THE ENVIRONMENTAL EFFECTS OF FREIGHT

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Executive summary

This review of the environmental effects of freight is structured by transport mode, addressing shipping, air cargo, trucking, rail, pipelines and intermodal terminals. It begins with a brief overview of the major environmental media or mechanisms through which transport can affect the environment. These include air pollution, global climate concerns, noise, water pollution, accidents, land use and habitat fragmentation. The modal discussions focus on air pollution, global climate issues, water pollution, accidents whose costs are environmental rather than primarily in human life, and certain land use planning issues. The review describes the impacts in qualitative terms, and then provides emission factors per unit of freight transported. The most recent estimates of the marginal social cost of some of the impacts are provided in the comparisons and conclusions.

The paper identifies comparable emission factors for only certain kinds of environmental harm, notably air pollution and noise. The air pollution data confirm conventional wisdom that trucking is by far the most harmful mode of goods transport. Rail seems to be somewhat more harmful than maritime transport, but this is not clear-cut; variations in the methods used to estimate the factors may outweigh the differences among them. With respect to noise the results are less clear. Conventional wisdom holds that road noise is worse than rail, but the available data only suggest this, rather than clearly demonstrating it. While airport noise is clearly an important problem, comparable noise indicators are not available for road or rail.

The problems involved in quantifying and comparing other environmental impacts are also highlighted. The pollution caused by ocean freight, for example, is only indirectly linked to the quantity transported. Moreover, there is no clear objective basis for comparing air and water pollution. Even more difficult are environmental harms like the introduction of nuisance species or the disposal of contaminated dredged materials, which affect marine ecosystems more than humans.

The Information and data given in this review describe the situation in the United and States and Europe. However, it should be noted that as the transportation systems in both these continents differ substantially, comparisons should not be drawn between the two continents.

I. Introduction

This paper provides an overview of the environmental impacts of the international transport of goods. It was prepared for the Joint Session on Trade and Environment Experts study on trade liberalisation, goods transport and the environment.

A) Defining Environmental Impact

"Environmental impact" may be considered to have three components:

- Environmental stressors such as pollutants, noise, or exotic species are released in natural ecosystems. Each tonne of goods transported places additional stress on the environment; many stressors may therefore be measured in units per tonne of goods transported;

- The total amount of stress placed on the environment depends on the quantity of goods and the distance they are transported; in the simplest form, total stress is the quantity of goods times the distance carried multiplied by the stress per tonne. The second component of stress involves the spatial pattern of goods transported, including the transport mode used;

- The environmental impact of the total stress is determined by the nature of the receiving environment. Ambient characteristics such as physical ecosystem characteristics, density of the human population affected, and whether the receiving ecosystem is considered critical or includes endangered species will determine both the physical impact of the stress and willingness to pay to prevent it.

This paper focuses primarily on the first component of environmental impact, with some attention to the third.

B) Quantifying and Comparing Stressors and Impacts

Some environmental stressors--notably air and water pollutant emissions--are easily quantified, and clearly rise with increases in freight. Others, such as airport noise or the introduction of exotic species, increase with the number of trips made, but not with distance travelled or quantity of goods carried. Moreover, the ecological harm caused by such stressors may not be quantifiable or directly related to quantity of freight. This raises the question of how to address stressors which cannot easily be expressed as emission factors per unit of freight. Three approaches may be taken to this issue:

- Limit the analysis to those stressors which can be easily quantified in comparable terms -- i.e. pollution. These are often considered to be the most harmful environmental impacts of transportation, and limiting the analysis to them may not distort the results significantly;

- Include all kinds of impacts, but be descriptive when quantification is not possible. This acknowledges the importance of all kinds of impacts, but unfortunately can make it easy to disregard those which are not quantified in comparable units;

- Use valuation techniques which convert all environmental impacts to the costs they impose, the costs of avoiding them, or willingness to pay to avoid them. The advantage of this approach is clearly that it provides a common unit of analysis with which to compare different kinds of impacts. The disadvantage is that such valuation is highly subjective and quite difficult to carry out.

This paper does not choose among these approaches, but provides information which could be located to permit any of them. It describes the major environmental impacts of freight in qualitative terms. When emission factors per unit of freight are meaningful and available, it provides them. In some cases estimates have been made of the social costs of environmental harms attributable to transportation; these are given as well.

C) Overview of Impacts by Environmental Medium

This paper is structured by transportation mode. Before beginning that discussion, it is useful to review the major impacts of transportation by environmental medium, in order to discuss the environmental impacts of stressors placed by many transportation modes. Subsequent chapters can then focus on the quantity of stress placed by each mode, rather than reiterating how it affects the environment.

This section also briefly discusses several transportation externalities which will not be addressed further in the paper. These are of several types. Some are too indirect to permit establishment of a clear link to freight. For others, data are not available to examine them in detail by mode of transport, so our consideration is limited to a broader discussion of the issue. Finally, some are not considered to fall within the concept of "environment" used in this paper.

Air Pollution

Air pollution is generally considered to be the most important environmental threat posed by transportation. The table below summarises the major pollutants emitted by moving vehicles, their source, and the harm they can cause to humans, ecosystems, global climate, and property (buildings and materials). Most of these pollutants are emitted by most forms of transportation.

Two points should be borne in mind. First, literature on transportation-generated air pollution generally describes the quantity of pollution and its environmental and health impacts one product at a time. However, in some cases chemicals combine to have additional impacts beyond the problems caused by each individually. The best-known example is that of photochemical oxidants, which form through chain reactions between hydrocarbons and other volatile organic carbon compounds (VOCs), nitrogen oxides (NO_X) and oxygen when in the presence of sunlight. This leads to the formation of photochemical smog, a particular problem in cities such as Athens and Los Angeles.

Second, trace quantities of many additional pollutants are emitted by transportation; these include benzene (a known carcinogen), toluene, polynuclear aromatic hydrocarbons, formaldehyde, cyanide, hydrogen sulphide, dioxin, and so on (Kürer pp. 485-6). Either because most governments do not yet regulate these emissions, or because much less is known about their impacts (the second point may follow from the first), these pollutants receive relatively little attention in discussions of the environmental threats posed by transportation.

Table 1. Summary of Environmental Damage by Air Pollution

Pollutant[a]	Source	Impact on:			
		Humans	Vegetation	Global Climate	Materials
Carbon monoxide (CO)	Incomplete combustion	Inadequate oxygen supply; heart, circulatory, nervous system		Indirect through ozone formation	
Carbon Dioxide (CO_2)	Combustion			Major greenhouse gas	
Hydrocarbons (HC - includes methane, isopentane, pentane, toluene, etc.)	Incomplete combustion, carburetion	Some are carcinogenic Ozone precursor	Build-up in soil, feed, food crops	Methane has high greenhouse potential, leads to ozone formation	
Nitrogen oxides (NO_X)	Oxidation of N_2 and N-compounds in fuels	Respiratory irritation and other problems.	Acidification of soil and water, over-fertilizing	NO_2 has high greenhouse potential, leads to ozone formation	Weathering, erosion
Particulates	Incomplete combustion, road dust	Respiratory damage, various toxic content	Reduced assimilation		Dirt
Soot (diesel)	Incomplete combustion	Carcinogenic			Dirt
Ozone (formed by interaction of other pollutants)	Photochemical oxidation with NO_X and HC	Respiratory irritation, ageing of lungs	Risk of leaf and root damage, lower crop yields.	High greenhouse potential	Decomposition of polymers

Source: Based on Button p. 30, Table 3.6; Kürer pp. 486-490
[a] Sulphur oxides from diesel engines (trucks and vessels) are also of some concern.

Global Climate Concerns

Transportation contributes to global climate change through emissions of carbon dioxide, methane and other hydrocarbons, nitrous oxide (N_2O), and water vapour discharged by aircraft. These gases absorb radiation in the stratosphere. Though transparent to sunlight, these reflect long-wave radiation normally emitted back into space by the earth. This may raise the temperature of the atmosphere. While the exact impacts of increases in these gases in the earth's atmosphere are not known for sure, the Intergovernmental Panel on Climate Change (IPCC) has predicted that a doubling of CO_2 concentrations could lead to a rise in sea levels by 3.5-5.5 cm per decade due to thermal expansion of ocean waters and melting ice caps and glaciers (Pickering and Owen, p. 72).

For most transportation modes, the same engine emissions have both local and global impacts. Standard data on air pollutant emissions cover all of the major greenhouse gases except CO_2. The Intergovernmental Panel on Climate Control (IPCC) has developed a methodology for estimating carbon emissions based on the amount of carbon in each type of fuel and the efficiency of combustion; the more efficient the combustion, the greater the share of the carbon converted to CO_2. Detailed data on emissions by mode of transportation are not readily available, because they require highly disaggregated data about fuel consumption (US Environmental Protection Agency (US EPA) 1994 p. 19 footnote 7). The information which could be identified on carbon dioxide emissions per ton-kilometre of freight is presented in the discussion of other air pollution by maritime transport, trucks, rail, and pipelines.

Most aircraft emissions data pertain to conventional pollutants emitted during landing and take-off cycles. These emissions contribute to both local pollution and to global climate problems, as do road or marine emissions. In addition, however, aircraft emissions during high-altitude flight, may have further impacts on the global climate, because they are emitted directly into the upper troposphere or stratosphere. The available information on this issue is discussed separately from low-altitude air pollution in the chapter on air transport.

Noise

Traffic is a major source of noise, particularly in urban areas. In addition to being unpleasant, noise contributes to such health problems as stress, sleep disturbances, cardio-vascular disease, and hearing loss. Surveys suggest that people feel more directly affected by noise pollution than by any other form of pollution. This has a political dimension which goes beyond the noise itself. German experience has found that as people become annoyed about noise, they become aware of other environmental pollution problems as well (Kürer p. 493).

Measuring the magnitude of noise pollution is complex. Volume is measured in A weighted decibels [dB(A)]; a level above 65 dB(A) is considered unacceptable and incompatible with certain land uses in OECD countries. However, a number of different parameters must be factored into an indicator of noise; volume, pitch, frequency, duration, and variability. Noise indicators are typically an average of volume and duration over a fixed period of time. The context in which the noise occurs is important; a noise which may be considered acceptable in a working environment during the day would be unacceptable in a residential neighbourhood at night. Similarly, noise which is expected, for example the acceleration of a truck which is visible, may be less annoying than that which is unexpected, such as the same truck when the auditor cannot see it (Filippi p. 129). In addition, the same volume of noise may be more tolerable when it is intermittent than when it is constant; thus railway noise can be more acceptable than quieter but more constant noise from road traffic (Kürer p. 494). Exposure is also frequently qualified by the number of people or share of the population exposed to this level of noise, or exposed to it for more than a fixed per cent of the time. However, obtaining data on actual exposures to noise is difficult. In addition, it is somewhat difficult to compare noise from different modes of transportation as these are measured with different metrics.

Water Pollution

The normal operation of transportation vehicles does not generate water pollution in the way that it generates air pollution. However, transportation has both direct and indirect impacts on water quality. Shipping activity, in particular, directly affects the environment in a number of ways. The routine discharge of ballast water from marine vessels, if ballast is not segregated from cargo, introduces oil pollution at sea and in coastal waters, and can lead to introduction of nuisance species transported from the boat's origin to its destination. Shipping is a source of oil and chemical spills at port, in coastal waters, and more rarely at sea. The routine maintenance dredging of ports and inland waterways stirs up toxic sediment and frequently leads to the disposal of dredged material in the open ocean. (Of course the existence of the toxic sediment stems from many sources other than transport; the dredging simply raises the toxics and poses the problem of where to resettle them.) These problems increase with growth in shipping, although they are less directly linked to ton-kilometres of freight than is air pollution.

The water-quality effects of land transportation are less direct. Road accidents and vehicle exhaust are both sources of oil and hazardous chemicals which run off the road into surface and ground water. The roads themselves, as well as parking lots, driveways, and other paved surfaces lead to an increase in impermeable surfaces, particularly in urban areas. Impermeable surfaces interrupt the filtration of rainfall into the ground water. An increase in impermeable surfaces will therefore aggravate flood risk and lead to more pollutant runoff into surface waters in heavy rains. These problems go far beyond the choice of freight transport mode, however. They are primarily linked to ownership of family cars and a preference for single-family homes, which combine to create land use patterns characterised by a dense network of roads in order to access each residence individually. While additional traffic means more highways and more chemicals on the roads, the highways themselves may account for a fairly small share of impermeable surfaces.

Accidents

Defining accidents as an environmental impact raises questions about how we define the environment. Some accidents clearly fit within any definition of the environment. Ship and pipeline oil spills, in particular, have obvious impacts on ecosystems and wildlife. Other accidents, particularly passenger transport accidents like car or plane crashes, have serious impacts on human health which might not fit within a narrow definition of the environment. The possibility of such an accident occurring could be considered a "quality of life" issue, and thus an element of the environment broadly defined. Other accidents fall somewhere in the middle; for example, truck accidents, train derailments, or gas pipeline accidents which release toxic or flammable chemicals. The risks posed here are both to the environment narrowly defined and to human health; separating these two dimensions is not obvious.

This paper implicitly takes the narrow view of the environment in its treatment of accidents. It considers marine and pipeline spills, but does not address issues of human life lost to transportation accidents. This is a somewhat arbitrary choice, of course and a different strategy might be taken. Spill data are easily quantified and can be related to the quantity of product transported; this makes it conceptually straightforward (though sometimes practically difficult, due to data availability) to compare the accidents associated with different modes of transport.

Land Use and Habitat Fragmentation

Land transportation systems are a cause of habitat fragmentation, the disruption of wildlife habitats and their division into smaller area (van Bohemen). Habitat fragmentation has four components. First, transportation lines cause direct destruction of habitat by replacing it with roads, rails, or other infrastructure. Second, a transport right-of-way will disturb adjacent habitat through chemical pollution, noise, light, or other impacts. Third, the right-of-way creates a barrier separating functional areas within a habitat. Many plants or animals will not cross such a barrier, so a road can have the effect of cutting their ecosystem in two. Ecosystem species diversity is a function of the total size of the area of uninterrupted habitat; thus dividing an area with a road could cut diversity in half rather than reducing it only by the actual area used by the road. Fourth, a transport right-of-way can lead to direct collisions between animals and moving vehicles.

The importance of road, rail lines, or pipelines as sources of habitat fragmentation will be related to their length and width and to the habitats through which they pass. Direct habitat loss, externalities like pollution and noise, and road kill will be directly affected by the volume of traffic and width of the road. Measures are available to minimise these impacts, by designing infrastructure such as roads and road barriers so as to minimise pollution or light, and so on. These problems are somewhat analogous to the water pollution problems discussed above, in that it may be possible, although difficult, to relate their growth to increased freight use.

The creation of barriers which divide ecosystems is much harder both to analyse and to manage. Moreover, the importance of such barriers is very much related to the nature of the surrounding environment. A road or rail line running through an urban area is not likely to cause ecosystem harm, since the area is already not in a natural state. Roads through sensitive areas like the Alps, or protected forest areas in the United States, however, can cause significant ecological harm. A rigorous analysis of the impact of different transport modes on land use and habitat fragmentation would require detailed knowledge of local ecology and land use patterns. Even with such information about particular ambient conditions, it is will be hard to establish a direct correlation with increased goods transport.

Summary data on land consumption by different transportation modes suggest that roads may cause more problems than other modes of transport. OECD 1993 (p. 30) indicates that the road network in the European Community consumes 28 949 km^2 of land, while the rail network consumes only 706 km^2. (Of course most goods shipped by rail -- as well as most rail passengers -- also rely on the road network to get between their origin or destination and the railhead.) However, while issues of land use and habitat fragmentation are an important component of the environmental impacts of both road and rail transport, analysing them adequately may not be possible in the context of a model of increased demand for freight.

II. Shipping

Shipping poses threats to the environment both on inland waterways and on the ocean. These problems come from six major sources; routine discharges of oily bilge and ballast water from marine shipping; dumping of non-biodegradable solid waste into the ocean; accidental spills of oil, toxics or other cargo or fuel at ports and while underway; air emissions from the vessels' power supplies; port and inland channel construction and management; and ecological harm due to the introduction of exotic species transported on vessels.

A) Operational Oil Pollution

Ships are designed to move safely through the water when they are filled with cargo. When empty, they fill their tanks with ballast water in order to weigh them down and so stabilize them as they cross the ocean. Before entering the port where they are to load up, they discharge the ballast water, whose weight will be replaced with freight. The water discharged is typically somewhat unclean, being contaminated with oil and possibly other wastes within the ballast tanks. Its discharge is therefore a source of water pollution. It should be noted, however, that segregated ballast tanks, which are required on newer tank vessels, reduce or eliminate the oily ballast problem. A similar source of pollution is bilge water; this is seepage which collects in the hold of a ship and must be discharged regularly. On oil tankers the bilge water is typically contaminated with oil which seeps out of the cargo tanks; thus this is also a source of oil pollution. Such discharges are referred to as “operational” pollution because they have long been considered a part of the normal operating procedures both of oil tankers and of other ships managing their fuel.

Oily discharges, even those hundreds of kilometres from the coast, wash up on beaches and shorelines, killing birds and contaminating tourist facilities. The 1973 International Convention for the Prevention of Pollution from Ships, and the 1978 Protocol for its implementation which entered into force on 2 October 1983 (referred to as MARPOL 73/78), put in place a set of discharge standards and equipment requirements designed to prevent operational oil pollution (Table 2):

Table 2. Major Components of MARPOL 73/78, Annex I (Oil Pollution)

Discharge Standards	Within 50 miles of the coast and in other special designated zones, oil tankers may discharge water containing up to 15 ppm oil. Above this concentration a sheen would be visible on the water's surface; thus any visible sheen is evidence of non-compliance. Beyond 50 miles of the coast and outside of special zones, oil tankers may discharge up to 30 litres per mile travelled, up to a maximum total discharge of 1/15,000 of their total cargo for existing tankers or 1/30,000 for new tankers.
Vessel Equipment Requirements	All new crude tankers over 20,000 tons dry weight must have ballast tanks completely segregated from their cargo tanks (SBT); this replaced an older practice of filling cargo tanks will ballast water, which led to mixing of crude oil residues with water. New tankers also had to install a crude oil washing technique (COW) to clean cargo tanks, which reduced oily water discharges from tank cleaning. Existing tankers over 70,000 tons had to install SBT; those between 40,000 and 70,000 tons had to install either SBT or COW. COW is considerably less expensive, so this was the choice of owners of existing ships.
Government Action	Facilities for reception of oily water must be installed in all ports.
Source: Mitchell 1993.	

Quantitative data are not available on the magnitude of the ballast water problem, although the MARPOL 15 ppm and 60 litres/mile standards can be used as a lower bound for tanker discharges per mile or kilometre in predicting the environmental impact of increased oil transport. MARPOL 73/78 has effectively addressed some, but not all operational oil pollution problems (Mitchell). On a more positive note, experts seem agreed that the vessel equipment requirements are being met, since compliance with international rules is a factor in vehicle classification and thus insurance rates. The requirement for reception facilities in ports, however, has apparently had little effect. Developed country ports typically have the required facilities, but those of less developed countries -- including some major oil exporters where ballast water discharges by empty tankers coming in to load up are an important problem -- have not made the necessary investments. This means that tanker captains are unable to dispose of oily ballast water properly in some ports.

B) Solid Waste Disposal

The disposal of plastics at sea is a significant source of environmental harm, since the materials are both buoyant and persistent. Debris is generally of several types. Fishing boats discard old nets and lines, frequently made of plastic. Freighters accumulate and sometimes discharge materials used to pack break bulk freight to keep it from shifting as the boat moves. This material, called dunnage, is typically either wood or plastic. Such materials have spread throughout the world's oceans, and have been found as far as the poles and the sea bottom. (GESAMP 1990, p. 19)

Discarded plastics pose a threat both to marine species and to coastal regions. Discarded nets carry out so-called "ghost fishing", continuing to trap animals as they drift through the water. Band-shaped packing materials can encircle marine mammals fish, or birds, forming a girdle which tightens as the animal grows. Marine organisms also ingest plastics, which can kill them or reduce the nutritional value of their food intake. In addition to their harm to marine life, plastics wash up onto beaches world-wide. Wood used for dunnage, if not grated or pulped can damage small boats which run into it.

Annex V of MARPOL 73/78 regulates the discharge of garbage from ships. All discharge of plastics is prohibited anywhere in the world. Wood dunnage may be discharged beyond twelve nautical miles from the shore if it has been pulped. Food waste may be chopped up and discharged at sea. Unfortunately, monitoring and enforcing these regulations is very difficult. Landside disposal of dunnage and plastics is quite expensive, so vessels have a strong incentive to dump at sea. Determining the amount of rubbish discarded is also difficult, and even estimated data are not available. Proposals under consideration to improve enforcement of these provisions include requiring vessels to record the rubbish they accumulate and how they manage it. When the route and number of people on board are known, it should be feasible to track obvious discrepancies in such records. Because data are not available about current discharges, however, it is hard to assess how much additional rubbish would result from increased ocean freight.

C) Accidental Spills

Spills from waterborne vessels are one of the major sources of water pollution from shipping. They are of several types. Cargo spills frequently occur while loading or unloading in port, due to handling errors or equipment problems. Such spills are typically relatively small in volume. They may be of any kind of cargo, though petroleum products (primarily cargo rather than fuel) and other chemicals are most common. Spills of non-hazardous cargo are more common than spills of toxics or flammable materials, because the precautions taken in handling dangerous products tend to promote much greater vigilance and far fewer careless spills.

Much less common, but potentially more dangerous, are cargo spills which occur when a boat runs aground or breaks up in bad weather. Such disasters typically occur when boats are moving into or out of ports or in other restricted areas, where there is little or no room for manoeuvring or going off course in case of bad weather. In comparison, in the open ocean, boats can handle storms or high winds with little risk of accident, because if they are blown off course they are unlikely to run into anything.

The table below provides data on oil spills in US coastal waters between 1992 and 1994. They show that relatively few spills are from oil tankers or barges, but those account for a large proportion of the oil spilled. Non-vessel spills, presumably those related to transferring fuel while in port, account for a large proportion of the incidents, though a more modest proportion of the oil. The very large volume of non-vessel spills in 1994 is attributable to one very large non-vessel spill, not to a trend.

Table 3. Oil Spills into US Navigable Waters, 1992-1994

Source	1992		1993		1994	
	Number of Incidents	Volume (in m^3)	Number of Incidents	Volume (in m^3)	Number of incidents	Volume (in m^3)
Tank Ships	193	449	172	264	174	264
Tank Barges	322	567	314	2 651	385	3 331
Other Vessels	4 795	1 513	4 944	1 558	4 736	1 258
Total Vessels	5 310	2 529	5 430	4 473	5 295	4 852
Non-Vessel	4 181	4 599	3 542	3 383	4 145	69 297
Total	9 491	7 128	8 972	7 856	9 440	74 149

Source: US DOT 1995, p. 215, Table 115.

The US Coast Guard has also related total spills of oil and chemicals in US waters to the total quantity of domestic and international cargo moved through US ports. Their data aggregate all spills rather than separating oil from chemicals, but they are nevertheless interesting. They show a decline in spills over the past decade, and might serve as an estimate of spills which could be anticipated with increased transport of freight.

Table 4. US Coastal Oil and Chemical Spills per Gallon Shipped

Year	Total Volume Spilled	Spills over 1 million gallons	Gallons shipped (millions)	Spills under 1 million/ million gallons shipped
1982	3.51	0	259 896	13.51
1983	3.03	0	248 430	12.20
1984	11.37	4.35	255 486	27.48
1985	6.18	0	246 960	25.02
1986	3.58	0	275 478	13.00
1987	4.60	0	287 238	16.71
1988	8.13	3.25	301 938	18.16
1989	13.05	10.50	309 288	8.24
1990	6.68	3.90	307 847	9.03
1991	1.42	0	287 851	4.77
1992	1.67	0	302 673	5.52
1993	1..49	0	312 434	4.77
1994	7.33	5.23	325 837	6.44
1995	1.99	0	333 128	5.96

Source: US Coast Guard 1996.

The cost of these spills is high. UNCTAD (p. 17) estimates that the cost of cleaning up spilled oil in a European port is on the order of $7 000 for several cubic meters of oil; chemical spills, of course, are much more expensive to clean up, as are massive oil spills like the Exxon Valdes. The financial cost of cleaning up spilled oil is a lower bound on its social cost, since it doesn't factor in the ecological harm done by the oil or any harm to health or property. The cost of preventing small spills could be higher than the costs of cleaning them up, however.

OECD (1993) reviews a number of studies which have estimated the financial costs associated with the risk of transportation accidents. Only one addresses the cost of shipping accidents.[1] Focusing on the former West Germany, it values the risk of accident at 0.00005 ECU or 0.0001 DM per tonne-kilometre. This is for inland rather than ocean shipping. To the extent that accidents occur when travelling in restricted channels, inland shipping might have higher accident rates than ocean travel; however the vessels regularly used for inland transport may have also be better equipped to handle narrow channels as well.

D) Air pollution

Freighters are not a major source of air pollution, nor is air pollution one of the major environmental consequences of shipping. Nevertheless, almost all commercial freighters are powered by combustion engines, so they do emit air pollutants. These occur under two distinct sets of circumstances; while underway and while docked (for light, heat, ventilation, etc.). For ocean-going vessels, emissions while in port are of greater concern than those while underway, because they are more likely to affect adjacent populations; at sea, of course, there is no adjacent population.

Several sets of emission factors are available per tonne-kilometre of freight carried for marine vessels, as shown in the table below. The sources do not specify whether these factors apply to inland or ocean shipping, or a combination of the two. They are, however, comparable to Dutch data cited in Table 7, which are explicitly for inland vessel traffic. It should be noted that in September 1997 a new annex to MARPOL 73/78 was adopted to include air pollutant emission levels for marine vessels in the international convention: Annex 6 on The Prevention of Air Pollution from Ships.

Table 5. Marine Air Pollutant Emission Factors, in grams per tonne-km

Pollutant	Befahy	OECD	Whitelegg
CO	0.20	0.018	0.12
CO_2		40	30
Hydrocarbons	0.08	0.08	0.04
NO_x	0.58	0.50	0.40
SO_2		0.05	
Particulates	0.04	0.03	
VOC			0.1

*Source*s: Befahy, Table 4. Hydrocarbon data are for methane only.
OECD (1991), Environmental Policy: How to Apply Economic Instruments, cited in OECD (1993), *The Social Costs of Transport*, p. 19
Whitelegg, John (1993), *Transport for a Sustainable Future -- The case for Europe*, cited in Commission des Communautés Européennes p. 5.

The US Environmental Protection Agency (1985) has estimated more detailed factors for calculating vehicle emissions per unit of fuel consumed. They separate vessels into several categories; commercial steamships, diesel-powered vessels, and motorships used on inland waterways, as well as auxiliary generators used to provide energy while in port. The US EPA emission factors are based on several key assumptions. One is that ocean-going vessels consume 80 per cent of the fuel used underway at slow speeds and the other 20 per cent moving at full power. Another is that diesel vessels consume 20 per cent of their fuel running auxiliary generators while at port and the remainder while underway. A third is that the generators used to provide auxiliary power operate at 50 per cent of their rated capacity on average; this is a sensitive assumption, since electric generators are much more polluting when running below rated capacity than when running at it. This brings them to the following composite emission factors, detailed in Table 6.

Table 6. US EPA Emission Factors for Marine Vessels in kg/103 litres

Pollutant	Commercial Steamships		Diesel Vessels[b]
	Residual Oil	Distillate Oil	
Particulates	2.316	1.796	1.438
SO_x[a]	19.1S	17.0S	13.6S+.64
CO	0.0174	0.5	1.46
Hydrocarbons	0.3452	0.4	3.492
NO_x	5.022	3.196	9.367

Sources: Factors for commercial steamships calculated from US EPA 1985 Table II-3.2 using methodology in EPA 1992 pp. 64-66.
Factors for diesel vessels calculated from EPA 1985 Tables II-3.2 and II-3.4 using methodology in EPA 1992 pp. 64-66.
[a] Emission factors for SO_x are considered theoretical by EPA, and are based on all of the sulphur in the fuel converting to SO_2. "S" refers to the per cent sulphur content of the fuel.
[b] Emission factors for diesel vessels are calculated as 0.8 * distillate oil EF + 0.2 * auxiliary generator emissions.

Several estimates are available of the air pollutants emitted by vessels which travel on inland waterways. One Dutch source provides aggregate data for all inland vessels, while US EPA data disaggregate data for three types of vessels. Unfortunately, the Dutch and US units are not the same, so comparison is difficult; however the Dutch data are comparable to those shown above for maritime activity in general.

Table 7. Emissions from Vessels Travelling on Inland Waterways

Pollutant	Netherlands (in grams/tonne-km)	United States (in kg/10^3 litres of fuel)		
		Rivers	Great Lakes	Coastal
CO	0.11	12	13	13
CO_2	33			
HC	0.05	6.0	7.0	6.0
NO_x	0.26	33	31	32
SO_2	0.04	3.2	3.2	3.2
Particulates	0.02	c. 470 gm/hour	c. 470 gm/hour	c. 470 gm/hour
*Source*s: Dutch data from the *Centraal Bureau voor de Statistiek,* Schoemaker and Bouman, p. 57 US data from US EPA (September 1985) p. II-3-2.				

E) Port and Channel Construction and Maintenance

The construction and maintenance of ports and inland shipping channels poses a number of environmental risks. Of particular importance is the dredging necessary to permit large vessels to enter ports, or to maintain inland channels. In natural estuaries and harbours, there is a balance between sediment transported out to sea and that which flows in with rivers and runoff, which tends to maintain an equilibrium depth. Often this is not deep enough to allow vessels safe passage, so navigational channels and harbours are dredged to deepen them. Because natural forces will tend to build up sediment until the channels and port return to their equilibrium, dredging to maintain safe depth is an ongoing maintenance activity. The need for such dredging is likely to increase in the future as ships become larger and require deeper ports or as inland water transport grows in importance.

Dredging poses direct threats to the areas in which it occurs. It introduces sediment into the adjacent water column, which is then redeposited on the bottom. This has a variety of usually short-term effects on pelagic fish and the benthic community. The suspended sediment increases turbidity, decreasing light penetration and photosynthetic activity. Dredging can also have longer term effects on water circulation patterns, particularly in estuarine areas where water circulation determines the distribution of fresh and salt water, patterns of dissolved oxygen, and other water quality parameters. Changes in salinity can affect the viability of freshwater wetlands and tidal marshes, with consequent impacts on the distribution of marine life. Changes in water circulation patterns can also alter sediment accumulation, thus affecting all ecosystems in the immediate area. (Marine Board 1985, pp. 124-128)

The disposal of dredged material poses serious environmental problems. An estimated 10 per cent of dredged silt is contaminated with oil, heavy metals, nutrients, and organochlorine compounds. Since coastal areas and harbours receive sediment from throughout the associated watershed, these contaminants come from the full range of water pollution sources; industrial discharges, municipal sewage, shipping, land run-off, etc. Data from the London Dumping Convention suggest that in the early 1980s about one billion tons of dredged material (contaminated and non-contaminated) were disposed of annually. (GESAMP 1990, p. 15)

Uncontaminated sediment poses few long-run problems. It can be used as landfill, to reclaim damaged coastal sites, create tidal marsh and wildlife habitat, and so on. Such uses apparently have only minor environmental effects during the operation itself. (Marine Board 1985, p. 129)

Disposal of contaminated sediment, however, is much more difficult. It may be deposited either on land or in open water; neither solution is ideal. Arguments for land disposal emphasise that it is easier to contain the sediment, monitor its environmental impact, and take corrective action, than it would be at sea. However, such disposal poses a number of possible harms, particularly surface or ground water contamination with heavy metals. Strategies to prevent leaching through use of impermeable liners and use of settling and retention basins can minimise this risk. They are expensive, however, and can significantly increase the area required for the containment site. (Marine Board 1985, p. 129)

Open water disposal of dredged materials can have both short and long-term impacts on the marine environment. In the short term, the problems are related to the placement of the sediment, and primarily concern the burial of marine organisms or their exposure to high concentrations of suspended particles, contaminants, and nutrients. Long-term effects are related to the rate of recolonization of the disposal area, the composition of the subsequent biological community, and the physiological and genetic impacts of exposure to contaminants. In the case of toxics which bio-accumulate, long-term concerns also include the possibility of human exposure as the chemicals move up the food chain. Assessment of these problems is difficult. Prevailing opinion among experts is that the effects are still largely unknown, so a cautious approach should be taken to any marine dumping of contaminated sediment. (Marine Board 1985, pp. 131-134)

F) Non-Indigenous Aquatic Species

Shipping is an effective means of transporting aquatic species from one part of the world to another. These so-called "exotic" species are most commonly transported in ballast water, although they may also attach to boat hulls or arrive within goods being transported. Most exotic invaders do not survive in their new environment, and so do not impose significant ecological or financial costs. Some flourish, however, and can crowd out other species or radically change the balance of existing ecosystems. Perhaps the best known recent example is the zebra mussel *Dreissena polymorpha*, a bivalve apparently brought from Europe in ballast water, which has multiplied rapidly in the north American Great Lakes. The mussels contributed to a decline in phytoplankton, an increase in water clarity in the lakes, decreases in the number of fish with planktonic larval stages and changes in habitat for adult fish. Their most costly impact has been to clog water intake pipes and valves in power plants, requiring expensive repairs and technology changes to prevent future problems. (National Ocean Pollution Program 1991, pp. 51-53)

The International Maritime Organisation (IMO), in the context of the MARPOL convention, is developing guidelines on how to prevent the transport of nuisance species in ballast water. The conventional approach is to change the ballast water in mid-ocean, discharging the fresh water picked up in port and replacing it with salt water. The flushing out of the ballast tanks removes most of the fresh water organisms which entered the tanks in port. Any residual organisms are likely to be killed in the tanks by the sea water taken on, since they cannot survive in salt water.

However, concerns remain that this may be inadequate to ensure that all potential nuisance species are removed. A number of other technologies are therefore under consideration by the IMO working group considering nuisance species. Of these the most likely are filtering the ballast water before it is taken on to remove all but the smallest organisms; heating it; or treating it with ultra-violet radiation. Chemical treatment is also being investigated, but is considered likely to create more problems than it solves. The working group expects to recommend guidelines during 1997.

The link between increased freight and growth of nuisance species problems is very approximate. With more trips made, the chance of problems will increase (all else being equal), but establishing a quantitative link is unrealistic. However, before the IMO recommends strategies to address the problem, they will estimate the costs involved. These costs may serve as an indicator of the nuisance species-related marginal cost of additional freight.

III. Air Transport

While air cargo accounts for a very small portion (less than one per cent) of world-wide freight, it is growing rapidly. Moreover, with increasing concern about global warming, concern about aircraft emissions has grown. Air freight therefore warrants consideration beyond its current importance as a means of transport.

Air transportation can threaten the environment in three important ways. Aircraft emissions at take-off and landing contribute to both conventional air pollution and global warming. Emissions during flight contribute to global warming. Noise, pollution, congestion, and other land-use issues pose major problems around airports. Establishing a link between these impacts and air cargo is difficult, however. An estimated two thirds of air freight is carried in commercial passenger flights, and projected increases in air freight are expected to be distributed in much the same way. (Snape and Metcalfe p. 176) For the one-third of air freight carried in cargo planes, allocating the air pollution and noise costs is straightforward. For the two-thirds carried in passenger craft, however, it is hard to know which externalities to assign to cargo and which to attribute to passenger travel.

A) Low-altitude Air Pollution

Low-altitude aircraft emissions include nitrogen oxides, carbon monoxide, and hydrocarbons. They are converted into ozone and other compounds that comprise smog. While aircraft emissions are minor relative to road traffic, and even relative to other means of transporting goods, they are rising faster than other emission sources, with the growth of air travel and air freight. (Vedantham and Oppenheimer 1994, p 1).

Low-level pollution is emitted during the aircraft's landing and take-off cycle (LTO). An LTO comprises the descent or approach of the plane from 915 meters (3000 feet), its touchdown, landing run, taxi in, idle and shutdown, start-up and idle, checkout, taxi out, takeoff, and climbout to 915 meters.

B) Global Air Pollution

Aircraft emissions during high-altitude flight are a significant source of greenhouse gases, although both their quantity and their exact impact are still matters of considerable scientific debate (Vedantham and Oppenheimer 1994, pp. 4-13; Crayston, personal communication). Global aviation accounts for more than two per cent of total anthropogenic carbon dioxide emissions. The altitude at which CO_2 is emitted (i.e. during landing and takeoff or while in flight) has no bearing on its environmental impact. In contrast, NO_X interacts quickly with other atmospheric chemicals, so its impact depends on the composition of the atmosphere where it is emitted. In the upper troposphere (up to 10 kilometres), where most aircraft miles are logged, NO_X emissions may react with other gases to form ozone, which is a potent greenhouse gas at this altitude. Although aviation accounts for only two per cent of global NO_X emissions, their discharge directly into the upper troposphere may greatly increase their impact on ozone formation. Water vapour emitted into the upper troposphere can form ice crystals which may enhance formation of cirrus clouds that trap heat, acting in much the same manner as greenhouse gases. In the stratosphere (from 17 to 30 or 40 kilometres), where some 20 per cent of aircraft fuel burn may occur, the impact of NO_X emissions on ozone can be positive or negative, depending on altitude, latitude and season; little is known about the dynamics of these interactions.

Equally little is known about the quantity of aircraft emissions at these altitudes. Vedantham and Oppenheimer 1994 (pp. 35-40) have made some rough estimates based on anticipated fuel usage and the CO_2 and NO_X content of jet fuel. Using their emission factors and an International Civil Aviation Organisation (ICAO) estimate that civil aviation consumes an average of 510 grams of fuel per tonne-kilometre[2], we can arrive at the following emission factors per ton-kilometre (Table 8):

Table 8. Estimated High-Altitude Aircraft Emissions, in grams/ton-km

Pollutant	Emissions in grams/kg of fuel[a]	Emissions in grams/ton-kilometre[b]
Carbon Dioxide	3.16	1.61
Nitrogen Oxides	10.90	5.56

[a] Vedantham and Oppenheimer 1994, pp. 39-40.
[b] Calculated as (emissions in grams/kg of fuel) x (510 grams of fuel/ton-kilometre).

C) Airport Externalities

Airports are a major nuisance to those who live or work in their vicinity. The major problem is the noise generated by planes taking off and landing. A second problem is the air pollution generated by the planes themselves, by road vehicles bringing passengers and freight to the airport, and in some areas by related industrial development which may spring up around the airport. A third issue in some places is the road traffic congestion created by those needing access to the airport. All of these issues combine in the problem of land use planning around airports, and particularly the conflicts which arise when airports must expand to satisfy increasing demand.

OECD (June 1993) discusses the problems involved in valuing the nuisance created by air traffic noise. One problem is the difficulty in measuring the quantity of noise; while decibels are commonly used, they do not take into account the duration or frequency of occurrence. One valuation method commonly used is differences in property values as a result of noise; while this may be useful for residential properties, it is more difficult for commercial properties. A second valuation method is the cost of reducing or eliminating the noise. A third approach is to calculate the cost of repairing harm caused by noise, typically health care costs. The study cites one estimate of the social cost of air cargo, at 2.3 ECU per 100 tonne/km.[3] However, it does not explain how this estimate was derived.

Several general strategies are available to address the externalities created by airports. One is to reduce the noise generated at landing and take-off. Noise standards categorise aircraft into two "chapters". Chapter 2 aircraft are those which were certified based on prototypes built before 1977, while Chapter 3 aircraft were certified based on later prototypes. Chapter 2 aircraft are being phased out gradually, and are expected to be out of use by 2002. However, US and European efforts to ban Chapter 2 aircraft from their airports in the late 1980s met with resistance from Third World airlines, which are more likely to be flying the older planes. An ICAO-negotiated compromise set the 2002 date and ensured that each individual plane would have a flying life of 25 years. Thus airport noise should begin to decline as we approach 2002 and the older, noisier planes are no longer in use. (Crayston, personal communication)

IV. Trucking

The environmental impacts of trucking have received a great deal of attention, particularly in comparison with the impacts of rail. Trucking poses threats to the environment from two major quantifiable sources, air pollution and noise. In addition, the use of trucks contributes to land-use related environmental stresses and to the environmental impacts of accidents. On the former issue, the general issues have been discussed above in the consideration of different environmental media. More detailed analysis of the problem by mode of transport requires consideration of local conditions which is beyond the scope of this paper. On the latter, data focus on accidents' cost in human life, rather on their environmental impacts more narrowly defined; therefore this issue is not addressed in this paper.

A) Air Pollution

Many different estimates have been published of truck air pollutant emissions, based on miles travelled, ton-kilometres of goods transported, quantity of energy consumed, and other measures. Even when calibrated in the same units, they vary substantially. Nevertheless, they give a general sense of the importance of the air pollution produced by trucks. They also give a good sense of the relative environmental impacts of truck and rail.

It is useful to bear in mind the many points at which differing assumptions may underlie the available data, which limit the comparability across estimates or across countries. Vehicle emission factors are based on vehicle tests conducted under protocols established by the European Community, the US EPA, and the Japanese government (Cucchi and Bidault 1991). The test cycles vary according to assumptions about truck idle modes, engine speeds, and other driving conditions. The test data are further adjusted to take into account variations in temperature, grade, speed, weight of load, and so on. The calculation of EPA emission factors may offer a typical example (Cambridge Systematics pp. 2-39 to 2-57). Once emissions from new vehicles within a given truck class have been determined in the laboratory, fixed coefficients are applied to adjust for vehicle age. This gives a set of emission factors for a vehicle class based on age of the vehicles. The age distribution of the vehicle fleet in that class is then determined, generally based on motor vehicle registration data. An assumption is then made of how many miles a vehicle of each age is likely to be driven; the expectation is that older trucks will be driven less than new ones. The products of age distribution and mileage are then used as weights to derive a weighted average emission factor for the vehicle class as a whole. This may be further adjusted for speed or particular driving conditions, as well as to control for cold starts, ambient temperature, and whether local conditions are typically mountainous or flat.

The tables below summarise emission factors from a number of sources, developed in several different countries. Because of the variation in the initial test procedures, in the algorithms used to develop overall truck class emission factors, and possibly additional modifications made by the authors of these studies, it is not possible to determine whether the differences among these factors reflect actual differences among countries, or variations in the estimation method. However, they do give a rough idea of the amounts of pollution involved.

Table 9. Truck Air Pollution Emission Factors, in grams/tonne-km

	Kürer[a] (Germany)		Schoemaker & Bouman[b] (Netherlands)				White-legg[c] (Europe)	Befahy[d] (Belgium)	OECD[e] (Europe)
	Local	Long-haul	Trucks	Trucks & Trailers	Truck-tractors & semi-trailers	Road freight overall	Road freight overall	Trucks and semi-trailers > 10 tonnes	Long-distance trucks
CO	1.86	0.25	2.24	0.54	0.34	0.90	2.4	2.10	0.25
CO_2	255	140	451	109	127	211	207		140
HC	1.25	0.32	1.57	0.38	0.34	0.68	0.3[c]	0.92	0.32
NO_x	4.1	3.0	5.65	1.37	2.30	2.97	3.6	1.85	3.0
SO_2	0.32	0.18	0.43	0.10	0.11	0.20	n.a.	n.a.	0.18
Particulates	0.30	0.17	0.90	0.22	0.19	0.39		0.04	0.17
VOC							1.1		

n.a. not available
[a] Kürer 1993, Table 5
[b] Schoemaker and Bouman p. 57, Tables 14 & 15
[c] Whitelegg, John (1993), *Transport for a Sustainable Future -- The case for Europe*, cited in Commission des Communautés Européennes p. 5. HC data are for methane only.
[d] Befahy 1993, Table 4
[e] OECD (1991), *Environmental Policy. How to Apply Economic Instruments*. Cited in OECD (1993), *The Social Costs of Transport* p. 19.

More disaggregated data on emission factors are available from US EPA. They are expressed in grams per mile, rather than grams per ton-kilometre. Emissions of some pollutants vary with speed of travel, while for others the variation across vehicle types is more important, as shown in the two tables below, Table 10 and Table 11. It should be noted that in the United States, cleaner new truck engines (and rebuilt engines) will be required in the model year 2004

Table 10. US EPA Truck Emission Factors for Selected Criteria Pollutants

	VOC (grams/mile)		CO (grams/mile)		NO_x (grams/mile)	
Speed	HDGV	HDDV	HDGV	HDDV	HDGV	HDDV
15 mph	11 726	3 162	163 533	16 063	5 875	17 192
25 mph	7 061	2 175	95 298	9 588	6 416	14 132
30 mph	5 892	1 865	79 005	7 931	6 686	13 513
35 mph	5 109	1 634	69 201	6 866	6 957	13 389
40 mph	4 579	1 464	64 040	6 220	7 227	13 745

Source: Mullen 1996 HDGV = heavy duty gasoline vehicle. HDDV = heavy duty diesel vehicle

Table 11. US EPA Particulate and SO2 Emission Factors, in grams/mile

Pollutant	HDGV	2BHDDV	LHDDV	MHDDV	HHDDV
Exhaust PM10	0.163	0.322	0.972	1.107	1.433
Brake Wear PM10	0.013	0.013	0.013	0.013	0.013
Tire Wear PM10	0.012	0.008	0.012	0.012	0.036
SO_2	0.214	0.223	0.384	0.433	0.539

Source: Mullen.
HDGV = heavy duty gasoline vehicle.
2BHDDV = Class 2 (8 501-10 000 lb) heavy duty diesel vehicle.
LHDDV = light (10 001-19 500 lbs) heavy duty diesel vehicle.
MHDDV = medium (19 50l-33 000 lbs) heavy duty diesel vehicle.
HHDDV = heavy (>33 000 lbs) heavy duty diesel vehicle.

B) Noise

Trucks are a significant source of road noise, and they may be a more significant source of noise than other modes of freight transport. Kürer has provided data on the actual level and quantity of noise produced by trucks, using data from the (former) Federal Republic of Germany. Individual vehicles would produce the following volumes of noise when passing at a distance of 25 meters:

Table 12. Noise Level of Individual Passing Trucks, in dB(A)

Truck Size	Noise level in built-up areas (travelling at 30-60 km/hour)		Noise level on open road (travelling at 60-100 km/hour)	
	Mean	95th percentile	Mean	95th percentile
Petrol delivery van	75	78	77-78	82-83
Diesel delivery van	75	80	79	84-85
Truck under 70 kW	78-79	83-84	81-82	85-86
Truck 70 kW - 105 kW	79-80	84-85	82-83	88
Truck 105 kW - 150 kW	81-82	86-87	83-84	89
Truck over 150 kW	84	90-91	84	91-92

Source: Kürer (1993) Figure 6

Relating this noise to the amount of freight transported, Kürer finds that both a five-tonne truck doing local hauling at a speed of 30 to 60 km/hour and a nine-tonne truck doing long-distance hauling at a speed of 60 to 100 km/hour emit the same estimated 64 dB(A) per tonne (Kürer, 1993, table 16; it is not clear how he relates volume to load weight). Comparing the noise emitted during a one-hour period in which 1000 tonnes are transported, he finds that local (5-tonne) trucks emit a noise level of 68 dB(A) to do the work while the long-haul (9-tonne) trucks emit a noise level of 67 dB(A) for the same load (Kürer, table 18). This suggests that for a given quantity of freight transported across a particular spot, the size of the truck does not make a major difference in terms of noise produced; more smaller trucks or fewer large ones balance out to a similar level of annoyance.

The ECMT (forthcoming) has reviewed a number of studies of the social cost of truck noise, expressed as a share of GDP. The studies apply different methods for estimating the cost of noise; valuation of damages imposed on health or property values, costs of preventing noise, and contingent valuation of willingness to pay to avoid noise. Within each category, the methods used vary. Nevertheless, the authors feel they can draw some general conclusions. First, they find that estimates of willingness to pay are consistently higher than damages or preventive expenditures, which they attribute at least in part to people giving higher values to the problem when it is hypothetical than when asked to write a check. They also observe that the costs of preventive action and damages are about equivalent, and therefore conclude that is preferable to make the necessary preventive expenditures than to bear the damages. Table 13 below summarises their findings:

Table 13. Cost of Truck Noise as a Share of GDP

Method	Country	Author and Year	Value as % of GDP
DAMAGE COST METHODS			
Fall in property value	Norway	Ringheim, 1983	0.06
Fall in property value	France	Lambert, 1986	0.08
Fall in property value	France	Tefra, 1990	0.06
Lost output, fall in property value	FRG	Wicke, 1987	2
Fall in property value	Sweden	Hansson & Markham, 1992	0.4
Fall in property value	Switzerland	Jean-Renaud, 1988	0.3
OVERALL FALL IN PROPERTY VALUE			0.20 - 0.40
PREVENTIVE MEASURES			
Prevention in urban environment	France	Tefra, 1990	0.02
Prevention expenditure	France	Perez, 1990	0.03
Prevention expenditure	France	CETUR, 1993	0.36
Prevention expenditure	Finland	Himanen, 1992	0.3
Prevention expenditure	Finland	cited by INRETS, 1989-91	0.3
Prevention expenditure; 55 dB(A)	FRG	Planco, 1985	0.15
Prevention expenditure	FRG	Diekmann, 1990	0.2
OVERALL PREVENTIVE MEASURES			0.20 - 0.40
WILLINGNESS TO PAY			
Desirable expenditure	France	OECD 1990	0.2 - 0.6
Willingness to pay	FRG	cited by INRETS, 1989	0.6 - 0.75
Willingness to pay and damage to health	Germany	Weinberger, 1992	1.4
Willingness to pay	Germany	INFRAS/IWW, 1994	0.7
Willingness to pay	Sweden	INFRAS/IWW, 1994	0.2
Willingness to pay	Switzerland	INFRAS/IWW, 1994	0.6
OVERALL WILLINGNESS TO PAY			0.65

Source: ECMT (forthcoming).

V. Rail

Railway travel is generally held up as a less environmentally damaging mode of land transportation than trucking. Data on air pollution certainly confirm this. For noise it is somewhat less evident, but rail may be less harmful in that respect as well. As has been discussed above, the relative impact of rail and trucking with respect to land use and habitat fragmentation cannot be assessed without more detailed consideration of local conditions; both modes of transport have the potential to generate significant harm to adjacent ecosystems.

A) Air pollution

Air pollution from railways is substantially lower than from trucks. Trains in North America tend to be powered by diesel-fired electric generators, which then use electric power to move the locomotive which pulls the rest of the train. In Europe most trains are electric only; it is therefore the structure of power generation which determines air pollution characteristics. The table below provides emission factors for rail, in grams per tonne-kilometre, from the same studies which were cited in Table 9 above for trucks. Although, as elsewhere, this table shows substantial variation among the studies, the large difference between rail and trucking in air pollutant emissions is consistent.

Table 14. Rail Air Pollution Emissions, in grams/tonne-km

Pollutant	Kürer[a]	Schoemaker & Bouman[b]	Whitelegg[c]	Befahy[d]	OECD[e]	Truck Emissions[f]
CO	0.15	0.02	0.05	0.06	0.15	0.25 - 2.4
CO_2	48	102	41		48	127 - 451
HC	0.07	0.01	0.06[c]	0.02	0.07	0.3 - 1.57
NO_x	0.4	1.01	0.2	0.40	0.4	1.85 - 5.65
SO_2	0.18	0.07			0.18	0.10 - 0.43
Particulates	0.07	0.01		0.08	0.07	0.04 - 0.90
VOC			0.08			1.1

[a] Kürer 1993, Table 5
[b] Schoemaker and Bouman, p. 57, Tables 14 & 15
[c] Whitelegg, John (1993), *Transport for a Sustainable Future -- The case for Europe*, Commission des Communautés Européennes p. 5. HC data are for methane only.
[d] Befahy 1993, Table 4
[e] OECD (1991), *Environmental Policy. How to Apply Economic Instruments*. OECD (1993), p. 19.
[f] From Table 9 above.

US EPA emission factors for locomotives differentiate among engine types for some pollutants, and average emission factors explicitly reflect the composition of the US fleet. In the United States, however, emissions controls on locomotives will be imposed in the future.

Table 15. US EPA Railway Air Pollutant Emission Factors in kg/litre of fuel

Pollutant	Engine Type					Average (based on US locomotive fleet)
	2-stroke supercharged switch	4-stroke switch	2-stroke supercharged road	2-stroke turbocharged road	4-stroke road	
Particulates						3.0
SO_X						6.8
CO	10	46	7.9	19	22	16
HC	23	17	18	3.4	12	11
NO_X	30	59	42	40	56	44
Aldehydes						0.66
Organic acids						0.84
Source: US EPA (1985), p. II-2-1 to II-2-2, Tables II-2-1 and II-2-2.						

B) Noise

The noise nuisance posed by rail is generally considered to be less than that posed by trucks. This is in large measure because railway noise is intermittent, whereas highway noise (including trucks) tends to be fairly constant. However, estimates of the noise created by an individual train passing are higher than those for trucks. US DOT/BTS (1994) gives the noise level of a diesel train at 100 dB(A), as compared with 90 to 95 for trucks (p. 168). Kürer places the average noise level of a train at 90 dB(A) as compared with 71 to 74 for trucks. On the other hand, his estimate of decibels per tonne are slightly lower for trains than for trucks; 63 for the former as compared with 64 for the latter (Kürer, 1993, table 16).

VI. Pipelines

Pipelines are used primarily to transport oil and natural gas products. In the United States they transport some 56 per cent of all ton-miles of crude and processed petroleum. Of the remainder, 39.7 per cent are transported by water, 2.9 per cent by truck, and 1.4 per cent by rail (US DOT/BTS 1995b, p. 212). Pipelines account for virtually all transport of natural gas products (Batten, personal communication). Relatively short pipelines also transport other products, including anhydrous ammonia (a fertilizer), propane, butane, other chemicals, and even ink; however these are quite minor relative to oil and gas pipelines. The environmental risks posed by oil and gas pipelines are of three kinds; accidents, air pollutant emissions, accidents, and habitat fragmentation threats to the ecosystem through which the pipeline passes. The first two problems are discussed below. The third has been discussed above in the first chapter of this paper.

A) Accidents

Pipeline accidents can have a number of different impacts. Obviously the most serious are injuries and loss of life; most effort to monitor pipeline accidents focus on these concerns. In addition, spills of petroleum products can contaminate land, surface water, or ground water. Accidental escapes of natural gas apparently do not pose a significant environmental threat, because it is light and disperses quickly in the atmosphere.

The table below summarises US data for 1992 (the most recent published) on oil and gas pipeline mileage, quantity transported, and accidents. Comparable data are not available for other modes of transport, so it is not possible to establish definitively the relative safety of pipelines and other modes of transport. For natural gas this is to be expected, since almost all of the product is transported by pipeline. For crude oil and petroleum products the major alternative to pipelines is inland waterways. While acknowledging that good data do not exist (for the United States, at least), both pipeline experts and petroleum industry associations feel that pipelines are by far the safest way to transport petroleum and natural gas, because they minimise contact with the potentially hazardous products.

Table 16. US Pipeline Safety Statistics

	Pipeline Mileage	Volume of Product Transported	Accidents	Barrels Lost	Injuries	Fatalities
Oil/Liquid	199 023[a]	588 800 10^6 ton-mile[a]	223[b]	152 320[b]	38[b]	5[b]
of which: crude oil	112 990[a]	334 800[a]	80[b]	67 357[b]	1[b]	1[b]
diesel fuel	86 033 (pipeline mileage for petroleum product lines)[a]	246 700 million (intercity ton-miles for petroleum product lines)[a]	11	2 220	2	0
fuel oil			17	4 522	0	0
gasoline			49	36 752	0	0
jet fuel			12	4 317	0	0
LPG			11	11 132	31	3
LNG			11	14 936	2	0
turbine fuel			7	2 465	0	0
misc.			7	6 775	0	0
Gas Pipeline	1 167,700[c]	20 298,119 million cubic ft[c]	180[d]	n/a	87[d]	15[d]

[a] US DOT/BTS 1995b, p. 55 Data on ton-miles are for inter-city transport of petroleum products; the source does not indicate whether petroleum consumed as pipeline fuel is included in this figure.
[b] US DOT/RSPA, Table 15. These figures apply to all liquids transported in pipelines, not only to petroleum products.
[c] US DOT/BTS 1995b, p. 58 Data on cubic feet-miles are not available for natural gas. Volume of product includes the gas consumed as pipeline fuel.
[d] US DOT/RSPA, Tables 9 and 10.

B) Air pollution

Goods move through pipelines because they are either pumped (for liquids) or compressed (for gases). The fuel flowing through the pipelines serves as the energy source for the pumps and compressors, which emit air pollutants as would any other machine. The only available aggregate estimates of pipeline emissions do not distinguish between oil and gas pipelines. They do suggest, however, that pipeline transport generates substantially less air pollution than the predominant alternatives.

Table 17. Pipeline Emissions, in grams/tonne-km

Pollutant	Emissions in grams/tonne-km	Truck emissions (for comparison)	Marine emissions (for comparison)
CO_2	10	207	30
CH_4	0.02	0.03	0.04
VOC	0.02	1.1	0.1
NO_x	0.02	3.6	0.4
CO	0.00	2.4	0.12
Source: Whitelegg, John (1993), *Transport for a Sustainable Future -- The case for Europe*, Commission des Communautés Européennes p. 5.			

VII. Intermodal

The transport of freight frequently involves shifting from one mode to another between origin and final destination. The transfer of marine freight to land transport raises perhaps the majority of concerns relating to intermodal transport; transfers between truck and rail are also a source of threats to the environment. The problems posed by intermodal terminals are in many respects similar to the neighbourhood externalities of airports, particularly with respect to neighbourhood conflict and the institutional division of authority.

Four general scenarios are possible for transferring freight off boats. Containers can be unloaded by crane directly from the boat onto rail at the dock. More often, containers are unloaded onto trucks which carry the containers to a railhead elsewhere within the port, to a railhead off the port, or to their final destination. The rail-on-the-dock option is by far the best, both in terms of speed of transfer and in terms of environmental impacts. On-dock rail lines eliminate the need for two separate mode changes -- boat to truck and truck to rail -- with all the congestion, pollution, and time loss entailed. However, many ports, particularly old ones, are not equipped with rail on the dock. Old ports are typically located in built-up areas, and the space is not available to bring rail lines up to the ships.

The use of trucks to move containers to the railhead is called drayage, and it is the major source of both inefficiency and environmental problems at ports. In a large port thousands of trucks are required each day for drayage; the port of Los Angeles, for example, now has 50 000 trucks coming in each day for this purpose. Drayage vehicles are a substantial source of noise, air pollution, and traffic congestion, both within the port and in the surrounding neighbourhoods. On the port they typically move slowly, idle their engines, and make frequent cold starts, so emissions are worse than they would be on the road. When the railhead is within the port (though not on the dock) the impact of road congestion and air quality on the surrounding neighbourhood is much less. However, vehicles which only operate within the port may not be subject to emissions controls which apply to other trucks, so they may generate more air pollution than would off-port vehicles.

Generalising about the environmental impact of these mode transfers is difficult, since it is very much related to the layout and volume of traffic at each terminal. However, an increase in freight moved, particularly an increase in marine freight, will result in a commensurate increase in the environmental problems posed at the terminals. The solutions to this problem can involve bringing rail lines onto the port and if possible down to the docks, expanding freight handling and storage space on the port, improving road access to bring trucks to the port, and so on. All of these solutions call for additional land within or adjacent to the port area. However, marine ports often do not have room to expand. Increasing demand for waterfront land in urban areas has raised the price of land needed for port activities, making it expensive and politically difficult to reserve the space for shipping. In some cases the construction of improved roads to alleviate congestion faced by trucks accessing the port attracts other development on adjacent land, defeating the purpose of the investment in terms of facilitating intermodal transport. Moreover, in many cases the land adjacent to ports is marsh or other wetlands. Rigorous environmental measures designed to protect wetlands make provision of adequate intermodal facilities at the port very difficult.

As in the case of airports, the complex patterns of overlapping jurisdictions with authority over the port, local land use, and environmental controls complicates the process of solving these problems. Residents near the port object to the dirt, noise and traffic which it creates, and often oppose any expansion of port activities as a result. Municipal or other local governments have jurisdiction over adjacent land use and transportation issues; they are caught between protecting the quality of residential neighbourhoods and seeking the economic activity associated with the port. Ports are typically run by regulated independent public authorities with no jurisdiction over land use. Their ability to make investments which would facilitate port operations, thus enabling them to compete for shipping, is constrained both by local land-use concerns and by national environmental concerns.

VIII. Comparisons and Conclusions

This review has attempted to summarise the environmental impacts of freight, in order to provide information concerning the impacts of trade liberalisation on the environment through transport of goods. The focus has been on describing the major mechanisms through which freight transportation can affect the environment, and identifying ways to quantify those links on a per-unit of good basis.

Some clear conclusions can be drawn by comparing the data presented in this paper. Data on air pollution permit the most straightforward comparison. As the table below shows, despite substantial variation among the estimates within each transport mode, trucks are clearly much more polluting than trains or boats. This applies across all pollutants. The data suggest that rail may be more harmful than marine transport; however this is much less clear. The use of different methodologies to derive the emission factors may well be more significant than any possible generalisation about the differences between marine and rail transport based on these data.

Table 18. Air Emission Factor Ranges for Truck, Rail, and Marine, in grams/tonne-km

Pollutant	Truck	Rail	Marine
CO	0.25 - 2.40	0.02 - 0.15	0.018 - 0.20
CO_2	127 - 451	41 - 102	30 - 40
HC	0.30 - 1.57	0.01 - 0.07	0.04 - 0.08
NO_x	1.85 - 5.65	0.20 - 1.01	0.26 - 0.58
SO_2	0.10 - 0.43	0.07 - 0.18	0.02 - 0.05
Particulates	0.04 - 0.90	0.01 - 0.08	0.02 - 0.04
VOC	1.10	0.08	0.04 - 0.11

Sources: Truck data are from Table 9 above. Rail data are from Table 14 above. Marine data are from Tables 5 and 7 above.

As regards noise pollution, recent data (ECMT, forthcoming) suggest that the mid-point of the range of external environmental costs for road noise is twice as high as that for rail. Moreover, comparison of the social costs of other external environmental impacts (see the table below) also indicates that the average external costs for road are higher than for rail.

Table 19. Comparison of the average external environmental and accident costs of road and rail transport (1991 ECU per 1 000 tonne-km)

External effect	Freight [a] ECU per 1 000 t km	
	Road	Rail
Accidents	7 - 11	0.75
Noise	3 - 7.5	1.8 - 3.5
Local pollution	2 - 8	0.6 - 2
Greenhouse effect	4	1
TOTAL	**16 - 30**	**4 - 7.5**

[a] Provisional figures.
Source: ECMT (forthcoming).

The other types of environmental harm caused by transportation are more difficult to evaluate, for example comparing the impacts of ocean freight with those of other modes of transportation. Although the most serious harm from shipping affects marine life rather than humans, damage to previously intact ocean ecosystems is still a serious environmental issue. Similar problems arise in looking at nuisance species. While some of their harms can be quantified -- notably the infrastructure repair necessitated by the zebra mussels in the North American Great Lakes -- it is difficult to place a value on the disruption of marine ecosystems. While the impact of increased freight on these problems can be described, that impact cannot be easily compared with the threat posed by different modes of transport. The same kind of analytical difficulty applies to the issue of habitat fragmentation in critical areas and sensitive ecosystems. In a few cases, such as the construction of roads through the Amazon or the Alaska pipeline, the public has become aware of the ecosystem costs of transport, but even in those cases it is difficult to compare ecosystem harm with more quantifiable harms posed by alternate methods of transportation or with the benefits of building the infrastructure.

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