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INFORMATION SUPPORT FOR CONTROL OF HAZARDOUS MATERIALS MOVEMENT

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Summary

The development of a prototype hazardous materials movement information system is discussed. Especially noted are the problems encountered in developing data capture and sampling procedures. Recommendations for sampling, inference and modeling as well as for data and policy analysis are provided.

Introduction

It has been estimated that hazardous materials constitute at least ten percent of the total volume of all materials transported in the U.S.A. [1]. In addition, the National Transportation Safety Board has estimated that there are at least 18000 different hazardous materials [2]. These figures provide some measure of the potential dangers that exist with respect to the transportation of hazardous materials. The combination of the high percentage and large variety poses many problems. Awareness is growing at all levels of government that effective plans must be made to manage emergencies that could arise when hazardous materials are involved in accidents, fires, spills or other mishaps en route.

Emergency management comprises mitigation, preparedness, response, and recovery, with these terms used in a special way. Mitigation is the prevention or alleviation of a possible disaster before it occurs. Preparedness includes planning, warning systems and inventories of resources. Response covers the immediate actions after a hazardous material accident, actions such as fire fighting, evacuation, rescue, and removal of debris and spilled material. The fourth component, recovery, returns the scene of the accident

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to the conditions that existed previously (see Burton, Kates and White [3]).

Emergency management responsibility falls on both the executive and legislative branches of government. Legislatures can pass laws to regulate routes and times of hazardous material movements, mitigating the danger to population centers, bridges, tunnels and other vital facilities. Executive actions include development of plans and procedures to help emergency managers perform the tasks of response and recovery. Both branches can assign responsibility and authority for responses, an area of confusion at present (see Quarantelli, p. 243 [4]).

Development of regulations, plans and procedures requires some knowledge of the materials, quantities and routes of hazardous material movements. This need has been recognized by state highway officials. The AASHTO subcommittee on highway transportation conducted a survey of fifty states, the District of Columbia, and Puerto Rico. The results illustrate the importance of such information. The critical problem most often cited was that of "unknown materials", followed closely by "no control over routes" [5]. In fact it has become clear that information is the central issue in dealing with risks of hazardous materials movement. We have very little of the relevant kinds of information. A high research priority should be to seek empirical information on actual flows. Three crucial methodological questions here are what data to gather, what kinds of sampling strategies can gather the data most efficiently, and how to analyze the data to reach meaningful conclusions.

In order to provide information for purposes of developing legislation and procedures to address the problems brought about by the transportation of hazardous materials, the State University of New York at Albany's Center for Disaster Management (CDM) participated, along with the New York State Department of Transportation (NYSDOT), in the development of a system that was to collect and analyze data on hazardous material movements on highways in New York State. The long term goal is to provide New York State with a means of measuring compliance with existing regulations, estimating the kinds and amounts of hazardous materials, determining the routes used, and identifying persistent violators of existing regulations. The objects of this paper are (i) to describe a pilot project on collection and analysis of data that has been conducted in the Albany New York area; and (ii) to discuss some general conclusions on sampling and modeling suggested by this preliminary work. These conclusions have implications on future efforts to obtain information on hazardous materials movements in many parts of the country.

Experience with a prototype system

A prototyping strategy was employed to obtain information about hazardous material movement. Only the general purposes of the system could be stated at the outset and there was little previous work to build upon.

TB-29 7-83 HAZARDOUS MATERIALS MOVEMENT SURVEY — INSTRUCTIONS SEE REVERSE SIDE — PAGE ___ OF ___ PAGES

TROOP 2	SURVEY NO. 3–6	DATE 7–12	CTY CODE 13–17	TRAVEL DIRECTION 18 N S E W	CIRCLE TYPE 19 S C T I	ROUTE NUMBER 20–23	
START TIME 24–29	STOP TIME 30–35	NO TRUCKS 36–39	NO. INT 40–43	NO. HAZMAT 44–47			
MEMBERS WORKING							

	TIME	CARRIER	(V) INTER-VIEW	(V) TB-30		TIME	CARRIER	(V) INTER-VIEW	(V) TB-30
1					26				
2					27				
3					28				
4					29				
5					30				
6					31				
7					32				
8					33				
9					34				
10					35				
11					36				
12					37				
13					38				
14					39				
15					40				
16					41				
17					42				
18					43				
19					44				
20					45				
21					46				
22					47				
23					48				
24					49				
25					50				
		TOTAL					TOTAL		

Fig. 1a. Form TB-29, Hazardous Materials Movement Survey (front).

TB-29B 7/83

INSTRUCTIONS:

Member In-Charge Of Detail:

(a) Print heading; remainder of Form may be handwritten.

(b) Complete ONLY the following on the heading of the form:

(1) Troop;

(2) Date;

(3) C/T/V (Division Location Code);

(4) Direction of Travel;

(5) Route - Circle type (I - Interstate, S - State, C - County, T - Town) and enter route numbers;

(6) Time Survey started; AND

(7) Time Survey ended.

(c) For MEMBERS WORKING, enter the names of the Members assigned to the checkpoint.

(d) For ALL trucks entering the checkpoint, record the TIME the vehicle was checked and the CARRIER NAME.

(1) IF a Detail Member suspects that hazardous materials are being transported, insure that the driver is interviewed. Indicate that an interview was conducted by placing a check mark in the column titled: INTERVIEW.

(2) IF the truck is carrying hazardous materials or is displaying a hazardous materials warning placard, place a check mark in the column titled: TB-30 and insure that a TB-30--Hazardous Material Vehicle Data Sheet is completed.

(e) Prepare and submit this Form with associated TB-30--Hazardous Material Vehicle Data Sheets to your Troop Traffic Supervisor.

Troop Traffic Supervisor:

(a) Review the submitted Forms for completeness.

(b) Each week, consolidate and submit all Forms with attached TB-30--Hazardous Material Vehicle Data Sheet to the Major--Traffic at Division Headquarters.

Major--Traffic: Consolidate the Forms and send them to the NYS Department of Transportation.

Fig. 1b. Form TB-29, Hazardous Materials Movement Survey (reverse).

Relevant data were identified first, and then procedures were developed to collect these data. Changes in both collecting and reporting were made as experience was gained.

Another state had estimated hazardous material volume on its principal highways (see Schmidt and Price [6]); this, along with a fairly comprehensive list of hazardous materials prepared by the Federal Department of Transportation [7], provided a starting point.

We were permitted to use State Police truck weighing teams for data collection. Observation of a state police truck weighing operation made it clear that all trucks could not be surveyed for hazardous materials concurrently with the weighing. While hazardous materials were being surveyed, no trucks were weighed.

Several trial survey forms were prepared, discussed, and, in one case, field tested. The final forms are the ones shown in Figs. 1 and 2. The first (Fig. 1), the Hazardous Materials Movement Survey (N.Y. State Police Form TB-29) is a log of all trucks observed at a checkpoint during the period of a hazardous materials survey. It is similar to a form used to log all trucks going through a checkpoint while weighing is being done. Because the form shows all trucks and the time for the survey, estimates can be made of total truck traffic and of the proportion of trucks that carry hazardous materials.

The second form, the Hazardous Materials Vehicle Data Sheet (N.Y. State Police Form TB-30) gives detailed information on each truck carrying hazardous materials and each truck displaying hazardous materials placards. The instructions for completing the form are printed on the back, and reproduced opposite the form as shown in Fig. 2. Driver information is collected for research on the records of drivers responsible for transportation of hazardous materials and is not used in the analyses reported here.

Zip codes for origins and destinations were also requested. However, drivers often do not know the zip codes and shipping papers do not generally show them. It is customary to use city, town, or village (C/T/V) for police reports, as other destinations are not readily obtainable in the field. Reporting and analysis, however, require locations to be identified in an unequivocal way that relates to geographical data on people and industries, and to traffic flow data. The staff of the Disaster Management Center decided to identify locations by the 633 zones of the New York State Department of Transportation arterial network. Recording C/T/V is adequate to identify the zone, but not anything more precise. An input program was developed to edit and store the information collected on the TB-30 form.

The system provides three flexible reports as well as a summary report. These reports can be restricted to any range of dates, or to a specific survey location. Flexibility is provided by allowing the user to select locations or time periods for each analysis. The first report focuses on what hazardous materials are observed, the second shows the sources of these materials, and the third shows the violations of hazardous material regulations that were discovered during the survey. The following paragraphs describe in greater detail each of the three flexible reports as well as the summary report.

TB-30 6/82 HAZARDOUS MATERIAL VEHICLE DATA SHEET

DATE	TIME : ☐ A.M. ☐ P.M.	ROUTE	☐ NORTHBOUND ☐ SOUTHBOUND ☐ EASTBOUND ☐ WESTBOUND	C/T/V	COUNTY

VEHICLE INFORMATION

CARRIER'S NAME		REAR LICENSE PLATE	STATE	VEHICLE CODE
PRINCIPAL CARGO ID NO. OR NAME	PLACARD		GALLONS OR POUNDS	
LOCATION OF LAST HAZMAT ONLOAD (C/T/V)		STATE	ENTRY ROUTE NO.	
LOCATION OF NEXT HAZMAT UNLOAD (C/T/V)		STATE	EXIT ROUTE NO.	

DRIVER INFO.

LAST NAME	FIRST NAME	M.I.	DOB	STATE OF LICENSE
UTT NUMBER	HAZMAT VIOLATION			

REMARKS:

MEMBER'S NAME	SHIELD	TROOP	STATION

INSTRUCTIONS:

(a) IF a vehicle is carrying hazardous material (hazmat) at a hazardous material checkpoint, complete this Form (original only).

(b) Print all entries.

(c) For REAR LICENSE PLATE, enter the rearmost plate of the vehicle.

(d) For VEHICLE CODE, enter the MV104A (Police Accident Report) code that corresponds to the vehicle.

(e) For PRINCIPAL CARGO ID NO. OR NAME, enter the cargo as listed in the Hazardous Material Emergency Response Guidebook.

(f) For PLACARD, enter the ID Number from the placard or panel OR the wording on the placard.

(g) For GALLONS OR POUNDS, enter the number of gallons or pounds carried as obtained from the vehicle's shipping papers.

(h) For LOCATION OF LAST HAZMAT ONLOAD, enter the city, town or village and state where the last hazardous material was loaded.

(i) For ENTRY ROUTE NO., enter the route used by the vehicle to enter the state (if applicable).

(j) For LOCATION OF NEXT HAZMAT UNLOAD, enter the city, town or village and state where the next unloading of hazardous material will occur.

(k) For EXIT ROUTE NO., enter the route to be used by the vehicle to leave the state (if applicable).

(l) IF an arrest is made for a Hazmat violation, complete the boxes titled: UTT NUMBER and HAZMAT VIOLATION. If no arrest is made, enter NONE in the box titled: HAZMAT VIOLATION.

(m) Submit completed forms to the Member In-Charge of the checkpoint detail.

Member In-Charge of Detail: Submit completed Forms with the associated TB-29--Hazardous Materials Movement Survey to the Troop Traffic Supervisor.

Fig. 2. Form TB-30, Hazardous Materials Vehicle Data Sheet. Opposite page: front; this page: reverse.

Types and amounts

A sample of the first report, "Types and Amounts of Hazardous Materials", is shown in Fig. 3. Unidentified cargoes, because they have been recorded with zero instead of a placard number, top the list, which is sorted by placard number. These are few, and this exhibit reflects initial pilot testing. The second type of cargo is for cargo number 2, or class B explosives; other cargoes are listed with the standard placard numbers.

Commonly used final products, rather than chemicals for industrial use, account for most of the hazardous materials observed. Hazardous materials may also be classified by the degree of hazard. The emergency response guidebook [7] lists approximately 2500 distinct hazardous materials. Of

NYS HAZARDOUS MATERIALS REPORTING SYSTEM

TYPES AND AMOUNTS OF HAZARDOUS MATERIALS
PASSING THROUGH: ALL POINTS
FROM: 70882 TO: 101282

CARGO	LOADS	PCT OF LOADS	QUANTITY
0	3	1.94	8000 P
2	1	.65	41823 P
1001	1	.65	0 G
1008	1	.65	3888 P
1017	1	.65	45000 P
1058	1	.65	30000 P
1072	2	1.29	5800 P
1075	6	3.87	36357 G
1139	1	.65	1650 P
1203	87	58.13	475366 G
1223	1	.65	7801 G
1263	3	1.94	46330 G
1759	1	.65	0 P
1824	1	.65	3200 G
1830	2	1.29	0 G
1980	1	.65	0 G
1995	35	22.58	144262 G
2078	1	.65	4600 G
2187	1	.65	60 P
2468	1	.65	22000 P
2501	1	.65	31842 P
2794	2	1.29	35040 P
9125	1	.65	49000 P

Fig. 3. Types and amounts report.

these, only 35 (approximately 1.5%) require evacuation of people in the event of a spill. Only one load of those shown in Fig. 3 requires evacuation. The material identified by placard number 1017 is chlorine, and a large leak calls for evacuation downwind of an area of 1.3 by 2 miles.

Origins and destinations

The second principal report, "Origins and Destinations of Hazardous Materials", is illustrated by Fig. 4. Each unique pair of origins and destinations for each material is shown, along with the number of loads. The order of listing is by code number of origin and code number of destination.

NYS HAZARDOUS MATERIALS REPORTING SYSTEM

ORIGINS AND DESTINATIONS OF HAZARDOUS MATERIALS PAGE 1
PASSING THROUGH: ALL POINTS
FROM: 70882 TO: 101282

ORIGIN	DESTINATION	CARGO	LOADS
UNKNOWN	ROTTERDAM	0	1
EAST GREENBUSH	ALBANY	0	1
PLATTSBURG	RIFLEY	2	1
COHOES	SARATOGA SPRINGS	1006	1
RENSSELAER	BINGHAMTON	1017	1
COHOES	PLATTSBURG	1058	1
ALBANY	HUDSON FALLS	1072	1
BREWSTER	SARATOGA SPRINGS	1072	1
RAVENA	WHITEHALL	1075	1
ALBANY	DUNKIRK	1075	1
CASTLETON	COHOES	1075	1
CASTLETON	WHITEHALL	1075	1
ALBANY	CHAMPLAIN	1139	1
UNKNOWN	**UNKNOWN**	1203	1
ALBANY	**UNKNOWN**	1203	3
ALBANY	ALBANY	1203	3
ALBANY	LAKE PLACID	1203	1
ALBANY	CLIFTON PARK	1203	1
ALBANY	BALLSTON SPA	1203	2
ALBANY	GLENS FALLS	1203	2
ALBANY	LAKE GEORGE	1203	1
ALBANY	HUDSON FALLS	1203	1
ALBANY	WHITEHALL	1203	5
ALBANY	PLATTSBURG	1203	1
ALBANY	ONEONTA	1203	1

Fig. 4. Origins and destinations report.

This is not alphabetical, but it groups nearby locations. Empty truck movements are not included in this report. This report supports both conventional origin and destination studies and counts of loads at each source. The report could be modified to support counts of loads to each destination by making the destination sort primary and the origin sort secondary.

The final products (Nos. 1203 and 1993 particularly) show dispersion to many destinations from few shipping points. The industrial goods are too few in variety or number of shipments to draw even tentative conclusions.

List of violators

The third principal report is illustrated in Fig. 5. It is a straightforward chronological listing of violations cited by the State Police while conducting hazardous materials surveys. The numbers are too small for any statistical analyses.

NYS HAZARDOUS MATERIALS REPORTING SYSTEM

LIST OF VIOLATORS
PASSING THROUGH: ALL POINTS
FROM: 70882 TO: 101282

DATE	CARRIER	CARGO	VIOLATION
73082	AD MCGRAW	1203	3 EQUIPMENT
73082	AD MCGRAW	1203	3 EQUIPMENT
73082	BOUNDARY	1203	1 PLACARDS
91382	MARYLANDHW	2076	1, 2, AND 3
91382	TRANSPORT	1203	3 EQUIPMENT
91382	TOPVALLEY	1993	3 EQUIPMENT
92482	ADIRONDACK	1203	3 EQUIPMENT
92882	J.P. SKIN	1203	3 EQUIPMENT
92882	SMITH EXP	1203	2 AND 3
92882	BILL ALLEN	1203	2 AND 3
92882	HOTLINE JK	1203	3 EQUIPMENT
92882	QUEEN BEE	1203	2 PAPERS
100482	SO. CAROL.	2501	2 PAPERS

Fig. 5. List of violators report.

Summary report

In addition to the principal reports described above, a summary report is provided, as illustrated in Fig. 6. This report shows numbers and proportions for the trucks analyzed in the principal reports. The high proportion of final products, as discussed above, accounts in part for the small

NYS HAZARDOUS MATERIALS REPORTING SYSTEM

SUMMARY REPORT

LOCATION OF CHECK POINT:	ALL POINTS
TOTAL NUMBER OF SURVEY DATES SUMMARIZED:	14
BEGINNING DATE:	70882
ENDING DATE:	101282
NUMBER OF TRUCKS THROUGH CHECK POINT:	1279
NUMBER OF TRUCKS TRANSPORTING HAZARDOUS MATERIALS:	155
PROPORTION OF TRUCKS TRANSPORTING HAZARDOUS MATERIALS:	.121
PROPORTION WITH IMPROPER PLACARDS:	.013
PROPORTION WITH IMPROPER SHIPPING PAPERS:	.032
PROPORTION WITH EQUIPMENT VIOLATIONS:	.065
PROPORTION WITH NONE OF THE ABOVE VIOLATIONS:	.916
NUMBER OF UNIQUE HAZARDOUS MATERIALS:	23
NUMBER OF UNIQUE ORIGINS:	20
NUMBER OF UNIQUE DESTINATIONS:	42

Fig. 6. Summary report.

number of unique materials and the fact that there are fewer sources than destinations.

Summarization for policy analysis is difficult because of the wide diversity in the nature, usage, and danger of the many hazardous materials. The first two reports give aggregate results for each type of material. From these reports, it is clear that commonly used final products account for most of the hazardous material observed. Of the total of 308 trucks observed with hazardous materials, final products accounted for 239 loads as follows:

Identification number	Product	No. of loads	
1075	LP gas	25	
1203	gasoline, motor fuel	126	
1223	kerosene	1	
1263	paints	8	
1993	asphalt, tar, fuel oil	71	
1999	tar, liquid	3	
2794	batteries	5	Total: 239

These 239 loads of final products accounted for 78% of all hazardous material loads observed in the surveys. They are largely consumer products delivered to either individual users or scattered retail outlets. Analysis of local economic data, rather than extensive highway interviewing, would keep regulatory officials aware of the amounts transported and routes used. This would reduce the demand on state police time by almost 80% and allow more intensive study of the remaining materials.

All 69 of the remaining loads were either waste materials for disposal or appeared usable only as inputs to manufacturing processes. Inputs to chemical manufacturing processes are generally needed on a regular basis. Chemical manufacturing facilities typically use special purpose equipment; the same chemicals are used and produced whenever the equipment is running. Subsequent sections contain recommendations to make the sampling efficient with respect to both estimation on the population and discovery of rare but important shipments.

Recommendations on sampling

The pilot surveys performed in the summer of 1982 were confined to the Albany area. This is a particularly appropriate location for a single site experiment. Albany is at the center of a metropolitan area containing two other medium sized cities. The total area population in 1980 was 795,000. The Capital district is a route center for through and terminating traffic from across the state. It contains major manufacturing, port and oil storage facilities. The location and timing of checkpoints were dictated mainly by time and manpower constraints on the State Police, and by the limited number of sites at which large numbers of trucks could be safely stopped. Yet it is well known in the traffic research literature that traffic flows are highly variable in time: by season, day of the week and by hour. They also vary in space: across urban, rural and suburban routes. Moreover there are complex, lagged statistical dependencies between flows on nearby and distant links. The sampling problem posed by the hazardous materials project is distinguished by its complexity, and by the binding constraints imposed on police activity.

Clearly the requirements of statistical efficiency and of the State Police will sometimes conflict. For example, it is statistically never desirable to enumerate flows totally at any time or place if comparable effort could obtain information on the sizeable fraction of all flows at many diverse times and places. Yet total enumeration at particular times and places is legally necessary when information gathering is combined with enforcement. Total enumeration was the procedure adopted in the pilot study. These considerations suggest that it is crucial to optimize the sampling strategy in space and time, subject to operational and legal constraints.

The traffic research literature contains much information on space—time properties of flow (see Breiman [8]); on optimum design of traffic censuses, including location of N checkpoints in a random N-point census (see Tanner and Scott [9]); and tools for extrapolating counts from short and arbitrary periods to annual flow estimates [10]. These well known tools must be brought to bear in optimizing the value of the hazardous materials data.

There have been few studies on flows of hazardous materials as such. Schmidt and Price [6] describe a sample of hazardous movements in Virginia. Their questionnaire was quite similar to that used in the New York pilot study, although compliance was voluntary for their respondents. While the Schmidt and Price study indicates the feasibility of a hazardous materials survey, its sampling and inference methodology was rather limited. First, no information was provided on optimization of the thirty-eight sample points with respect to flow density in space and time. Second, it appears that the confidence bounds on true annual flow proportions used were constructed around observed proportions without taking into account seasonal and day-of-the-week variation in flows. Both these shortcomings can be remedied: the first by careful location and timing of checkpoints, and the second by applying statistical theory to condition confidence bounds on flow volumes or proportions with prior information on seasonal fluctuations.

Distinct sources of variability in hazardous materials flows need to be studied carefully. Small scale (daily) time variation in truck movements are illustrated in Table 1 at one of the State Police checkpoints and at one other location. These examples reveal substantial variability in trucks as a fraction of all flows in a given hour and in the fraction of daily truck traffic which occurs in any hour. Optimum timing of surveys clearly requires information of this type. The current truck weight program in New York State provides very detailed hour by hour information on various types of trucks (e.g., by number of axles) and a limited set of nineteen locations. This information will be valuable in estimating daily time variation in truck movements.

In any effort to develop an optimum statewide sampling program for hazardous materials, spacing (location) of checkpoints is probably more important than any consideration of timing. Statistical efficiency dictates choice of locations where hazardous flows are most dense. Without prior knowledge of such locations the best strategy may be to choose points where total vehicular flow is high. The annual traffic reports (NYSDOT, Planning Division) provide very useful guidelines here, giving average annual daily traffic (AADT) at a very large number of locations on state highways. For example, in the Capital District 1981 AADT, counts are given at 19 points on I-87 in Albany County. Certainly many hazardous materials move on non-state highways, and total vehicular movement may not always be a good guide to truck traffic or to hazardous materials flows. But spatial coverage of the AADT flow reports is excellent, and in the absence of other information they provide the best starting point for planning any large scale survey of hazardous materials. Other states have comparable flow reporting systems.

TABLE 1

(a) Examples of time variability in truck movement: northbound traffic on 1–87 between Exit 9 and Exit 10, July 20—21

I = hour, II = proportion of daily truck total which passed in the hour, III = trucks as proportion of all vehicles passing in the hour

I	II	III	I	II	III
9	0.06	0.27	21	0.03	0.19
10	0.04	0.20	22	0.04	0.18
11	0.05	0.21	23	0.03	0.19
12	0.05	0.22	00	0.04	0.26
13	0.05	0.21	01	0.01	0.47
14	0.06	0.22	02	0.01	0.41
15	0.06	0.20	03	0.01	0.41
16	0.06	0.14	04	0.01	0.42
17	0.07	0.14	05	0.02	0.50
18	0.06	0.12	06	0.03	0.41
19	0.05	0.21	07	0.05	0.37
20	0.03	0.16	08	0.05	0.26

(b) Proportion of daily truck traffic at specified hours on NY32 0.6 miles east of Rt. 378, July 8—9

I = hour, II = proportion of the day's northbound truck traffic, III = proportion of the day's southbound truck traffic

I	II	III	I	II	III
9	0.05	0.06	21	0.02	0.02
10	0.07	0.08	22	0.01	0.01
11	0.08	0.07	23	0.02	0.01
12	0.06	0.08	00	0.01	0.01
13	0.07	0.07	01	0.003	0.01
14	0.08	0.06	02	0.005	0.01
15	0.08	0.10	03	0.003	0.01
16	0.07	0.11	04	0.01	0.01
17	0.03	0.04	05	0.01	0.004
18	0.04	0.04	06	0.05	0.02
19	0.02	0.03	07	0.14	0.07
20	0.02	0.02	08	0.04	0.05

Source: Truck Weight Program, Data by courtesy of William Rapp, New York State Department of Transportation.

The problem of optimally locating checkpoints to monitor hazardous material flows is substantially complicated by variations in their patterns of origins and destinations. Many of the commoner materials (such as gasoline) are ubiquitous and are probably uniformly distributed among total truck movements, except near such places as fuel oil storage facilities. The "shotgun" origin—destination philosophy of the pilot study seems appropriate to detect such flows. But movements of exotic and more dangerous types of materials are rare events both in space and in time. It will be argued in the next section that the O—D survey philosophy is inappropriate to detect such flows unless it is supplemented by separate trip generation studies.

These considerations suggest several lines of further research which should be explored before any large scale survey of hazardous materials movement is undertaken. Potential research topics include practical questions about the location and timing of checkpoints, and theoretical questions about the statistical properties of flow estimates based on the survey data. These research questions are summarized in the following recommendations, which constitute the main conclusions of this study. The time, cost and effort required for further study of these questions are trivial compared to the costs that would be imposed on state police or other agencies by a statistically ill-conceived sampled program. Some specific recommendations follow.

1: Investigate the costs and benefits of flow and discovery sampling

As implied in the discussion of the pilot survey above, sampling truck movements at checkpoints can serve two distinct and sometimes conflicting purposes. One is to obtain an estimate of total flows of various kinds on the particular route segment. Another is to identify origins and destinations of hazardous materials through an interview with the driver. The interview requirement for flow sampling could be minimal. If details on quantity are not required, inspection of the placard alone might be sufficient without an interview. Discovery sampling requires a more time-consuming and potentially disruptive stop.

We feel that public economic and present traffic data are adequate for estimating flows of consumer fuels (72% of all hazardous materials observed) and possibly all consumer products (78% of all hazardous materials observed). Detailed interviews of these trucks should stop at once. Questions about origins and destinations should be continued for all other hazardous materials (22% of all hazardous materials or 2% of all trucks). Because of these small percentages, we believe that the State Police could conduct the interviews with all such trucks concurrently with truck weighing operations. For these largely industrial materials, the interviews should be expanded to determine the specific industrial facilities that ship and receive the material. Follow-up interviews should be conducted with the shippers and receivers to obtain estimates of the patterns of shipments.

2: Optimize sampling locations taking safety and statistical efficiency into account

State police indicated that in the pilot study area only a limited number of sites were physically acceptable as safe truck checkpoints. It is very important that in any planned survey, state police or other agencies should inventory acceptable survey sites. Among safe sites, survey locations should be optimized for statistical efficiency. In the case of New York State the AADT flow figures, which are tabulated for many thousands of points statewide, should be studied for clues on optimum locations for survey points, taking into account: (1) peaks in flow, (2) location with respect to major manufacturing centers where hazardous materials may concentrate, and (3) topologically strategic links (e.g., cut sets) in the state highway network. Comments on proposed survey points should be solicited from the state police.

3: Choose effective survey times

Optimum timing of surveys should be studied in the light of existing information on seasonal and daily variation of truck locations and with reference to distinct seasonal patterns for hazardous materials. Until recently little was known of time variation of truck movements in the state but the current truck weight program in New York is providing some such information on truck movements as a whole. If possible, divergent seasonal patterns of some specific hazardous materials should be studied. For example, seasonal variations in heating oil movements may be the opposite of those for aggregate truck flows.

4: Evaluate effectiveness of checkpoint locations and times for enforcement purposes

The New York pilot study had state police administer the sample survey. It seems likely that police will be involved in any future survey efforts. It is therefore imperative to evaluate possible conflicts between surveying activities and the principal obligation of the state police: law enforcement.

Statistical sampling calls for a known probability of inclusion of a load in the sample for shipments during all times and at all locations. This should not conflict with the enforcement need to present a credible risk of being caught to potential violators. Enforcement is needed for all shipments, while data collection may be needed only for a fraction of shipments, as indicated above. The criteria on network structure, AADT and industrial location used to optimize sample locations from a statistical point of view should be appraised in terms of enforcement effectiveness, in which an element of surprise may be important. For example enforcement considerations may dictate more night-time surveys than flow peaks would warrant.

5: Relate inferences to average annual daily traffic data

The pilot study questionnaires provide absolute numbers of all trucks and absolute quantities of hazardous materials passing the checkpoints. A count of all vehicles is not obtained. Procedures must be studied to deal with time fluctuations in hazardous movements. It needs to be determined whether the standard seasonal adjustment procedures used in generating AADT for all vehicles are appropriate for hazardous truck movements.

Several different strategies could be used to develop annual flow estimates. One approach would be to focus exclusively on statistical variation in hazardous material movements without reference either to total truck flow or to vehicular flow. Alternatively, hazardous materials movements could be studied as a fraction of all truck movements, in the hope of predicting hazardous flows by applying standard seasonally adjusted factors to predicted truck flows. Or similar factors could be applied to total vehicular AADT, on which a far greater volume of data is available. To decide among these alternatives requires detailed analysis of (1) statistical properties of truck traffic as a fraction of AADT, and (2) statistical properties of hazardous movements as a fraction of truck flows. The first question is extensively dealt with in traffic research literature but of the second we know very little.

6: Determine most appropriate methods for inference

It is necessary to investigate the sampling properties of the flow estimators. One important decision must be whether point estimates and confidence intervals are to be given on hazardous materials as proportions of truck (or total) flow, or whether absolute estimates of hazardous flows are to be made. Different inferences are required in each case. Methods of incorporating prior knowledge of seasonal fluctuations into estimators and bounds must be studied. For common materials normal/binomial theory on proportions may be appropriate but for rarer hazardous materials a sampling theory of rare events (Poisson processes) should be applied.

Alternatives to sampling: trip generation, distribution and network models

The philosophy of traffic modeling implicit in the hazardous materials project combines point counts of actual flows with a conventional origin—destination survey (incorporated in Form TB-30). This approach could be usefully supplemented by the trip-generation/distribution/mode split/route assignment paradigm that is standard in urban travel demand models. For certain of the rarer hazardous materials the checkpoint survey method may be too crude to provide usable flow estimates. For such types of material a detailed study of trip origin and termination patterns within and through the state may be the only reliable method of predicting hazardous materials movements.

Generation/distribution/mode split/routing/assignment algorithms are standard procedures in transportation modeling. In the case of hazardous materials an origin—destination constrained modeling format might be most appropriate, predicated on identification and mapping of both sources and sinks for at least the principal hazardous materials. By analogy with the mathematically similar (though smaller scale) problem of journey-to-work models, it should be possible to develop reasonably accurate generation models in multiple regression format. These flows could be distributed, assigned and routed. It has been shown that the 633 zone statewide network model would represent an excellent base on which to implement distribution models. The results could then be compared with the flow data base developed from the checkpoint surveys. If the history of travel demand models is a valid analogy, the O—D point survey methodology implicit in the pilot study might evolve into an integrated modeling framework focusing on the distinct spatial patterns of sources and sinks for different hazardous materials, and on trip distribution and routing possibilities. One compelling advantage of this approach over a simple checkpoint survey is an ability to predict new flow patterns based on hypothetical constraints. Using the DOT statewide network, rerouting plans for local spills or disasters could be explored, as well as the impact of hypothetical legislation restricting certain materials to certain routes. These considerations suggest the following research problems.

7: Identify sources and sinks

A survey of literature and of published data sources should be conducted with a view to mapping sources and sinks of the major hazardous materials. These patterns differ enormously for different materials, at national, regional and local scales. For example, some of the rarer and more dangerous chemicals are specific to certain kinds of industry, which may be located easily through business and professional directories. Gasoline and other fuels and heating oils, on the other hand, possess quite widely dispersed patterns of origin and intermediate distribution (wholesaling), while their pattern of final consumption closely mirrors the state's population distribution. Some appropriate secondary data sources for this data survey include: (1) city, business and professional directories; (2) the Census of Retail Trade, which provides information on gasoline sales in towns, counties and non-urban parts of counties; (3) the Annual Survey of Manufactures, with information on many industry groups in SMSAs, and containing specific figures on fuel consumption; and the Census of Transportation, which provides a detailed breakdown of chemical and other commodity flows, although these are only regionally disaggregated to the state level.

8: Use regression model for trip-generation

The feasibility of multiple regression trip-generation models for hazardous materials should be explored, using the data sources identified in the preceding recommendation. As a very crude illustrative example, gasoline sales were regressed on population over all cities in New York State in the 2,500 to 50,000 population range, for which sales data were available. The R values were 0.79 (1972) and 0.73 (1977). Thus even as crude a measure as population provides useful predictions of gas sales. With information on gas prices per gallon and tanker capacities, vehicle termination estimates per city could be developed for the most common of all hazardous materials. Evidently a multiple regression approach incorporating more predictors could be expected to produce a much better generation model.

9: Integrate the surveys with a network model

In the New York case, the possibility of integrating the hazardous materials survey with the statewide NYSDOT network is attractive, and its implications should be explored before a final version of the TB-30 form is adopted. The CDM group discussed several possibilities with NYSDOT staff. Two potential approaches are possible.

Firstly, zip-codes of last stop and next stop could be solicited on the TB-30. A computer-based dictionary relating zip-codes to the DOT loading nodes could be constructed. This would involve a one-time effort of perhaps three person weeks of work. One advantage of using zip-codes would be an extremely detailed spatial breakdown of last and next stops. However, in the pilot surveys, truckers' manifests and other papers did not always include zip-codes, and troopers found it impractical to press drivers for such information. The zip-code approach would be hard to implement, although the report generator and data structures have been designed to accommodate zip-codes where available.

Secondly, a computer-based dictionary could be designed mapping place names in the state into the DOT loading zones. The names of last and next stops are solicited on TB-30. In principle a complete gazeteer of city, village and town names for the state could be compiled. Such a computer-readable gazeteer probably exists in many states. However, a more economical approach would be to build a dynamic, expanding list of place names as the TB-30 forms accumulate. The computer programs written by the CDM group could easily be modified to build such a dictionary.

Conclusions

Using the various methods described in the preceding sections, the amount of hazardous material passing through population centers, highways, bridges, tunnels and other facilities can be estimated. Even the limited samples reported have an important implication for future data collection efforts. We propose that the purpose of data collection for industrial chemicals be primarily to discover specific sources and destinations, rather than estimate volumes. Once sources and destinations are discovered, users and producers can be contacted and volumes can be estimated from knowledge of the manufacturing processes. Discovery sampling is covered in the literature of accounting but is not directly applicable because roadside sampling is dispersed in location as well as among the population of trucks. For those hazardous materials that are final products, especially consumer goods, volume estimates can be developed from economic models rather than roadside surveys. The information would be most effective if it were tied to a statewide network model of major highways, for which total traffic volume is regularly estimated.

Wherever the quantity and nature of material pose an unacceptable risk, regulations can be enacted to mitigate the damage caused by an accident.

Regulations should cover routes, times, vehicle safety, and operators' qualifications. Governmental units should also prepare for hazardous material accidents by making an inventory of response capabilities that are available on the routes to be used for hazardous material movement. Police, fire departments, users of chemicals, transporters, and private clean-up contractors should be included. Responsibility for response and recovery actions should be planned in advance. Weaknesses in response capabilities can be addresses by aiding fire departments, establishing regional response teams, or requiring users of hazardous materials to provide more services.

Most of the preceding recommendations are applicable to monitoring hazardous movements in any populous area with a moderately dense transportation network. In New York State the potential for progress is particularly good because of the exceptional technical resources and data (e.g., network models) available in NYSDOT. A distinctive feature in this pilot study was the role played by the State Police and the fact that materials sampling could be efficiently combined with an ongoing weighing program. Opportunities for such cooperation exist in many other states.

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