Developing a Plan for R&D in Dangerous Goods Transport

M. Martin, M. Matthews, and L. Rucker

ABSTRACT

In 1980 the Canadian Parliament passed the Transport of Dangerous Goods Act. Among the mandates given by the Act to the Transport of Dangerous Goods (TDG) Directorate of Transport Canada was the responsibility to "undertake . . . programs of technical research and investigations into" various aspects of dangerous goods transport. In this paper are presented (a) the methodology used to arrive at the identification and priority ranking of research and development (R&D) areas in dangerous goods transport and (b) the application of this methodology to the development of an R&D plan for a group of selected dangerous (nonradioactive) goods. Priorities for assigning resources to conduct this work must reflect (a) the risks involved in transporting given quantities of various dangerous goods, (b) the lack of safety information with respect to this activity, and (c) the possible need to enhance relevant technology and regulations with respect to the transport of dangerous goods. To arrive at raw R&D priorities for each dangerous commodity, container, transport mode, and safety subfunction, a methodology, called the technology matrix, was selected. Each cell in this matrix represents a particular R&D area, and a set of factors that are a function of the relative contribution to risk of each dimension of the matrix is developed. Available data including the TDG Directorate's data base of dangerous occurrences were used to develop a number of scores for each cell in the technology matrix for a set of 17 dangerous commodities. Multiplying these scores by each other yields the preliminary R&D priority score for a given cell of the matrix. This approach was used for the selected commodities and for transport by rail and road and warehousing. The research areas with the top scores were then presented to an expert panel for confirmation and refinement to the individual R&D project level.

The traditional approach to setting research and development (R&D) priorities is to consider a set of potential R&D projects and assign a priority to each project according to a given set of criteria (1). In the situation described here, the problem was different: there were no identified research projects, only a question: "What R&D should be conducted to enhance safety in the transport of dangerous goods in Canada?"

That is the question faced by the Transport of Dangerous Goods (TDG) Directorate of Transport Canada. TDG was created to unify, oversee, coordinate, and enhance safety measures related to dangerous goods transport in Canada. Within this broad mission, TDG has a clear mandate to coordinate R&D at a national level and to undertake R&D in the field of dangerous goods transport (Section 26 of the TDG Act, Canadian Parliament, 1980).

An R&D plan was developed for TDG. Within the context of this paper, R&D is given its broadest meaning:

- Gathering and analyzing information,
- Investigating problems, and
- Designing and testing solutions to problems.

In general, the motivation for conducting R&D in any area reflects a variety of factors:

- The area has a high potential pay-off. For example, if R&D could lead to the resolution of a particular problem, the benefits could be significant.
- The research has a good chance of generating new knowledge. In particular it does not duplicate research already under way.
- The research can be cost justified either in relation to other possible projects or in relation to a given funding envelope.

It is shown how these broad principles were applied in setting priorities for R&D projects and in developing an overall multiyear R&D plan for TDG. The prime criterion used in developing this plan is the maximization of net social benefit. The main components of social benefit are

- The reduction in the social and material cost of dangerous goods transport accidents in terms of lives saved, injuries avoided, and reduced material damage and disruption;
- The cost of the research (a liability); and
- The cost of implementing any positive result from the research.

Additional criteria for including R&D projects in the plan are

- The need to avoid duplication with other R&D work carried out by other jurisdictions or agencies,
- The potential spinoff benefit that the R&D could yield for Canada, and
- A departmental preference for performance-oriented R&D as opposed to specific hardware designs because that is the ultimate character of TDG regulations.

Given these broad objectives, a methodology was required that would develop R&D priorities without necessarily starting with a set of given potential projects. On the other hand, it was unlikely that, starting from such a vast topic as dangerous goods transport, a list of specific R&D projects could be developed through a purely deductive process. Therefore, the concept of a TDG R&D area was developed. Priorities would be developed for an R&D area, specific projects within this area would be called for, and then project ranking would be done. A TDG R&D area is defined as a unique combination of

- Commodity or group of commodities,
- Container,
- Mode,
- Transport operation, and
- Safety subfunction.

These terms are defined as follows:

- Commodity means any commodity classified as a dangerous good in the regulations pertaining to the TDG Act. For purposes of the initial R&D planning effort described here, 17 commodities were selected as test commodities for application of the methodology. These are primarily energy-related commodities.
- Container is the full system used to transport the commodity (e.g., tank trailer, glass bottles packed in cartons).
- Mode for purposes of this first effort was limited to rail, road, air, shipping (when the vessel is not the container itself), and warehousing (because of the TDG Act concern with the "presentation" of dangerous goods for transport).
- Transport operation is defined as an activity that takes place in relation to the transport of dangerous goods. For the pure transport modes listed previously, operations are transport (vehicle in transit) and handling (loading and unloading). For warehousing, operations are storage and handling.
- The safety subfunction is any system or activity that prevents or reduces the risk of damage from a dangerous goods spill.

PROTECTION FUNCTIONS

Enhancing safety in the transport of dangerous goods involves the following major functions:

- Prevention,
- Avoidance,
- Control,
- Cleanup, and
- Monitoring.

Figure 1 shows the process whereby a dangerous goods spill occurs--or does not occur--and how the protection functions come into play at various stages of this scenario:

- Prevention is concerned with the prevention of an accident situation. An accident situation is a situation that could ultimately lead to a dangerous goods spill (for example, a skid on a wet road).
- When an accident situation has set in, avoidance is the function that comes into play. Avoidance attempts an exit from the accident situation.
- If avoidance is not totally successful an accident occurs. Dealing with the potential or actual dangerous goods spill calls for the application of the control function. If the material is fully contained, the accident becomes an incident from a TDG standpoint (although it may be an accident from a traffic standpoint). If there is a material release,

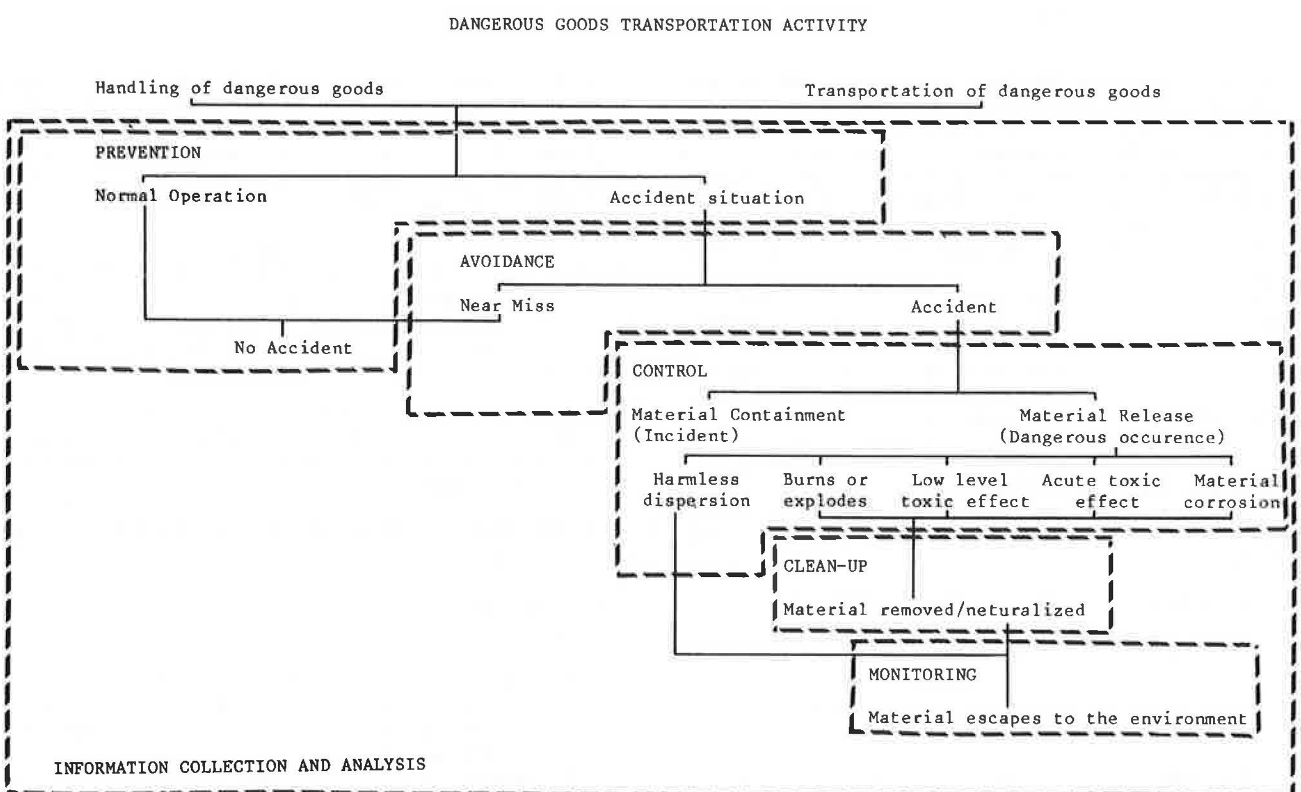


FIGURE 1 Protection technology in relation to transport of dangerous goods.

TABLE 1 Selecting a TDG R&D Planning Methodology Option

	R&D Planning Methodology Option						
Criteria	Delphi	Champion	Dangerous Occurrence Investigation	Commissions of Inquiry	Opinion Polls	Scenarios	Technology Matrix
Information required	Minimal	Minimal	High	High	Medium	Medium	High (initially)
Complexity	Medium	Low	Medium	Medium	Low	Medium	High
Cost of implementation	Low	Low	High	High	Medium	Medium	High (initially)
Outside acceptability	Medium	Medium	Medium	Medium	Low	Low	High
Quality of results	Medium	Medium	Medium	Medium	Low	Low	High
Risk of choosing wrong priority	Medium	Medium	Medium	Medium	High	High	Low
Time to get results (determine R&D priorities)	Short to medium	Short	Medium to long	Long	Medium	Short to medium	Long (initially)

Source: Thorne Stevenson & Kellog and Hooper & Angus staff opinions.

the accident, in TDG terminology, becomes a dangerous occurrence.

- When the spill has occurred, the next function is cleanup.
- The monitoring function comes after cleanup.

Planning R&D in monitoring was not pursued further because monitoring is under the jurisdiction of Environment Canada.

Each of these functions is broken up into the subfunctions given in Table 1. In addition, Figure 2 shows examples of technologies that can be used to carry out these subfunctions. This listing does not necessarily represent the complete set of technologies that pertain to a particular subfunction, and these technologies comprise both hardware systems and human elements (e.g., training).

1. PREVENTION

1.1 Right of way design
- 1.1.1 Other traffic
- 1.1.2 Load restrictions
- 1.1.3 Road/track stability
- 1.1.4 Loading space
- 1.1.5 Storage area manoeuverability

1.2 Vehicle design
- 1.2.1 Steering system
- 1.2.2 Braking system
- 1.2.3 Coupling mechanisms
- 1.2.4 Wheels/tires
- 1.2.5 Vehicle/container interaction
- 1.2.6 Container security

1.3 Speed, scheduling and routing
- 1.3.1 Traffic considerations
- 1.3.2 Driver training
- 1.3.3 Regulations (enforcement)

1.4 Vehicle storage and sorting
- 1.4.1 Overnight storage
- 1.4.2 Commodity monitoring requirements
- 1.4.3 Shunting operations
- 1.4.4 Commodity separation

1.5 Communications systems
- 1.5.1 Shipper/receiver communications
- 1.5.2 Transportation crew communications
- 1.5.3 Public information
- 1.5.4 Traffic information

1.6 Filling systems
- 1.6.1 Level indicator
- 1.6.2 Overflow devices
- 1.6.3 Loading access
- 1.6.4 Mechanical loading equipment

1.7 Maintenance and inspection
- 1.7.1 Right of way maintenance
- 1.7.2 Vehicle maintenance
- 1.7.3 Communications equipment maintenance
- 1.7.4 Filling equipment maintenance
- 1.7.5 Commodity storage and handling maintenance
- 1.7.6 Vehicle storage and sorting maintenance
- 1.7.7 Visual inspections
- 1.7.8 Non-destructive inspection
- 1.7.9 Testing (for compliance with regulations)

1.8 Training
- 1.8.1 Transportation system engineers and designers
- 1.8.2 Vehicle drivers/pilots/captains/engineers and crew
- 1.8.3 Maintenance staff
- 1.8.4 Inspection staff
- 1.8.5 Training staff
- 1.8.6 Other operations personnel
- 1.8.7 Systems administration personnel
- 1.8.8 General dangerous goods awareness
- 1.8.9 Enforcement

1.9 Commodity identification
- 1.9.1 Container markings
- 1.9.2 Container identification/commodity correlation

1.10 Commodity storage
- 1.10.1 Container structure
- 1.10.2 Container packaging and restraints
- 1.10.3 Commodity handling
- 1.10.4 Commodity thermal control
- 1.10.5 Commodity separation

2. AVOIDANCE

2.1 System and component design
- 2.1.1 Vehicle collision avoidance systems
- 2.1.2 Vehicle derailment systems and vehicle/right-of-way containment systems (barriers)
- 2.1.3 Position/location indicators
- 2.1.4 Navigation aids
- 2.1.5 Communication aids
- 2.1.6 Container integrity monitors

2.2 Training
- 2.2.1 Operator reflex training
- 2.2.2 Dangerous goods awareness

3. CONTROL

3.1 Containment (prior to release)
- 3.1.1 Pressure relief/control
- 3.1.2 Temporary shielding
- 3.1.3 Temperature control
- 3.1.4 Explosion suppression
- 3.1.5 Container structural integrity

3.2 Site command and situation analysis
- 3.2.1 Site organization and command
- 3.2.2 Medical training (dangerous goods)
- 3.2.3 Chemical mixing/reactions
- 3.2.4 Commodity identification (using HAZCHEM or other guides)
- 3.2.5 Commodity detection and interpretation
- 3.2.6 Firefighting involving dangerous goods
- 3.2.7 Safety equipment use
- 3.2.8 Site stabilization models (operational and chemico-physical models)

3.3 Personnel equipment
- 3.3.1 Clothing
- 3.3.2 Breathing apparatus

3.4 Commodity detection
- 3.4.1 Gas detectors
- 3.4.2 Liquid level detectors
- 3.4.3 Aerial liquid spill detectors
- 3.4.4 Radiation detectors
- 3.4.5 On-board spill detectors

FIGURE 2 Protection functions, subfunctions, and technologies in the transport of dangerous goods.

3.5 Commodity identification
- 3.5.1 Placards
- 3.5.2 Documentation
- 3.5.3 Containment/commodity correlations
- 3.5.4 Gas analyzers
- 3.5.5 Liquid spill analyzers
- 3.5.6 Solid spill analyzers

3.6 Firefighting
- 3.6.1 Dousant (solid (earth), gas, liquid, fog or foam)
- 3.6.2 Dousant delivery systems (pump trucks, hoses, valves, fire hydrants, dousant supply trucks, etc..)
- 3.6.3 Personnel equipment
- 3.6.4. Firefighting communications equipment
- 3.6.5 Personnel transport (Fire Chief's vehicle, personnel transporters, ladder trucks, ...)
- 3.6.6 On-site information sources
- 3.6.7 Fire station resources

3.7 Containment (following release)
- 3.7.1 Controlled discharges
- 3.7.2 Container plugging
- 3.7.3 Spill booms
- 3.7.4 Temporary storage

3.8 Site stabilization
- 3.8.1 Physical stabilization equipment (e.g. cranes, earth movers, ...)
- 3.8.2 Medical support equipment
- 3.8.3 Command/communications equipment
- 3.8.4 Personnel transporters
- 3.8.5 Public barriers
- 3.8.6 Police equipment

3.9 Neutralization
- 3.9.1 p^H adjustment
- 3.9.2 Biodegrading
- 3.9.3 Incineration
- 3.9.4 Precipitating
- 3.9.5 Gelling
- 3.9.6 Sorbents
- 3.9.7 Chemical modification

4. CLEAN-UP

4.1 Spill/release containment
- 4.1.1 Leak plugging
- 4.1.2 Land containment
- 4.1.3 Water containment (On/In)
- 4.1.4 Vapour suppression

4.2 On-site commodity neutralization
- 4.2.1 Incineration
- 4.2.2 Chemical modification
- 4.2.3 Sorbents
- 4.2.4 Gelling
- 4.2.5 Precipitating
- 4.2.6 Bio-degrading

4.3 Material collection
- 4.3.1 Mechanical recovery from land
- 4.3.2 Mechanical recovery from water-floating
- 4.3.3 Mechanical recovery from water-sinking
- 4.3.4 Recovery from air
- 4.3.5 Transfer systems
- 4.3.6 Temporary storages
- 4.3.7 Handling devices

4.4. Material transport
- 4.4.1 Road
- 4.4.2 Rail
- 4.4.3 Air
- 4.4.4 Marine

4.5 Material disposal
- 4.5.1 Incineration
- 4.5.2 Landfill
- 4.5.3 Disposal at sea
- 4.5.4 Deep well injection
- 4.5.5 Burial
- 4.5.6 Secure containment above grade

5. MONITORING

5.1 Commodity analysis
- 5.1.1 Pocket-portable small detector system
- 5.1.2 Person-portable electronic detector systems
- 5.1.3 Vehicle-portable computer-controlled instruments with pre-developed software
- 5.1.4 Mobile laboratory equipment
- 5.1.5 Fixed laboratory equipment (off-site)
- 5.1.6 Fixed laboratory equipment (on-site)

5.2 Environmental sensing
- 5.2.1 Ambient air, surface water temperature sensors
- 5.2.2 Groundwater temperature sensors
- 5.2.3 Ambient air pressure instruments
- 5.2.4 Groundwater piezometers
- 5.2.5 Windspeed and direction indicators
- 5.2.6 Surface water flowmeters
- 5.2.7 Survey equipment
- 5.2.8 Solar radiation sensors
- 5.2.9 Rainfall measuring equipment
- 5.2.10 Ground displacements sensors (inclinometers)
- 5.2.11 Air quality instruments
- 5.2.12 Soil analyzers
- 5.2.13 Ice thickness indicator

5.3 Data acquisition and conditioning
- 5.3.1 Cabling
- 5.3.2 Power supply
- 5.3.3 Filtering
- 5.3.4 Amplification
- 5.3.5 Signal display
- 5.3.6 Signal recording
- 5.3.7 Signal transmission
- 5.3.8 Equipment chassis/structure/protection

5.4 Human impact monitoring
- 5.4.1 Post accident medical, police, fire and EMO reports
- 5.4.2 Hospital records
- 5.4.3 Coroners' report
- 5.4.4 Follow-up medical examinations of affected population
- 5.4.5 Psychological surveys of affected population

5.5 Stabilization procedures monitoring
- 5.5.1 Event recorders
- 5.5.2 Lead party reporting
- 5.5.3 Accident filming equipment

FIGURE 2 continued

OPTIONS

Seven different options for setting TDG R&D priorities were identified:

- Delphi,
- Champion,
- Dangerous occurrence investigation,
- Commission of inquiry,
- Opinion polls,
- Scenarios, and
- Technology matrix.

These options are not totally distinct: some of their features overlap, but each option has a distinct focus.

Delphi

An expert panel is constituted. This panel is made up of TDG Directorate personnel or outsiders, or both. Each panel member is asked for an independent priority-ranked list of potential R&D projects along with reasons for recommending this list. The lists and reasons are collected and distributed anonymously to all panel members. The panel members are then asked to resubmit, and so on. Presumably, each panel member will be influenced by the lists submitted by other members and the process will converge after three or four rounds.

Champion

A totally open call is made for R&D proposals from qualified agencies in and out of Transport Canada. Each proposal is assessed and rated on the basis of potential benefits, cost, and strength of the argument presented in its support. Proposals with the highest ratings are given highest priority.

Dangerous Occurrence Investigations

A representative sample of dangerous occurrences is investigated in detail using a variety of techniques (e.g., simulations, interviews, scaled models). All factors influencing these occurrences are determined. Then R&D priorities are established by the Directorate on the basis of a thorough review of these factors.

Commissions of Inquiry

When a commission of inquiry is appointed to investigate a major dangerous occurrence with high public profile, the TDG Directorate monitors the proceedings. The Directorate then bases its R&D priorities on the commission's recommended corrective measures.

Opinion Polls

Industry or the public, or both, can be asked directly about those areas in which risks are perceived to be greatest. Results of such polls can then be compiled and weighted according to the individuals or groups polled, and priorities can be assigned on this basis by the Directorate.

Scenarios

In this technique a series of disaster scenarios is generated. The technologies or regulations required to avoid or reduce the risk of such occurrences are postulated. The R&D that could ultimately lead to the development of such technologies or regulations is then assigned a top priority ranking.

Technology Matrix

This approach proceeds in three stages:

- Stage 1: Information collection and analysis. This is where the data required for Stage 2 are gathered and analyzed.
- Stage 2: Developing initial priorities for TDG research areas. In its most elementary form, a research area is defined as a combination of the commodity, mode, container, operation, and safety subfunctions. The combination of the various dimensions of the research areas makes up an array or matrix--hence the name. Initial priorities are assigned on the basis of scores that reflect the relative contribution to societal risk of each TDG research area. Because some research areas may involve identical technologies, it is possible to pool scores for such areas in an overall score for the technology.
- Stage 3: Final R&D priorities. This is a sifting process whereby the top scoring technology research areas yielded by Stage 2 are examined by one or more expert panels in order to arrive at a final R&D priority listing.

Some elements of this approach are similar to the one described in a 1983 study conducted by the Transport Development Centre of Transport Canada (2). The TDC study describes a method of assigning safety R&D based on a fault-tree analysis developed as a possible planning tool--but not put in use--by the U.S. Coast Guard.

Table 1 gives an assessment of the seven options against the following criteria:

- Information required,
- Complexity,
- Cost of implementation,
- Outside acceptability,
- Quality of results,
- Risk of choosing wrong priorities, and
- Time to get results (i.e., determine R&D priorities).

On the basis of this assessment, the technology matrix approach was selected. Initially, its cost and time of implementation are high because the amount of information required is high, but this was a first attempt at developing a TDG R&D plan and it was believed that the methodology would become more and more useful as the quality of data improved over time. Quality of results was therefore the key criterion in the selection of a methodology.

TECHNOLOGY MATRIX APPROACH--STAGE 1: INFORMATION COLLECTION AND ANALYSIS

In this stage, the information required for the next two stages is collected and analyzed:

- Accident statistics,
- Dangerous goods transportation statistics,
- Trends, and
- In-depth analyses and the like.

TDG is currently developing a dangerous occurrence reporting system. This system of mandatory reports, when in place, will provide key input to Stage 2. However, if the methodology is to be applied it will have to be supplemented by forecasts of future dangerous goods flows.

To fulfill its mandated leadership role in fostering R&D in dangerous goods transport, TDG will need to keep abreast of developments in this field. To communicate effectively with all agencies involved in this expanding field, TDG will require an R&D information retrieval and cataloging capability. Developing and maintaining this capability is also part of Stage 1.

It should be noted that the output of Stage 1 is itself an R&D program. As a result the R&D plan in any given year will be made up of two major sections:

- Section 1: Information plan. A plan to collect and analyze the information that will enhance the application of Stages 2 and 3 of the methodology in the next planning cycle (e.g., next year).
- Section 2: Technology R&D plan. A plan to conduct technical R&D that is developed using the best information available in the current year.

This approach implies that, for any TDG R&D plan, a budgetary decision must be made about the allocation of resources between these two sections. A careful examination of the other R&D planning methodology options reveals that this type of budgetary decision is common to all options. Whatever the method used to determine priorities for technology R&D, some effort must be expended to gather and analyze the information needed to apply the methodology. It is expected that, as time goes on, the relative level of effort expended on Stages 1 and 2 will gradually shift from Stage 1 to Stage 2.

TECHNOLOGY MATRIX--STAGE 2: DEVELOPING PRELIMINARY PRIORITIES

Approach

Ideally, the preliminary priority scores assigned to research areas in the course of Stage 2 of the methodology should be a direct reflection of the social cost forecast to result from deficiencies in particular research areas in the absence of R&D follow-on improvements. Consider, for example, the following research areas:

Commodity	Sulphuric acid
Mode	Truck
Container	Bulk
Operation	Handling
Safety subfunction	Training in spill containment

The priority score to be assigned to this research area should reflect the expected social cost (risk) that can be attributed to insufficient training in dealing with sulphuric acid spilled during handling.

The chances of finding a number of past events that fall exactly in this category and would allow the development of a reliable forecast are extremely low. Even if such events occurred in the past, many went unreported because of a lack of uniform enforcement of reporting requirements in certain modes. Yet, the risk is there.

To compensate for the lack of data, the methodology "borrows" data across commodities. As a result, two steps are carried out:

- Step 1: Develop individual indicators that reflect the risk inherent in each element of the research area, in some cases independently of others.
- Step 2: Perform a chain multiplication of these indicators to obtain a priority score for each research area.

If this approach is followed there is a better chance of having the data base needed to develop the individual research area scores needed for the methodology.

The drawback of this approach is that it implies mutual independence of the elements of the research area. For example, the procedure may yield a given individual score for bulk handling in the road mode. This score will then be applied to all commodities. But, an investigation of individual releases of dangerous goods during bulk handling in the road mode may show that these occur primarily with certain types of commodities (i.e., nonflammable liquids). To what extent that is an issue can only be determined after a complete data base of dangerous occurrences has been established. At this point, the inclusion of Stage 3 in the methodology addresses this issue in part.

Computation

For a definition of the raw priority scores for a combination of the commodity, mode, container, operation, and safety subfunction, let

a_1 = forecast of the transportation activity level of the commodity and container combination by this mode in year t;
a_2 = propensity in year t of this mode to experience dangerous occurrences when the operation is applied to the container;
a_3 = expected social cost of a dangerous occurrence for the mode, operation, and container in year t;
a_4 = hazard index of the commodity (a means of ranking the hazard inherent in a spill of each dangerous commodity); and
a_5 = propensity of the subfunction to contribute to the social cost resulting from a dangerous goods release occurring for the mode, the operation, and the container in year t.

If R&D in a particular year t_o is considered, the relevant year t for the previous definitions is a year when any R&D conducted in year t_o will have a possibility of reducing risk due to dangerous goods transport. The minimal time span for $t-t_o$ is therefore the minimal lead time between R&D and effective implementation. The priority score of a research area is then $a_1 \times a_2 \times a_3 \times a_4 \times a_5$.

PRELIMINARY R&D PRIORITY SCORE FOR A SET OF RESEARCH AREAS

The data sources used to compute the factors a_1 to a_5 listed earlier were a combination of

- Statistics Canada commodity flow data,
- Commodity usage forecasts,
- U.S. data on deaths, injuries, and monetary damage from accidental releases of dangerous goods during transport,
- National Fire Protection Association data on the relative danger of various dangerous goods, and
- An analysis of the TDG data base of accidental releases of dangerous goods (dangerous occurrences).

Each of these data sources contributed to one or more of the factors as discussed hereafter. For brevity, only the derivation of factors (and subsequent R&D priorities) for the rail mode of transportation will be presented. The reader is referred to the report (3) for further details.

a_1: Forecast of Transport Activity Level

There is a significant lead time between the start of an R&D effort and the ultimate implementation of any positive result of this effort. In the case of dangerous goods transport, a 5-year lead time appears reasonable. Thus R&D planned in 1984 and initiated in 1985 would affect TDG in 1990 and later.

To arrive at reasonable forecasts of commodity flows in the period 1990-2000 the recent history of transport activity in Canada for the commodities under investigation was analyzed. Most of the commodities were energy related and Energy Mines and Resources forecasts of Canadian usage of these commodities were used to extrapolate recent history to the forecast period. For nonenergy commodities the commodity flow forecast was linked to real GNP growth to reflect the fact that these materials are basic industrial raw materials.

Table 2 gives estimated rail tonnes and tonne-kilometers for the selected commodities for the year 1981 and forecasts for 1990. The 1990 forecasts are the a_1 factors that would be used in developing the raw priority scores under the technology matrix methodology.

Of interest in Table 2 is the growing importance of propane as a surface cargo in Canada over the next 5 to 10 years.

Tonne-kilometers was selected as the indicator of activity for road and rail transport because risk is, in great part, proportional to quantity moved and exposure duration.

TABLE 2 Commodity Flow Forecasts for Selected Commodities

	Thousand Tonnes by Rail		Million Tonne-Kilometers by Rail	
	1980	1990	1980	1990
Hydrogen (gas)	–	–	–	–
Hydrogen (liquid)	0.033	0.044	0.010	0.013
Natural gas (liquid)	4.1	5.6	0.41	0.56
Propane	1,586	4,310	906	2,462
Gasoline	1,562	1,504	1,057	1,018
Diesel	3,279	3,675	1,665	1,866
Aviation gasoline	–	–	–	–
Aviation turbo	66	77	28	33
Kerosene	1.6	0.7	1.9	0.76
Heavy fuel oil	691	408	468	276
Light fuel oil	538	218	364	148
Petroleum (crude)	198	171	52	45
Methanol	393	528	600	806
Ethanol	–	–	–	–
Sulphuric acid	1,202	1,615	865	1,163
Chlorine	527	709	187	251
Total	10,048	13,221	6,194	8,069

Source: Thorne Stevenson & Kellogg and Hooper & Angus application of EMR forecasts and real GNP growth rates to Statistics Canada commodity transport data.

At this stage there are no transport statistics that relate to specific containers. The best that could be done was to use a rough estimate of what proportion is transported in bulk and what proportion is transported in packages.

a_2: Propensity of Mode, Operation, and Container to Experience Dangerous Occurrences

The propensity of a given mode, operation, and container to experience dangerous occurrences is expressed in relation to the total dangerous good throughput for that mode, operation, and container. The factor a_2 therefore applies to all dangerous commodities and is equal to the number of dangerous occurrences per unit of throughput of all dangerous commodities for that mode, container, and operation.

Note that, when the same throughput unit is used for a_2 and for a_1, there is a cancellation of units in the multiplication operation. As a result the final scores obtained for handling are commensurate with those for transport.

For rail the factor a_2 represents the dangerous occurrence frequency per tonne or tonne-kilometer of dangerous goods related to a given container and operation combination.

Data collected by TDG show that total dangerous goods transport by rail amounts to about 15 million tonnes per year. The commodities selected for this study whose rail volume amounts to 10 million tonnes per year account for two-thirds of the rail volume.

At this stage the split of dangerous goods transported in bulk and in packages is not known. It is estimated that for the selected dangerous goods transport is 100 percent bulk for rail. For other dangerous goods it is assumed that packaged shipments account for 5 percent of rail transport and 10 percent of truck transport.

Yearly dangerous occurrence statistics, split by mode, container type, and operation, were extracted from the TDG data base. Combining these with commodity flow statistics yielded the factor a_2.

Table 3 gives the dangerous occurrence frequency (a_2) for rail for both container types and operations.

TABLE 3 TDG Occurrence Frequency: a_2

	Rail	
	Bulk	Package
Transport, occurrences per billion tonne-km	2.6	35
Storage, occurrences per million tonnes	–	–
Handling, occurrences per million tonnes	0.34	27

Source: TDG, EMR forecasts and Thorne Stevenson & Kellogg and Hooper & Angus estimates.

a_3: Average Social Cost of a Dangerous Occurrence

Social cost is made up of four components:

- Lives lost,
- Injuries sustained,
- Direct material damages, and
- Indirect damages (e.g., evacuation, disruptions).

Deaths and injury statistics were extracted from the TDG Directorate data base (damages data were unavailable). On the basis of these statistics and the analysis of U.S. dangerous goods data, it was possible to develop estimates of social cost for dangerous occurrences in Canada. This estimation is given for rail in Table 4.

Cost estimates were calculated using the principle that the social cost of a dangerous occurrence for bulk shipments is four times that for packaged shipments and that material damages add 40 percent to the social cost of deaths and injuries.

TABLE 4 Average Social Cost of Dangerous Occurrences (1981-1983): a_3

	Rail	
	Transport	Handling
Deaths/year	–	–
Injuries/year	2.3	1
Number of occurrences/year	31	13
Bulk	24	8
Package	7	5
Social cost due to deaths and injuries ($000)		
All occurrences	230	100
Per occurrence		
Bulk	8.9	10.8
Package	2.2	2.7
All	7.4	7.7
Total social cost per occurrence ($000): a_3		
Bulk	12.5	15.1
Package	3.1	3.8
All	10.4	10.8

Source: TDG Directorate and U.S. DOT Materials Transportation Bureau data and Thorne Stevenson & Kellogg and Hooper & Angus staff estimates.

The estimated social cost of dangerous occurrences in Canada given in Table 4 is appreciably higher than are the U.S. estimates. It is believed that this is linked to the apparent underreporting of dangerous occurrences in Canada compared to the United States. Because only the more important releases tend to be reported in Canada, the estimated average social cost per release tends to be higher.

The estimated material damages shown in Table 4 are based on U.S. data that are supposed to include the cost of decontamination (cleanup). How well that cost is estimated by those who fill out U.S. hazardous materials incident reports may be open to question. This reservation obviously extends to the Canadian estimates also.

a_4: Composite Hazard Index

The factors a_2 and a_3 are strictly mode, operation, and container dependent. To indicate the relative potential for damage represented by each dangerous commodity, actual accident data would be required. However, the number of dangerous goods is so large that, except for a few large-volume commodities, the TDG data base yields few observations with respect to specific commodities. Therefore, to reflect the potential danger represented by a given dangerous good, a composite hazard index, which reflects the hazard ratings that can be assigned to this product along various hazard dimensions (e.g., fire, health), was developed.

The approach was to use two consistent National Fire Protection Association (NFPA) codes (Codes 325M and 49), both of which assign values for health, flammability, and reactivity, and add their individual components. A more intricate approach than simple addition could be used. For example, the sum of the squares of the individual components could be used to emphasize any hazard dimension for which a given commodity has been assigned a high value by the NFPA. For example, 3, 2, and 1 would result in a higher hazard index than 2, 2, and 2, but, for the first application of the methodology, simplicity was opted for.

Table 5 gives the derivation of the composite index. These are the a_4's that have been used in applying the methodology. This form of hazard index is applicable to a broad range of commodities and works equally well for liquids, gases, and solids.

TABLE 5 Assignment of Hazard Index: a_4

Commodity	Hazard	NFPA Code 325M	NFPA Code 49	Hazard Index (a_4)
Hydrogen (gas)	Health	0	0	
	Flammability	4	4	4
	Reactivity	0	0	
Hydrogen (liquid)	Health		3	
	Flammability	x	4	7
	Reactivity		0	
Natural gas (gas)	Health	1		
	Flammability	4	x	5
	Reactivity	0		
Natural gas (liquid)	Health		3	
	Flammability	x	4	8
	Reactivity		1	
Propane	Health	1	1	
	Flammability	4	4	5
	Reactivity	0	0	
Gasoline	Health	1	1	
	Flammability	3	3	4
	Reactivity	0	0	
Diesel	Health	0	0	
	Flammability	2	2	2
	Reactivity	0	0	
Aviation gasoline	Health	1		
	Flammability	3	x	4
	Reactivity	0		
Aviation turbo	Health	0		
	Flammability	2	x	2
	Reactivity	0		
Kerosene	Health	0	0	
	Flammability	2	2	2
	Reactivity	0	0	
Heavy fuel oil	Health	0	0	
	Flammability	2	2	2
	Reactivity	0	0	
Light fuel oil	Health	0	0	
	Flammability	2	2	2
	Reactivity	0	0	
Petroleum (crude)	Health	1	1	
	Flammability	3	3	4
	Reactivity	0	0	
Methanol	Health	1	1	
	Flammability	3	3	4
	Reactivity	0	0	
Ethanol	Health	0	0	
	Flammability	3	3	3
	Reactivity	0	0	
Sulphuric acid	Health		3	
	Flammability	x	0	5
	Reactivity		2 (w)	
Chlorine	Health		3	
	Flammability	x	0	5
	Reactivity		0 (oxy)	

Source: NFPA plus Thorne Stevenson & Kellogg and Hooper & Angus methodology.

a_5: Subfunction Contribution to Social Cost of a Dangerous Occurrence

The last factor, a_5, focuses on the subfunctions themselves; it is a weight proportional to the risk associated with technological faults within the individual subfunctions defined earlier.

The method chosen for assigning subfunction weights was one which analyzed dangerous occurrence statistics kept by TDG. This approach provided a clearly defensible, easily updatable basis for assigning weights to individual subfunctions. Weights were assigned using an analysis of accident statistics and identification of occurrences of subfunction faults.

The weights are equal to the frequency of faults in subfunctions that contribute to dangerous occurrences. It is assumed that any positive change within a subfunction brought about either directly or indirectly by R&D programs will result in a decrease in that portion of the social cost of dangerous occurrences attributable to that subfunction.

To establish the subfunction weights used in the methodology an extensive examination of TDG dangerous goods occurrence reports for the years 1981-1983 was undertaken. The last complete year of data available (1983) was chosen as the basis for the assignment of the weighting factors. Most of the reports investigated provided good descriptions of the dangerous occurrences and allowed for a reasonable evaluation of the subfunctions at fault in the release of hazardous goods. Reports from before 1983 were found to be less specific in their description of the event: most of the 1981 reports provide little more than basic information about whether or not the spill was due to a "traffic" accident.

In all, 125 dangerous occurrence reports for 1983 were analyzed for road and rail (these were augmented by 25 rail occurrence reports from 1982 to overcome a deficiency in the data), and faults were identified in all subfunctions: prevention, avoidance, control, and cleanup. The frequency of these faults was found to range from a high of 136 for "containment prior" in the control function to a single identifiable fault for "transport" in the cleanup function.

These statistics were divided among the five modes considered in this investigation: rail, road, air, marine, and warehousing, and further subdivided into occurrences during transport, storage, or handling. These results for transport by rail are given in Table 6. The weighting factors are equal to the number of faults for a given safety subfunction divided by the total number of occurrences within that category (e.g., in rail bulk transport with 23 occurrences, subfunction 1.2, "vehicle design," was identified as potentially at fault five times; thus the weighting factor for this subfunction is 5/23 = 0.22).

Monitoring is not given in Table 6 because the dangerous occurrence reports in the Directorate's files focus strictly on the release and its immediate aftermath, not long-term site monitoring following cleanup. Long-term monitoring is the responsibility of Environment Canada.

The result of the chain multiplication of a_1 through a_5 is a_6, the raw score for each cell of the technology matrix.

Because of similarities in chemical properties, many standards and procedures cut across commodities. Consequently, a research project pertaining to one commodity will often yield results applicable to another commodity. Therefore raw R&D priority scores were developed for research areas that group commodities together. This was achieved through a subfunction commonality matrix that takes into account similarities in codes and procedures.

The combined a_6 score for research areas covering a group of commodities is simply the addition of the individual a_6's for the research areas and the commodities that make up this group.

The top priority R&D areas for the rail mode are

- Enhancement of Class 111, 105, and 112 rail cars to achieve "minimal release" (i.e., as close to zero release as possible) under accident conditions;

TABLE 6 Technology Matrix–Bulk Rail

Function	Transport Subfunction	a_5	Handling Subfunction	a_5
Prevention	1.1 Right-of-way design	0.260	1.1 Right-of-way	–
	1.2 Vehicle design	0.220	1.2 Vehicle design	–
	1.3 Speed/scheduling/routing	0.170	1.3 Speed/scheduling/routing	–
	1.4 Vehicle storage/sorting	–	1.4 Vehicle storage/sorting	–
	1.5 Communications	0.040	1.5 Communications	–
	1.6 Filling systems	0.040	1.6 Filling systems	–
	1.7 Maintenance/inspection	0.350	1.7 Maintenance/inspection	–
	1.8 Training	0.220	1.8 Training	1.000[a]
	1.9 Commodity identification	0.040	1.9 Commodity identification	–
	1.10 Commodity storage	0.260	1.10 Commodity storage	–
Avoidance	2.1 System and component	0.390	2.1 System and component	1.000[a]
	2.2 Training	0.260	2.2 Training	–
Control	3.1 Containment (prior)	0.960	3.1 Containment (prior)	1.000[a]
	3.2 Site command/analysis	0.040	3.2 Site command/analysis	–
	3.3 Personnel equipment	–	3.3 Personnel equipment	–
	3.4 Commodity detection	0.090	3.4 Commodity detection	–
	3.5 Commodity identification	0.040	3.5 Commodity identification	–
	3.6 Site stabilization	0.130	3.6 Site stabilization	–
	3.7 Firefighting	0.040	3.7 Firefighting	–
	3.8 Containment (following)	0.090	3.8 Containment (following)	–
	3.9 Neutralizing	–	3.9 Neutralizing	–
Cleanup	4.1 Containment	–	4.1 Containment	–
	4.2 Neutralization	–	4.2 Neutralization	–
	4.3 Collection	–	4.3 Collection	–
	4.4 Transport	–	4.4 Transport	–
	4.5 Disposal	–	4.5 Disposal	–

[a]Fewer than five occurrences available for these areas.

Source: Thorne Stevenson & Kellogg and Hooper & Angus analysis of TDG dangerous occurrence reports.

• Development of systems and components for accident avoidance when an accident situation has arisen;
• Enhancement of current procedures for maintenance and inspection of rolling stock, tracks, and associated systems; and
• Enhancement of training of rail personnel in accident avoidance and dangerous goods awareness.

These are the research areas that were presented to the expert panels in Stage 3.

The corresponding top R&D areas for dangerous goods transport by road and for warehousing and storage were also developed. The reader is again referred to the report (3).

DEVELOPING THE TDG R&D PROGRAM

Following the development of the raw priority scores and the identification of the top priority research areas, the next step in the methodology was to ask experts to express opinions in response to the following questions:

• What research projects would logically fit into these research areas?
• What useful knowledge is likely to be gained from conducting research in these areas?
• Are there other research areas or projects that are worth pursuing?

Individuals knowledgeable in all aspects of safety in the transport and storage of dangerous goods were identified and requested to participate in the survey. Their joint responses show:

• General approval of the technology matrix approach;
• Concern regarding the availability and quality of statistical data used to identify research areas with recommendations that the data base be developed further;
• A view that research relating to bulk container design for the selected commodities is well under way, primarily in the United States; and
• An overall recommendation that TDG place its R&D emphasis on (a) dangerous goods training, (b) maintenance and inspection procedures, (c) regulations, and (d) enforcement.

Results of Expert Panel Survey

The respondents recommended that TDG should place its R&D emphasis on areas that are related to enhanced dangerous goods training, maintenance and inspection procedures, regulations, and enforcement. This trend toward "soft" not hardware-oriented R&D was clear from an analysis of the total number of points allocated by the panel members to the individual project areas.

For the road mode only 25 percent of the allocated points were for the project areas dealing with tank and truck design consideration. Nearly 50 percent of the points were for areas relating to enhancement of personnel training and regulations. The remaining projects, suggested by the panel members themselves, dealt exclusively with "soft" research and accounted for the remaining 28 percent. Thus, for road, nearly 75 percent of the points allocated by the panel was directed toward regulatory- and personnel-oriented R&D.

For rail the split was not as distinct: 43 percent of the points were allocated to hardware and design projects, although the comments indicated that this area would best be left to established experts such as the Association of American Railroads. The remaining points were assigned to training and maintenance and inspection-oriented research projects.

Development of Specific R&D Projects

The next step in the development of an R&D plan for TDG involved investigating each mode and research area individually. By combining the various respondents' project recommendations and suggestions, certain prominent project ideas were further developed into distinct research programs for TDG.

Only those areas that were given high ranking by the panelists were developed into detailed programs. The programs presented reflect the combined project recommendations of all the panel members who responded to the questionnaire.

All the projects chosen address areas of specific Canadian interest and have a medium to high chance of success. It must also be made clear that the programs follow TDG's definition of R&D, specifically:

- Gathering and analyzing information,
- Investigating problems, and
- Designing and testing solutions to problems.

Timing estimates reflect categorization of projects as research, design, or development and are related to long-, medium-, or short-term time requirements for field implementation of results.

Examples of the R&D programs developed from the panel responses, for the rail mode, are given in the following section.

Rail Research Project

This project was to address six areas. The first two areas were (a) enhance Class 111 tank cars to achieve minimal release of contents under a variety of conditions and (b) enhance Class 105 tank cars to achieve minimal release of contents under a variety of conditions.

These two research areas were grouped together because the comments and the projects recommended for these areas were essentially the same. It was generally thought that any work done in the area of tank car design should be left in the hands of the experts, specifically the Association of American Railroads (AAR). The Railway Progress Institute/AAR Railroad Tank Car Safety Research and Test Project has been investigating all facets of tank car design for 15 years.

This project was responsible for developing many of the recently adopted design modifications to improve tank car design. These recommendations include

- Double shelf couplers,
- Head shields,
- Thermal protection, and
- Skids for bottom discontinuities.

Because of the AAR's wealth of background and experience, it was believed that little should be undertaken without at least some association with the AAR.

The third area the rail research project was to address was the development of systems and components to "exit" from accident situations. This research area was not particularly well understood, as some of the project suggestions would indicate. The proposed projects included

- Study devices for checking alertness of crew,
- Investigate how rail cars behave during a derailment,
- Investigate the state of the art in accident avoidance, and
- Develop technology to permit emergency brake application from both ends of a train.

There was no agreement among the panelists about the type of research to be undertaken. Consequently, no research program was established for this area.

The fourth area addressed by the rail research project was the enhancement of current maintenance and inspection procedures. A number of research projects were suggested for this area:

- Relate accident likelihood to track and equipment failure, then improve inspection and maintenance strategies;
- Develop inspection procedures to detect failure of roller bearings; and
- Upgrade track and roadbed standards to provide safer right-of-way.

Most of the suggestions dealt with development or improvement of maintenance and inspection procedures for track and rail equipment.

Track and roadbed concerns are common to all rail transportation operations and are not specifically related to dangerous goods transport. Because many agencies are involved in track and roadbed research, it was thought that TDG should concentrate on investigating maintenance and inspection procedures for rail equipment specific to dangerous goods transport. The proposed research program is shown in Figure 3.

The first step in the program is to identify the currently practiced maintenance and inspection procedures that are designed to signal or prevent certain recognized types of rail tank car or equipment failures. An example would be to identify the many different methods currently used for hot box detection.

Another task will be to investigate all accidents involving dangerous goods tank cars in an attempt to identify the specific car or equipment failure or failures that played a part in the accident.

The third phase of the program would estimate both the cost of enhanced maintenance and inspection procedures and their potential for reducing the likelihood or severity of accidents. In this manner the effectiveness of specific maintenance and inspection practices can be established. From these results, a series of recommendations for new or improved maintenance and inspection procedures can be created by TDG for use by the industry.

To develop the recommendations, including the investigation of tank car accidents and modeling the effect of various procedures on accident severity, would require about 2 person-years.

The fifth area addressed by the rail research project was the enhancement of training of rail personnel in accident avoidance and dangerous goods awareness. This was the highest ranked rail research area. Several respondents suggested that this should be a priority research area for Transport Canada. The research projects proposed included

- Develop a certification process and organize training procedures,
- Effect regulations training, and
- License personnel involved with dangerous goods after completion of a training program.

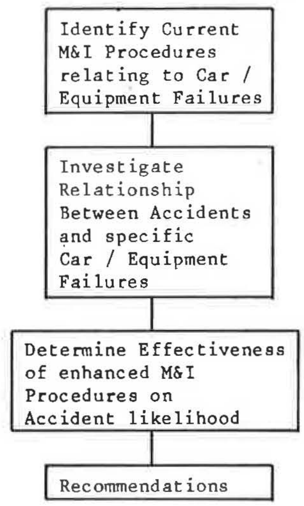
It was evident from the suggestions that not just training but certification and licensing as well were of concern to the panelists. A detailed description of the proposed program may be found in the report (3).

The sixth area addressed by the rail research project consisted of R&D suggestions from panel members. Restricting dangerous goods trains to specific routes, equipment, and personnel was the most popular independent research area suggested by the expert panelists. Two projects proposed for this area were

BACKGROUND: In many cases the knowledge of what would be proper Maintenance and inspection procedures exists.

Problem is to accelerate upgrading and cover costs.

R&D PLAN:



TIMING: Medium term

FIGURE 3 Fourth rail research area—enhance current maintenance and inspection procedures.

- Study the feasibility of running dangerous goods trains using only special equipment, routes, and personnel and
- Investigate handling dangerous goods cars in trains with improved instrumentation, highly trained crews, and so forth.

The first stage of the suggested research program is to identify what conditions should be controlled, and in what manner, in order to create a "special" dangerous goods train. Parameters such as train route, equipment, number and qualifications of operating personnel, availability of emergency response teams, and so forth should be considered. For each of the parameters identified, the feasibility of imposing the condition must be considered. Not just economic feasibility but the actual physical reality of each situation must be considered. For instance, it may not be possible to wait for a trainload of a given commodity to be produced at Point A before it is shipped to Point B.

When a set of parameters has been identified, the effectiveness of the individual (or combined) operating conditions can be established. A cost-benefit analysis will identify those operating conditions that reduce the risk of dangerous goods rail transport for a comparatively low increment in operating costs. Recommendations regarding the potential for enhanced safety of using improved operating conditions and the makeup of such "special trains" can be produced for future use as determined by Transport Canada.

CONCLUSIONS AND RECOMMENDATIONS

The R&D program developed for TDG is made up of two sections: technical programs and information collection and analysis. The technical programs were developed with the application of technology matrix methodology (Stage 2) as outlined in the previous sections.

Of equal or greater importance, at the present time, is the future application of the methodology to provide R&D programs for other commodities. When the methodology is applied again, it is hoped that the information available will have been enhanced both in quality and quantity. Part of the R&D plan therefore consists of a plan to upgrade the TDG information base. This is what is called Stage 1 of the methodology.

Enhancement of information gathering techniques was recommended in each of the following areas:

- Commodity flow statistics,
- Commodity flow forecasts,
- Dangerous occurrence statistics, and
- Information and methodology to support development of an improved dangerous goods hazard index.

For each of these areas a plan was developed to obtain the additional information required. In developing the plan all information gathering activities were evaluated from four viewpoints:

- What is the earliest possible date that the information sought can be available?
- What will be the estimated cost of the information gathering activity?
- What probability of success does the activity have (i.e., how likely is it that useful data will be obtained)?
- To what extent will the information generated by the project enhance the quality or quantity of the information currently available?

On the basis of these four factors, the priority of the information being sought was estimated. Also, an approximate cost was assigned to each activity. Using this information, the TDG Directorate will be able to allocate their information gathering budget over the coming year.

The combination of the technical research programs with the information gathering and analysis programs provided TDG with a comprehensive R&D plan. It is believed that successful completion of these recommended research programs, as well as periodic development of new R&D priorities and their associated programs, will establish TDG as a leader in dangerous goods transport R&D.

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