Assessing the Incentives for Hazardous Material Transportation

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Hazardous Material Transportation

A hazardous material is one that can cause imminent danger to the carrier and the surrounding communities through which it is being transported.

Transportation of hazardous materials (Hazmat) in the United States has continuously grown in the last decades.

Annual hazmat transportation now exceeds 300 million annual shipments and nearly 320 million tons of material.

A hazardous materials transportation incident is any occurrence resulting in an uncontrolled release of materials, during transport, that are capable of posing risk to health, safety, and property.

Hazardous Material Transportation

The commercial transportation of hazardous materials (Hazmat) is highly regulated by:

1) Environmental Protection Agency (EPA);
2) The Code of Federal Regulations (CFR);
3) The Department of Transportation (DOT); and
4) The Transportation Safety Administration (TSA).

Shippers are responsible to ensure:

1) correct packaging and labeling;
2) identification of all materials;
3) timely movement with no undo delays;
4) emergency response information is provided;
5) special licenses for hazmat drivers; and
6) security plans are in place for certain shipments.

Hazardous Material Transportation

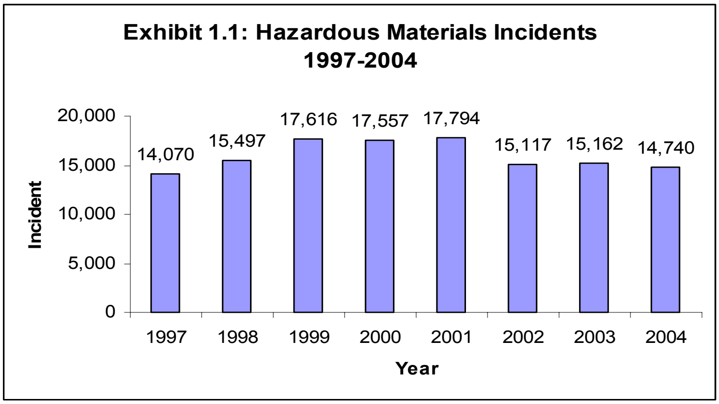
All hazmat drivers need special TSA licenses which require FBI background checks.

All facilities which store, treat, and dispose of hazardous materials need to be permitted. Permits need to be updated periodically and ensure:

1) facilities meet regulatory standards;
2) identification of risks to nearby communities;
3) contingency plans in case of incidents.

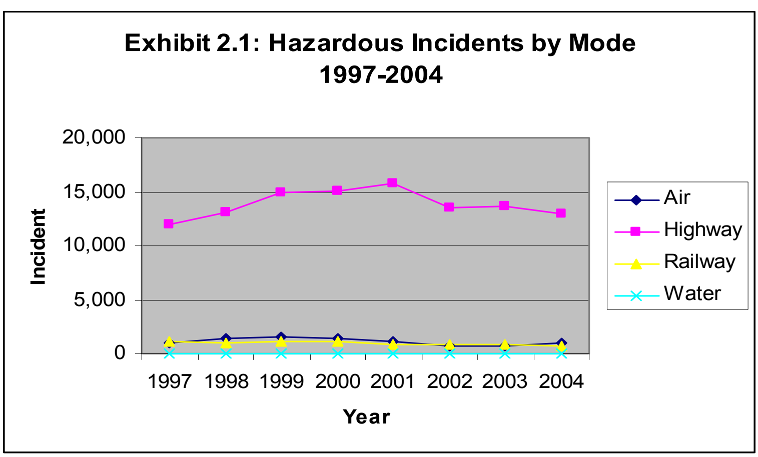
All incidents which have potential for danger to human health or the environment need to be reported. Oral reports are required within 24 hours and within 30 days written reports need to be filed. Not all traffic accidents involving hazmat transportation are incidents. Incidents require a release of hazardous material.

Hazardous Material Transportation



United States Hazardous Materials Incidents

Hazardous Material Transportation



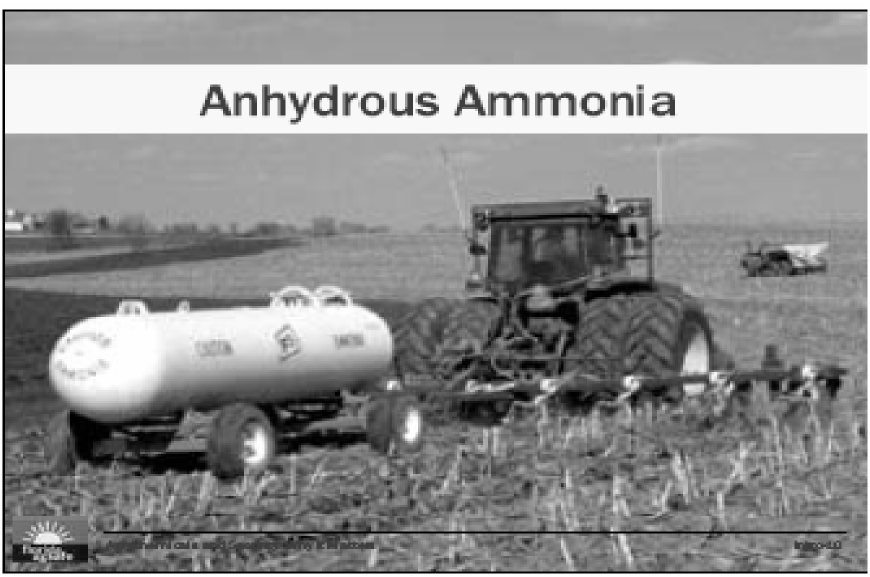
United States Hazardous Materials Incidents

Hazardous Materials in Agriculture

Agricultural chemicals can be hazardous materials. Fertilizers and pesticides contribute to agricultural production. They have also been involved with environmental degradation, workplace accidents and terrorist attacks.

The 1993 attack on the World Trade Center in New York and the 1995 attack ion the Federal Office Building in Oklahoma City utilized fertilizer and fuel based explosives.

Anhydrous ammonia is the most important hazardous material used in agriculture.



Anhydrous Ammonia

The US DOT includes anhydrous ammonia in its top 50 hazardous materials

The primary use of anhydrous ammonia is as a fertilizer.

At room temperature and normal atmospheric pressure, ammonia is a pungent, colorless, and lighter than air gas. The material is usually shipped as a liquid since more material can occupy the same space in a liquid form rather than as a gas.

Anhydrous ammonia is caustic and can cause severe chemical burns. Victims exposed to even small amounts of anhydrous ammonia require immediate treatment with large quantities of water to minimize the damage.

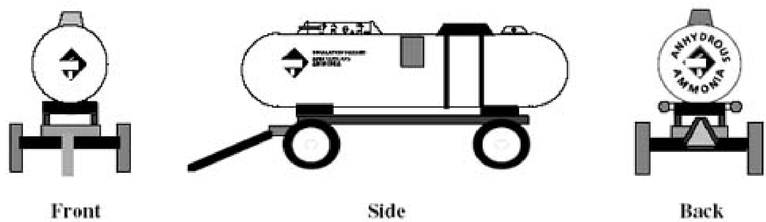
Anhydrous Ammonia

When pressure is released on liquid ammonia it quickly converts to a gas. This conversion will freeze atmospheric moisture forming a white colored cloud. The temperature of the vapor cloud can range from -45° F to -100° F in the first 10 to 12 feet of the cloud, which may rapidly freeze everything it touches.

Anhydrous ammonia has been used in the process of making the illegal drug methamphetamine. Methamphetamine is a powerful central nervous system stimulant with a high potential for abuse and dependence. One simple recipe for making methamphetamine requires anhydrous ammonia. The popularity of this drug has resulted in farmers increasingly finding their ammonia tanks have been tapped by “cooks” using anhydrous ammonia to produce methamphetamine.

Hazardous Material Transportation

In most states farm transportation of hazardous materials is given an exemption from commercial transportation requirements. The most important hazardous material in agriculture in anhydrous ammonia. Anhydrous ammonia is generally transported and stored on the farm in nurse tanks, with a capacity of 1000 to 2000 gallons.



Hazardous Material Transportation

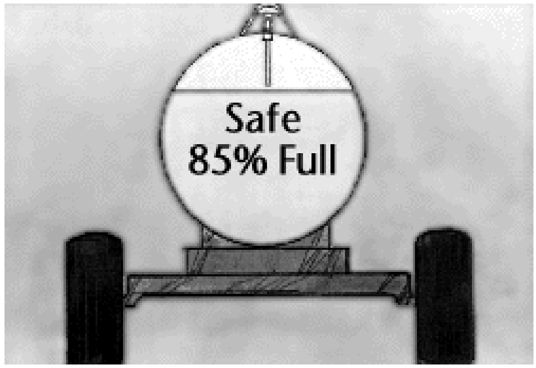
Regulations for farmer transportation of anhydrous ammonia are made by the states.

In North Dakota:

1) Up to two nurse tanks can be pulled
2) Length of truck and nurse tanks no more then 75 feet
2) Maximum speed is 25 mph
3) Transport must be made during daylight hours
4) Proper signs, reflectors, and safety chains are required

Other states allow higher speed but only one nurse tank. Some states allow night transportation. Some states regulate the pressure allowed in the nurse tank.

Hazardous Material Transportation



Hazardous Material Transportation

Commercial transportation of anhydrous ammonia on highways is well regulated. Drivers receive specialized training.

Farm transportation of anhydrous ammonia is less regulated with little enforcement.

Given distances involved and the lack of enforcement the incentives imposed upon farmers could be to accept risks in hazardous material transport.

Since some of the risks involved include social and environmental risks, farmers might not fully internalized by farmers.

A Spatial Optimization Model

A spatial optimization model will be developed to ascertain a least cost distribution network for anhydrous ammonia in representative North Dakota counties.

The purpose of the model is to assess if the incentives placed upon hazardous material transporters leads to an overuse of relatively unregulated farmer transport.

North Dakota is an agricultural state with low population density. There is concern in North Dakota that with population decreasing in rural areas that the network of agribusiness dealers is decreasing. This would lead to greater farm to dealer distances.

A Spatial Optimization Model

The anhydrous ammonia distribution system contains:

1) commercial transportation from the manufacturer o the dealer;
2) A number of licensed dealers that store and sell anhydrous ammonia to farmers
3) Farmers who transport the anhydrous ammonia to farms from the licensed dealer location

For purposes of the model, the number and size of dealers are fixed by the current technology and the anhydrous quantity needs determined by the crops grown in the counties. The location of the dealers is endogenous to the optimization model

A Spatial Optimization Model

The objective function is to minimize the total cost of anhydrous ammonia distribution, including:

1) the private cost of shipping anhydrous ammonia from the manufacturer to the licensed dealer;
2) the private costs of transporting anhydrous ammonia from licensed dealer to the farm;
3) the social cost of shipping anhydrous ammonia from the manufacturer to the licensed dealer; and
4) the social costs of transporting anhydrous ammonia from licensed dealer to the farm.

Social costs are the probability weighted personal and property damages from accidents and incidents.

A Spatial Optimization Model

The objective function of minimizing the total cost of anhydrous ammonia distribution is constrained by:

1) A quantity constraint for anhydrous ammonia requirements
2) Regulations limiting commercial transportation
3) Regulations limiting farm transportation to:
   i) 25 mph
   ii) Only driving in daylight hours
   iii) Only towing two 1500 gallon nurse tanks
   iv) The Storage constraints of the licensed dealers

A Spatial Optimization Model

The Objective Function

$$\underset{a_{xy},b_{xyij},c_{xym}}{Min} \sum_{xym} t_{xym}\ q_{xym}\ dist\ (xym) + \sum_{xyij} r_{xyij}\ s_{xyij}\ dist\ (xyij)$$

$$+ \sum_{xyij} a_{xy}\ b_{xyij} \times (injury + damage) \times dist\ (xyij) \times prob_{farm}$$

$$+ \sum_{xyij} a_{xy}\ c_{xym} \times (injury + damage) \times dist\ (xym) \times prob_{comm}$$

a_{xy} is a *(0,1)* variable which indicates that a distributor is located at point *(x,y),*
q_{xym} is the quantity of anhydrous shipped from manufacturer to distributor
t_{xym} is the transportation cost per ton mile from manufacturer to distributor
dist (xym) is the distance from manufacturer to distributor
dist (xyij) is the distance from distributor to the farm
r_{xym} is the quantity of anhydrous shipped from distributor to farm
s_{xym} is the transportation cost per ton mile from distributor to farm
b_{xyij} is the number of trips from a farm located at (*i,j*) to a distributor located at (*x,y*)
c_{xym} is the number of trips from the manufacturer to distributor (*x,y*)
inj and *damage* are the personal injury and property damages per accident
$\text{prob}_{\text{farm}}$ and $prob_{comm}$ are the probabilities of accidents for farmer and commercial transported anhydrous

A Spatial Optimization Model

Subject to,

$$\sum_{xy} a_{xy} r_{xyij} \geq N\ demand_{ij}$$

Ndemand$_{ij}$ is the total anhydrous ammonia demand by each farm

$$\sum_{xy} r_{xyij} \leq N\ storage_{ij} \times 2.5$$

Nstorage$_{xy}$ is the quantity of anhydrous storage at each distributor.

$$\sum_{xy} r_{xyij} \leq q_{xym}$$

1275 is the capacity of a nurse tank

$$b_{xyij} \geq r_{xyij} / (2 \times 1275)$$

6986 is the capacity of a commercial tanker

$$c_{xym} \geq q_{xym} / 6986$$

Data

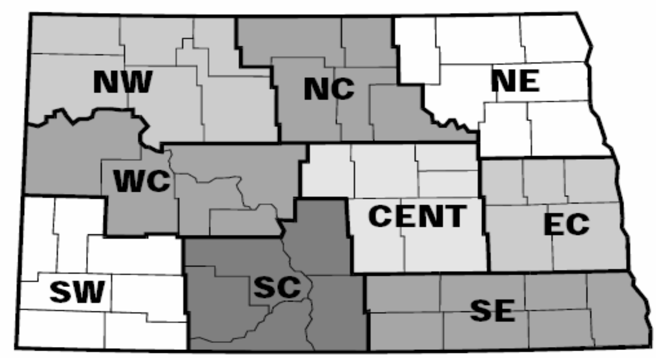
This model was used to assess transportation incentives for three representative North Dakota counties.

North Dakota is an agricultural state with low populations density and high transportation costs. Population is 642,000, area is 68,976 square miles in area with an average of 9.3 people per square mile.

North Dakota is in the northern Great Plains, it is flat and dry. Principle crops include spring wheat, durum, barley, canola, sunflowers, sugarbeets, corn, dry edible beans, and soybeans.

Farms and ranches occupy more than 39 million acres, almost 90% of North Dakota's land area.

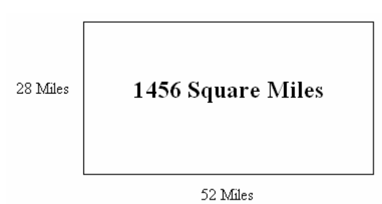
Data



North Dakota has 53 counties.
North Dakota also has a square road grid facilitating transportation studies.

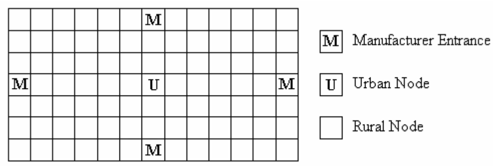
Data

Three representative counties were formed for the optimization model. Each representing population and crop production statistics of North Dakota's eastern, central and northern counties. Each county was given the average size and shape of North Dakota counties. Each was formed to have one urban area, the county seat. In North Dakota county seats were established in the center of counties in order to facilitate transportation to the court house and administrative offices.



Data

To facilitate the analysis, the counties were divided into 91 rectangular nodes, each are potential locations for licensed dealers. Each node contains farmland, although urban nodes have less farmland. Each network consists of 364 potential links between the manufacturer entrances and potential licensed dealer locations. There are 8,190 potential links between potential nodes of licensed dealers and nodes containing farm land. Four nodes are designated as highway entrances into the county.



Data

Four crops are selected to quantify the use for anhydrous ammonia: Spring wheat, durum wheat, barley, and corn. Nitrogen needs per acre per crop were taken from North Dakota Agricultural extension service. Based upon conversations with local extension experts it was estimated that 50% of total nitrogen application was anhydrous ammonia. Population density is taken from census data and used for the risk calculation. Urban nodes are assumed to have 25% of the crop acreage as the rural nodes.

Attributes of the Western County

	Total	Per Urban Node	Per Rural Node
Demographics			
Population	8,703	4,383	48
Cropland (acres)	115,069	319	1,275
Crop Composition			
Barley (acres)	15,433	43	171
Corn (acres)	3,971	11	44
Wheat Durum (acres)	43,049	119	477
Wheat Spring (acres)	52,616	146	583
Quantity Demanded			
Anhydrous Ammonia (gallons)	1,414,672	3,922	15,675

Attributes of the Central County

	Total	Per Urban Node	Per Rural Node
Demographics			
Population	12,231	6,471	64
Cropland (acres)	94,402	262	1,046
Crop Composition			
Barley (acres)	20,126	56	223
Corn (acres)	14,169	39	157
Wheat Durum (acres)	4,152	12	46
Wheat Spring (acres)	55,955	155	620
Quantity Demanded			
Anhydrous Ammonia (gallons)	1,291,300	3,580	14,308

Attributes of the Eastern County

	Total	Per Urban Node	Per Rural Node
Demographics			
Population	16,887	9,687	80
Cropland (acres)	113,083	313	1,293
Crop Composition			
Barley (acres)	10,469	29	116
Corn (acres)	34,746	96	385
Wheat Durum (acres)	1,715	5	19
Wheat Spring (acres)	66,153	183	733
Quantity Demanded			
Anhydrous Ammonia (gallons)	1,664,475	4,605	18,443

Data

The risk formulation presented by Abkowitz and Cheng (1988) is the basis for the calculation of the accident probabilities and the damages from a release of anhydrous ammonia during transport. Property damages, mortality and morbidity costs are from Abkowitz and Cheng (1988) and from recent court cases involving anhydrous ammonia in North Dakota.

Information on plant capacity came from local North Dakota agribusinessmen.

Accident rates are for different road types. Road grid information is comes from the upper Great Plains Transportation Institute

Parameter	Value	Source
Capacity of Nurse tank	1500 gallon	Weber
Capacity of commercial transport	6986 gallon	Weber
Average fatalities per anhydrous ammonia incident	0.01526718	Abkowitz and Cheng 1988
Average injuries per anhydrous ammonia incident	$1,160,000.00	Abkowitz and Cheng 1988
Average cost of fatalities in dollars	0.22900763	Abkowitz and Cheng 1988
Average cost of injury in dollars	$938,482.00	Abkowitz and Cheng 1988
Average damage to property per anhydrous ammonia incident	$5,703.31	Abkowitz and Cheng 1988
Interstate Accident Rate	0.79	Harwood and Russell 1990
Principal Arterial Accident Rate	2.62	Harwood and Russell 1990
Minor Arterial Accident Rate	3.43	Harwood and Russell 1990
Collectors Accident Rate	2.23	Harwood and Russell 1990
Local Accident Rate	2.03	Harwood and Russell 1990
Fraction of Accidents Involving Hazmat	0.0014	Harwood and Russell 1990
Impact Distance of AA accidents	1.0 mi all directions	Harwood and Russell 1990

Data

Cost per loaded mile for a 5 axle 42 foot tanker truck derived from the Jack Faucett Associates/SYDEC study for the Federal Highway Administration (FHWA) was utilized for the parameter of the manufacturers transportation cost per mile. Cost was $3.45 per loaded mile.

The per-mile cost of towing nurse tanks was not available. Instead it was estimated from the California Air Resources Board's Motor Vehicle Emission Inventory models. Thus the costs was estimated to be $1.38 per loaded mile. This is might be low, and will need to be assessed within a sensitivity analysis.

Simulation

Simulation used GAMS (General Algebraic Modeling System)

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This program computes the expected net social cost of transporting and delivering anhydrous
ammonia to a representative ND county.
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Program may be freely distributed with appropriate attribution.
OPTION limrow=0; OPTION limcol=0;
SETS
xgrid xcoordinates /x1*x7/
ygrid ycoordinates /y1*y13/
manu  manufacturers /m1*m4/
road  /rural,urban/
county /west,central,east/
;
ALIAS (xgrid,xg1,xg2);
ALIAS (ygrid,yg1,yg2);
PARAMETERS
fixed fixed costs for distribution points
afcost probability wieghted cost per mile of accident for farm
rfcost probability weighted cost of inj from release for farm PER MILE
adcost probability weighted cost per mile of accident for distributors
rdcost probability weighted cost of inj from release for distributors PER MILE
miles(road) percent road that is rural versus urban
pop(road) population by rural and urban per sq mile
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Results

Minimization of Social Cost
Model Solution for Locations of Licensed Dealers
Western County

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Results

Minimization of Social Cost
Model Solution for Locations of Licensed Dealers
Central County

						LD						
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Results

Minimization of Social Cost
Model Solution for Locations of Licensed Dealers
Eastern County

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Results

Minimization of Private and Social Cost

The simulation model locates licensed dealers near the highway entrances to the counties. The number of dealers and the size of counties implies that the 25mph during daylight is not a binding constraint. Farmers are not forced to drive at unsafe speeds or at night.

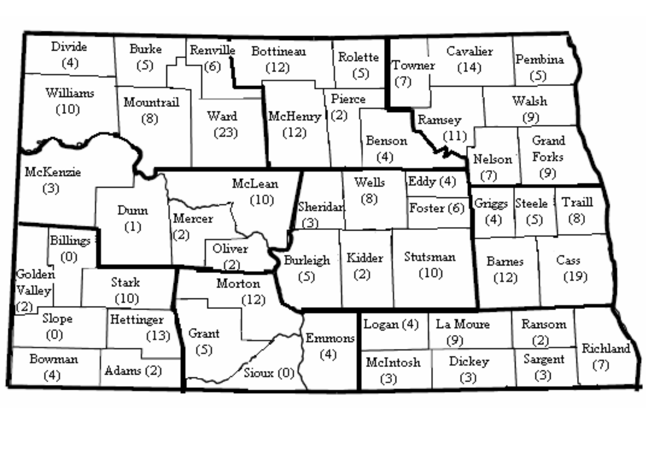
The simulation was run with the minimization of only private cost. Given that individuals might not incorporate the external social and environmental cost of accidents and hazardous material incidents in their decision making, the results of private and social costs were compared.

The results were very similar. The reason for the similarity is the low actual accident rates in North Dakota. Because roads are flat, straight, with good visibility, and low traveled frequency, there are few accidents. Because of low population density the impact of potential incidents is low.

Thus the private cost simulation is similar to the public costs simulation.

Results

North Dakota Licensed Dealers of Anhydrous Ammonia per County



Results

North Dakota Licensed Dealers of Anhydrous Ammonia per County

The actual number of licensed dealers of anhydrous ammonia per North Dakota county is presented above. On average there are approximately six licensed dealers per western and central counties and approximately 8 per eastern county. There is a significant disparity between the number of licensed dealers determined by the model for each county (Western 12, Central 11, Eastern 14) and the actual average number.

A possible explanation for this is that the capacity at the actual plants are greater than what was utilized in the model or the quantity demanded per each constructed county for anhydrous ammonia is greater than the actual quantity demanded per county. Sensitivity analysis results will be discussed later that evaluate a few of these possibilities.

Sensitivity Analysis

Sensitivity analysis was performed on the transportation costs. Results are displayed for the Central County

Fifty Percent Increase in Farmers transportation Costs

	LD				LD							
			LD									
												LD
LD					LD							LD
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Fifty Percent Decrease in Farmers transportation Costs

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Sensitivity Analysis

Sensitivity analysis was performed on the transportation costs. Results are displayed for the Central County.

Given that the number of licensed dealers is exogenous to the model, there is little impact on the location of the plants. As the ratio of farm transport to commercial transport costs decreased, the dealers are more congregated at the highway entrances to the counties.

Conclusions and Observations

Given low accident rates and low population density, there is little difference between the private cost and the social cost of anhydrous ammonia transport.

The low social costs imply that the incentives brought upon farmers do not imply an overuse of farm transport relative to commercial transport.

Additional simulations with larger plant sizes may mean greater distances, but 100 miles that farmers can legally transport anhydrous ammonia during daylight hours is not a binding constraint.

Conclusions and Observations

Farmers transport hazardous materials on local roads. They are familiar with these roads. It is not likely that farmers maintain a 25 mph speed limit. But accident rates imply that safety is not a great issue.

This model might have different results in more populated states, with higher social costs of hazardous waste incidents.

Increased controls over commercial transport of anhydrous ammonia need to be balanced with the risks of non-commercial transport.

References

Zimanski M. 2007. Private and Social Cost of Anhydrous Ammonia Transportation a Model for Anhydrous Ammonia Distribution in North Dakota. Thesis submitted to the Graduate School. North Dakota State University