accident rates, fault rates, release damages and monetary costs represent actual rates and values, as described briefly earlier in this paper, and as detailed more fully in Stewart(10).

### 5.1 Input Routines

Table 1 shows the railway and truck variables that define the array dimensions currently used within the RISKMOD model. This demonstration example will illustrate the railway model.



**Figure 3: The Relationship of Input and Other Major Arrays in RISKMOD**

Risk Calculations	Subroutines	Arrays
5. SPILLFREQ (Spill Frequency)	5.a ACCIDRATE 5.b SPILLRATE	accid splpro = accid * faultrate
6. SPILLCONS (Spill Consequences)	6.a SPILDAMAGE 6.b SPILCOST 6.c ACCIDCOST	spldam = damcon * damexp splcost = spldam * damcost acccost = accdam * damcost
7. LINKRISK (Risk per Link)	7.a RISKESTIM 7.b RISKCOST	riskdan = spldam * splpro riskdama = accid * accdam riskcost = splcost * splpro riskcosta = acccost * accid

**Figure 4: Flowchart Showing Risk Calculation Routines in RISKMOD**

Summaries	Subroutines	Arrays
8. ROUTRISK (Route Risk)	8.a ROUTSUM 8.b ROUTSUMC	triskd(damtyp) triskc(damtyp) triskc(link) gtriskc

**Figure 5: Summary Routines in RISKMOD**

In Table 2.a the accident rate table for derailments is shown (accrate). There are four such tables, one for each accident type. In each of these tables the accident rate is defined in terms of volume class (in Billion Ton Miles), speed, and accident cause, which are the three variables found to be significant by Turcke et al. (5) in their study of railway accident data. Table 2.b shows the fault rate table (faulrate), which contains the probability of 8 discrete spill sizes, given a derailment has occurred (there are four fault rate tables to match the four accident rate tables). The 8 spill sizes correspond to instantaneous or continuous releases occurring in multiple cars, and in one car at a high rate, medium rate and low rate of discharge. The low, medium and high release rates are commodity specific, while the multiple category, which is intended to represent a simultaneous release from several cars, would reflect a higher damage level which at present has not yet been quantified.

Table 3.a contains the areas expected to experience damages, should these 8 spills occur. There are also seven other damage types considered in the RISKMOD model, which are shown in the summary tables later in this example. These areas are calculated externally by damage prediction programs (7 and 8). There are three levels of damages (high, medium and low) which represent, for this damage type, serious injuries, moderate injuries, and minor injuries. Table 3.b lists the costs assigned to these three levels of injuries, which for this damage type have been established from automobile accident statistics (9). The costs are given in terms of four exposure types, which for injuries are: residential, industrial, passengers, and employees. Although the values are currently constant for these exposure types, this provides for any differences regarding costs to employers for employee injury as opposed to public injury, which may involve litigation costs. Table 3.c contains the expected injury damages resulting from a derailment accident as opposed to the spill of goods (if the values in this table can be added to expected spill damages). The damages are estimated for accidents occurring at 3 different speeds. There are 32 such tables, since there are 4 accident types and 8 damage types.

Table 4 provides the link data for the two link sample. Densities are shown only for two damage types, fatalities and injuries. However, the model requires densities of all 8 damage types currently used. And since all of these types have four exposure types, 32 densities are required per link. All of the input data has now been read into RISKMOD. The calculation routines will now use these data to determine the prevailing risks on each link. The example calculation tables show only one link to simplify the presentation.

## 5.2 Risk Calculations

Table 5.a shows the link-specific accident rates which have been selected from the accident rate table (2.a) by using the link volume class and speed descriptors of the link file (4.a). The accident rates have been summed over the accident causes which are highlighted for derailments in Table 2.a. The second accident rate in Table 5.a is simply the per kilometre rate multiplied by the link length, which was provided in the link file. In Table 5.b the accident rates of Table 5.a have been multiplied by the corresponding fault rates (2.b). This results in spill rates per kilometre and per link.

The tables in routine 6 show the link-specific consequences that are expected following a spill (Tables 6.a and 6.b) and following any accident, with or without a spill (Table 6.c). There are 8 tables per link generated by each of these subroutines, one for each damage type. Table 6.a shows the number of injuries (serious, moderate, and minor injuries and the total number) that are expected for each of the 8 spill sizes. There are found by multiplying the damage areas (3.a) by the appropriate densities in the link file (4.a). Table 6.b contains the cost of these injury damages, which is obtained by multiplying Table 6.a by the cost of the damages (3.b). Table 6.c

contains the costs of injury damages, which result from the four types of accidents. This table is obtained by multiplying accident damages (3.c) by the cost values (3.b).

Table 7.a and 7.b bring in the frequency aspect of risk to produce risk estimates for each damage type and for each link. Table 7.a shows the risk of injury on link 1 for each of the 8 spills and for each of the 4 accident types. The risk of injury from spills is found by multiplying spill damages (6.a) by the spill probability (5.b). The risk of accident injury is found by multiplying the accident rate (5.a) by the expected damages, given an accident (3.c). Table 7.b is obtained by multiplying spill costs (6.b) by the probability of a spill (5.b).

**Table 1: Variable Dimensions Currently Used in RISKMOD to Define Array Dimensions**

NUMBER OF VARIABLES	RAILWAY VARIABLES	TRUCK VARIABLES (IF DIFFERENT THAN RAILWAY)
Mlinks = 2	Number of links (any number can be used; this example has 2 links.)	
Mlinktyp = 4	Link type descriptors: speed, volume, track type, # of crossings	speed, volume, road type, # of crossings
Macctyp = 4	Accident Type: derailment, collision, crossing, leak	overtun, collision with overtun, collision, other
Macccau = 4	Accident Cause: fixed plant, equipment, operations, other	road conditions, equipment, operations, other
Mtrktyp = 2	Track Type: main track, yard	roadway, terminal
Mspdclas = 3	Speed Class: 0-50 kph, 50-80 kph, 80-160 kph	urban 0-50 kph, suburban 50-80 kph, rural 80-100kph
Mvolclas = 4	Volume Class: .1 BTM, .1-1 BTM, 1-10 BTM, 10-100 BTM	local 2 lane, collector 4 lane, arterial 6 lane, freeway
Mloalev = 2	Load Level: full, empty	
Mreltyp = 2	Release Type: shell/instantaneous, valve/continuous	
Mrelel = 3	Release Level: Multiple, High, Medium, Low	
Mdamtyp = 8	Damage Type: fatality, injury, property, rivers, lakes, evacuation, response, delay	
Mdamlev = 3	Damage Level: high, medium, low	
Mexptyp = 4	Exposure Type: 4 types for each damage type	

**Table 2.a: One of 4 Accident Rate Tables (accirate) Used in Routine RACCIRATE**

Accident Type 1: DERAILMENT (per car-kilometre)			Track Type 1: Mainline	
Accident Cause 1: Fixed Plant				
Volume Classes:	.10 BTM	.1-1 BTM	1-10 BTM	10-100 BTM
0-50 kph	6.27E-06	7.45E-07	4.64E-08	3.11E-08
50-80 kph	3.73E-06	3.37E-06	2.34E-08	2.95E-08
80-160 kph	3.73E-06	3.37E-06	2.34E-08	2.95E-08
Accident Cause 2: Equipment				
Volume Classes:	.10 BTM	.1-1 BTM	1-10 BTM	10-100 BTM
0-50 kph	4.66E-06	5.54E-07	3.45E-08	2.31E-09
50-80 kph	2.77E-06	2.51E-06	1.74E-08	2.20E-08
80-160 kph	2.77E-06	2.51E-06	1.74E-08	2.20E-08
Accident Cause 3: Operational				
Volume Classes:	.10 BTM	.1-1 BTM	1-10 BTM	10-100 BTM
0-50 kph	4.18E-06	4.97E-07	3.09E-08	2.08E-08
50-80 kph	2.49E-06	2.25E-06	1.56E-08	1.97E-08
80-160 kph	2.49E-06	2.25E-06	1.56E-08	1.97E-08
Accident Cause 4: Other				
Volume Classes:	.10 BTM	.1-1 BTM	1-10 BTM	10-100 BTM
0-50 kph	9.64E-07	1.15E-07	7.14E-09	4.79E-09
50-80 kph	5.74E-07	5.19E-07	3.60E-09	4.54E-09
80-160 kph	5.74E-07	5.19E-07	3.60E-09	4.54E-09

**Table 2.b: One of 4 LPG Fault Rate Tables (faulrate) Used in the Routine RFAULRAT.**

Accident Type 1: DERAILMENT (fault rate/accident) Mainline				
Release Level:	Multiple	High Rel	Medium Rel	Low Rel
Instant. Rel. Type	0.00E+00	9.34E-04	1.26E-04	1.26E-04
Continuous Rel. Type	0.00E+00	4.91E-03	1.55E-04	4.65E-04



**Table 3.a: One of 8 Damage Area Tables (damcon) used in the Routine RDAMAGETB**

DAMAGE TYPE 1: INJURY (SQ.KM. AFFECTED)				
Level 1: High dam.				
	Multiple	High Rel	Medium Rel	Low Rel
Instanteous Release	0.000	0.091	0.000	0.000
Continuous Release	0.000	0.048	0.000	0.000
Level 2: Medium dam.				
	Multiple	High Rel	Medium Rel	Low Rel
Instanteous Release	0.000	0.138	0.000	0.000
Continuous Release	0.000	0.073	0.000	0.000
Level 1: Low dam.				
	Multiple	High Rel	Medium Rel	Low Rel
Instanteous Release	0.000	0.754	0.000	0.000
Continuous Release	0.000	0.398	0.000	0.000

**Table 3.b: One of 32 Damage Cost Tables (damcost) used in the Routine RDAMCOST**

INJURIES (1990 Can. \$)	High Dam.	Med Damage	Low Damage
Residential	60700	5800	1200
Industrial	60700	5800	1200
Passengers	60700	5800	1200
Employees	60700	5800	1200

**Table 3.c: One of 32 Accident Damage Tables (accdam) used in the Routine RDAMACC**

DERAILMENT MAINLINE SPEED: 0-50 KPH			
INJURIES (per accident)	High Damage	Med. Dam	Low Dam.
Residential	0	0	0
Industrial	0	0	0
Passengers	0	0	0
Employees	0.008	0.0124	0.0555
DERAILMENT MAINLINE SPEED 50-80 KPH			
INJURIES (per accident)	High Damage	Med. Dam	Low Dam.
Residential	0	0	0
Industrial	0	0	0
Passengers	0	0	0
Employees	0.008	0.0124	0.0555
DERAILMENT MAINLINE SPEED: 80-160 KPH			
INJURIES (per accident)	High Damage	Med. Dam	Low Dam.
Residential	0	0	0
Industrial	0	0	0
Passengers	0	0	0
Employees	0.008	0.0124	0.0555

**Table 4.a: Link Characteristics Table (damexp) used in the Routine RLINKS**

Link #	Name	Start Node	End Node	Length	No. of Crossings	Type: 1	Type: 2	Type: 3	Dam. Type	Density (people/sq km)			
						MI/Yd	Speed	Vol.		Residen-tial	Indus-trial	Passen-gers	Emplee
1	Urban	1151	1152	1000	1	1	2	4	Fatality	4000	0	0	2
									Injury	4000	0	0	2
2	Mc-Yard	1150	1151	1000	0	2	2	4	Fatality	2	0	0	200
									Injury	2	0	0	200

### 5.3 Summaries

The final tables provide the previous information in summary format for all links of a route. Whenever possible, any aggregate sums are calculated and displayed in the tables. Tables 8.a and 8.b show both links of this example to illustrate the summary tables that are available for a route.

Table 8a provides risk values for each damage type and for each link per shipment of dangerous goods. The values can be summed for damage type, so that a risk of fatality, for example, can be noted for the route. This table gives spill damages and accident damages separately and as a combined sum. Table 8.b provides the risk cost values in the same format as Table 8.a, but also in a grand total for the route, as all damage types can be summed now that they are evaluated in terms of dollars. This latter summary is basically the "bottom line" of the risk analysis, which can be used to compare routes, or individual links within a route, to determine the acceptability of the risks.

#### 6. SUMMARY OF RISKMOD MODELLING APPROACH

This paper has shown the relationship between the arrays used to store input, intermediate, and output data in the computer program RISKMOD. The model structure is relatively simple and straight forward, but the data that the model manipulates is not. The numerous tables of the sample calculation, which are only a small portion of the data generated by RISKMOD, illustrate the need for a computer program such as RISKMOD.

The amount and quality of information supplied by the input files dictates how well the model will estimate the actual risks that are experienced during the transportation of dangerous goods. With so much importance attached to these data, the need for consistent data collection and management is crucial for the success of a model such as RISKMOD. With Transport Canada's collection of data in a central database on dangerous occurrences involving dangerous goods, the updating of previous model predictions using actual Canadian data is now becoming a reality.

#### ACKNOWLEDGEMENTS

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**Table 5.a: Link-Specific Accident Rate Table (accid) used in the Routine ACCIDRATE**

LINK # 1 URBAN		
Derailment	7.57E-06 /car-km	7.57E-05 /car-link
Collision	3.73E-09 /car-km	3.73E-06 /car-link
Crossing	4.48E-08 /car-km	4.48E-05 /car-link
Other	0.00E+00 /car-km	0.00E+00 /car-link

**Table 5.b: Link-Specific Spill Rate Table (splpro) used in the Routine SPILLRATE**

LINK # 1 URBAN			
Instantaneous Release	Multiple	0.00E+00 /car-km	0.00E+00 /car-link
	High	7.50E-11 /car-km	7.50E-08 /car-link
	Medium	1.01E-11 /car-km	1.01E-08 /car-link
Continuous Release	Low	1.01E-11 /car-km	1.01E-08 /car-link
	Multiple	0.00E+00 /car-km	0.00E+00 /car-link
	High	3.94E-10 /car-km	3.94E-07 /car-link
	Medium	1.24E-11 /car-km	1.24E-08 /car-link
	Low	3.73E-11 /car-km	3.73E-08 /car-link

**Table 6.a: Link 1 Spill Damage Table (spldam) used in Routine SPILDAMAGE**

DAMAGE LEVEL	INSTANTANEOUS RELEASES				CONTINUOUS RELEASES			
	Multiple	High	Medium	Low	Multiple	High	Medium	Low
Injury Residential								
High	0	0.37	0.00	0.00	0	0.19	0.0	0.0
Medium	0	0.55	0.00	0.00	0	0.29	0.0	0.0
Low	0	3.02	0.00	0.00	0	1.59	0.0	0.0
Injury Industrial								
High	0	0.00	0.00	0.00	0	0.00	0.0	0.0
Medium	0	0.00	0.00	0.00	0	0.00	0.0	0.0
Low	0	0.00	0.00	0.00	0	0.00	0.0	0.0
Injury Passengers								
High	0	0.00	0.00	0.00	0	0.00	0.0	0.0
Medium	0	0.00	0.00	0.00	0	0.00	0.0	0.0
Low	0	0.00	0.00	0.00	0	0.00	0.0	0.0
Injury Employees								
High	0.0	0.00	0.00	0.00	0	0.00	0.0	0.0
Medium	0.0	0.00	0.00	0.00	0	0.00	0.0	0.0
Low	0.0	0.00	0.00	0.00	0	0.00	0.0	0.0
TOTALS:	0.0	3.9	0.0	0.0	0	2.1	0.0	0.0

**Table 6b: Link 1 Spill Cost Table (splcost) used in the Routine SPILCOST**

	INSTANTANEOUS RELEASES				CONTINUOUS RELEASES			
	Multiple	High	Medium	Low	Multiple	High	Medium	Low
INJURY Residential								
High Damage	0	22,202	0	0	0	11,713	0	0
Medium Damage	0	3,199	0	0	0	1,682	0	0
Low Damage	0	3,621	0	0	0	1,909	0	0
INJURY Industrial								
High Damage	0	0	0	0	0	0	0	0
Medium Damage	0	0	0	0	0	0	0	0
Low Damage	0	0	0	0	0	0	0	0
INJURY Passengers								
High Damage	0	0	0	0	0	0	0	0
Medium Damage	0	0	0	0	0	0	0	0
Low Damage	0	0	0	0	0	0	0	0
INJURY Employees								
High Damage	0	11	0	0	0	0	0	0
Medium Damage	0	2	0	0	0	0	0	0
Low Damage	0	2	0	0	0	0	0	0
TOTALS:	\$0	\$29,036	\$0	\$0	\$0	\$15,305	\$0	\$0

**Table 6c: Cost Table for Link 1 (accocost) used in the Routine ACCIDCOST**

	DERAILMENTS	COLLISIONS	CROSSING ACCIDENTS	OTHER
Injury Residential				
High Damage	0	0	0	0
Medium Damage	0	0	0	0
Low Damage	0	0	0	0
Injury Industrial				
High Damage	0	0	0	0
Medium Damage	0	0	0	0
Low Damage	0	0	0	0
Injury Passengers				
High Damage	0	28225.5	23187.4	0
Medium Damage	0	4164.4	495.9	0
Low Damage	0	3853.2	66.36	0
Injury Employees				
High Damage	485.6	3927.29	254.94	0
Medium Damage	71.92	580	38.28	0
Low Damage	66.6	536.28	35.16	0
TOTALS:	\$624	\$41,287	\$24,078	\$0

**Table 7.a: Risk of Damage per Shipment (riskdam) used in the Routine RISKESTIM**

DAMAGE TYPE: INJURY LINK # 1								
EXPECTED RISK DAMAGE FROM SPILLS (FREQUENCY*CONSEQUENCE)								
(riskdam = spldam * spipro)								
	Instantaneous Releases				Continuous Releases			
	Multiple	High	Medium	Low	Multiple	High	Medium	Low
High damage	0.0E+00	2.7E-08	0.0E+00	0.0E+00	0.0E+00	7.6E-08	0.0E+00	0.0E+00
Med. Damage	0.0E+00	4.1E-08	0.0E+00	0.0E+00	0.0E+00	1.1E-07	0.0E+00	0.0E+00
Low Damage	0.0E+00	2.3E-07	0.0E+00	0.0E+00	0.0E+00	6.3E-07	0.0E+00	0.0E+00
Spill Related Risk of Injury damage: 1.1E-06								
EXPECTED RISK FROM ACCIDENTS (Frequency*Consequence)								
(riskdama = accid * accdam)								
	Derailments	Collisions	Crossing	Other				
	High damage	6.1E-07	2.0E-06	1.7E-05	0			
Med. Damage	9.4E-07	3.1E-06	4.1E-06	0				
Low Damage	4.2E-06	1.4E-05	3.8E-06	0				
Accident Related Risk of Injury damage: 5.0E-05								

**Table 7.b: Risk Cost per Shipment (riskcost) used in the Routine RISKCOST**

DAMAGE TYPE: INJURY LINK # 1								
EXPECTED RISK COST FROM SPILLS (riskcost = spicost * spipro2)								
	Instantaneous Releases				Continuous Releases			
	Multiple	High	Medium	Low	Multiple	High	Medium	Low
High damage	0	0.001666	0	0	0	0.004618	0	0
Med. Damage	0	0.000240	0	0	0	0.000663	0	0
Low Damage	0	0.000272	0	0	0	0.000753	0	0
Spill Related Risk Cost of Injury damage: \$0.01								
EXPECTED RISK COST FROM ACCIDENTS (riskcosta = damcost * riskdama)								
	Derailments	Collisions	Crossing	Other				
	High damage	0.0368	0.1199	1.0495	0.0000			
Med. Damage	0.0054	0.0177	0.0239	0.0000				
Low Damage	0.0050	0.0164	0.0045	0.0000				
Accident Related Risk Cost of Injury damage: \$1.28								

**Table 8a: Route/ Link Summary of Risk Damage per Shipment.**

SUMMARY OF SPILL RELATED RISK								
Link	Fatality	Injury	Property	Rivers	Lakes	Evacuation	Response	Delay
1 Urban	1.1E-07	1.1E-06	9.1E-11	0	0	0	0	0
2 McYard	6.4E-08	6.7E-07	1.1E-09	0	0	0	0	0
Totals:	1.7E-07	1.8E-06	1.2E-09	0	0	0	0	0
SUMMARY OF ACCIDENT RELATED RISK								
Link	Fatality	Injury	Property	Rivers	Lakes	Evacuation	Response	Delay
1 Urban	5.5E-06	5.0E-05	8.1E-05	0	0	0	0	0
2 McYard	1.1E-05	3.1E-04	9.5E-04	0	0	0	0	0
Totals:	1.7E-05	3.6E-04	1.0E-03	0	0	0	0	0
ROUTE SUMMARY OF RISK (SPILL RISK + ACCIDENT RISK = TRISKD)								
	Fatality	Injury	Property	Rivers	Lakes	Evacuation	Response	Delay
Risk Sum:	1.7E-05	3.6E-04	1.0E-03	0	0	0	0	0

**Table 8b: Route and Link Summaries of Risk Cost per Shipment (trisc, gtrisc)**

SUMMARY OF SPILL RELATED RISK COSTS (FOR ONE SHIPMENT)								
Link	Fatality	Injury	Property	Rivers	Lakes	Evacuation	Response	Delay
1 Urban	\$0.09	\$0.01	\$0.03	\$0.00	\$0.00	\$0.00	\$0.00	\$0.00
2 McYard	\$0.05	\$0.00	\$0.00	\$0.00	\$0.00	\$0.00	\$0.00	\$0.00
Totals:	\$0.15	\$0.01	\$0.03	\$0.00	\$0.00	\$0.00	\$0.00	\$0.00
SUMMARY OF ACCIDENT RELATED RISK COSTS								
Link	Fatality	Injury	Property	Rivers	Lakes	Evacuation	Response	Delay
1 Urban	\$4.79	\$1.28	\$3.38	\$0.00	\$0.00	\$0.00	\$0.00	\$0.00
2 McYard	\$9.52	\$2.52	\$29.46	\$0.00	\$0.00	\$0.00	\$0.00	\$0.00
Totals:	\$14.30	\$3.80	\$32.83	\$0.00	\$0.00	\$0.00	\$0.00	\$0.00
ROUTE SUMMARY OF RISK COSTS (SPILL RISK COSTS + ACCIDENT RISK COSTS= TRI)								
	Fatality	Injury	Property	Rivers	Lakes	Evacuation	Response	Delay
Risk Costs:	\$14.45	\$3.82	\$32.86	\$0.00	\$0.00	\$0.00	\$0.00	\$0.00
FINAL SUMMARY: TOTAL RISK COSTS PER LINK AND ROUTE (GTRSKC)								
Link	SPILLS		ACCIDENTS		TOTAL			
1 Urban	\$0.13		\$9.45		\$9.57			
2 McYard	\$0.06		\$41.50		\$41.56			
ROUTE TOTAL	\$0.19		\$50.94		\$51.13			

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