An Economic Feasibility Study of Short Sea Shipping Including the Estimation of Externalities with Fuzzy Logic

by

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“ἔτι εἰ ὅτι μάλιστα πάντα οὕτως ἔχει καὶ οὐχ οὕτως,
ἀλλὰ τό γε μᾶλλον καὶ ἧττον ἔνεστιν ἐν τῇ φύσει τῶν ὄντων:”

Αριστοτέλης, “Μεταφυσικά - Βιβλίο Γ′”

“Again, however much all things may be “so and not so,” still there is
a more and a less in the nature of things;”

Aristotle, *Metaphysics,* IV, 4, 1592-1593 (Translation by W.D. Ross)

To my late father

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ABSTRACT

The continuing growth of freight transportation has placed significant stress on U.S. and European transportation networks. The dominance of trucking as the main mode of domestic general cargo transportation has caused environmental and societal problems, such as traffic congestion, air pollution, highway accidents, noise, and increased energy consumption. Using inland and coastal waterways, short sea shipping (SSS) can alleviate these problems. SSS can provide efficient and reliable door-to-door transportation as part of an intermodal system, where ships perform the long-haul leg and trucks the short haul, collection and distribution leg.

This dissertation examines the economic feasibility of SSS. The environmental and societal advantages of SSS over competing modes are translated into lower external costs. External costs or externalities are the hidden costs not reflected in transportation prices. This non-inclusion is considered a market failure by economists. Estimating their monetary value is a challenging task. There is an inherent subjectivity, imprecision, and vagueness in current external cost valuation methods. This dissertation addresses this vagueness and imprecision of externalities using fuzzy logic. Fuzzy logic allows us to treat subjectivity with mathematical rigor. Several factors that determine the impact level of transportation externalities are modeled as fuzzy input variables. The outputs are the damage costs of major air pollutants and the external costs of traffic congestion. A fuzzy inference system can provide site-specific monetary estimation for these externalities under defined conditions, instead of average values. The results show that SSS has great

potential for further improving its environmental performance by lowering ship emissions at ports, where most of its external costs occur, by implementing procedures, such as "cold ironing."

The dissertation assesses the feasibility and competitiveness of SSS, in comparison to the all-truck mode, in two realistic business cases of prospective short sea operations along the U.S. East Coast. SSS is highly competitive, due to its significant energy efficiencies. Furthermore, its environmental performance, in terms of monetary impact of emissions is superior, due to location. Combining the internal operational costs with the external cost estimates, the two case studies demonstrate the fair pricing principle in freight transportation, where prices are based on the full social cost of a transportation mode.

CHAPTER 1

INTRODUCTION

Freight transportation, as an activity, is a vital component of the economy, an indicator, and a contributor of economic growth. Transportation networks facilitate the movements of goods and people to markets and are essential for the prosperity of a society and the competitiveness of an economy. Efficient transportation generates logistical savings for businesses, through economies of scale, production, and distribution flexibilities. The current trends of globalization and decentralized production methods have led to a significant growth of both international and domestic freight transportation during the last two decades. The increase of domestic cargo transportation, which has been carried out mostly by trucks, has caused environmental and societal problems, such as traffic congestion, air pollution, highway accidents, and increased energy consumption. In 2007, highway congestion cost an estimate of $78 billion in wasted fuel and lost time (Schrank and Lomax, 2007). Truck traffic contributes significantly to congestion on major coastal interstate highways, such as the I-95 and the I-5. Highway or even rail expansions are too costly and require significant amount time to accommodate this imminent freight traffic growth. The U.S. Federal Highway Administration (FHWA) estimates that the average cost of highway construction is $32 million per lane mile, without including the cost of interchanges, bridges, or other environmental costs.

U.S. international trade, especially imports of containerized cargo, is growing steadily with an average annual growth rate of 8% since 1990. Container traffic through the U.S. ports exceeded 44 million TEUs in 2007 (Figure 1.1). The U.S. Department of Transportation (DOT) forecasts that by 2020, even at moderate rates of domestic growth, the international container trade will double from its current levels (Maritime Transportation System Task Force, 1999). This cargo flow surge has placed significant stress on the U.S. transportation network. Major coastal ports are currently operating near their maximum capacity, suffering from bottlenecks and delays in container movements. According to the American Association of Port Authorities (AAPA), the average dwell time of containers sitting idle in the yard is six to seven days for the U.S. ports, compared with only one to two days or even hours in some Asian ports.

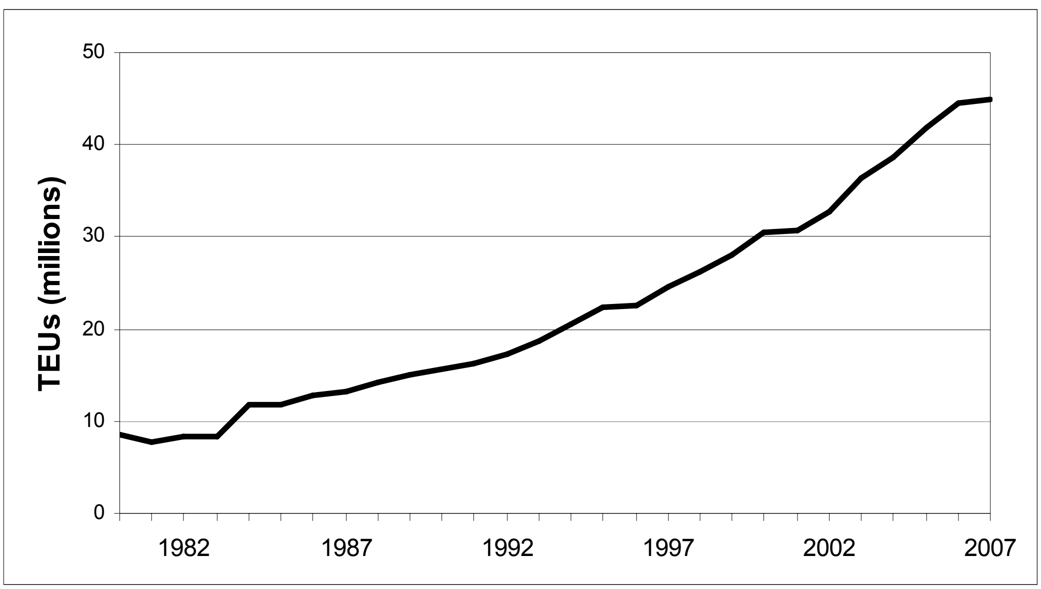


Figure 1.1: Container Traffic at U.S. Ports

(American Association of Port Authorities, 2008)

Short sea shipping (SSS) is a sustainable transportation mode and an environmentally friendly solution for the capacity and mobility problems of the U.S. freight transportation system. Although there is no worldwide consensus on the definition of SSS, the definition given from the U.S. Maritime Administration (MARAD), as “a form of commercial waterborne transportation that does not transit an ocean and utilizes inland and coastal waterways to move commercial freight,” is the most widely accepted. The focal point of SSS in the U.S. is the transportation of containerized general cargo. SSS offers many advantages over the land-based transportation modes; it is more energy efficient, more environmentally-friendly, safer, and requires less public expenditures on infrastructure. It can add more capacity to the transportation network, which is necessary in order to accommodate the future growth of the international trade, at a relatively low cost. Overall, SSS can generate more public and environmental benefits.

The practice of using the waterways for transporting cargo has been known since the ancient times, when commodities were traded with ships traveling within sight from the coasts. In the U.S., cargo is transported along the navigable rivers of Mississippi, Ohio and in the Great Lakes. However, the rapid growth of road and rail transportation in the twentieth century led to the decline of coastal and inland shipping. Currently, only about 9% of the total cargo in weight, mostly bulk commodities, is being transported by water in the Mississippi river system and in the Great Lakes, compared with more than 60% that is being transported by trucks (Bureau of Transportation Statistics, 2006). The recent deterioration of traffic conditions in the land transportation networks has renewed the interest for SSS. Both MARAD and the European Commission (EC) are trying to revive SSS as a new, alternative, and sustainable mode of freight transportation.

In Europe, the EC has actively supported SSS through funding of short sea projects, since 1992, under its common transport policy. SSS has become a fundamental cornerstone of EU's transport policy, a major component of the Marco Polo programs and a part of the Trans-European Networks (TEN-T). In 2001, the 'White Paper on European transport policy for 2010' emphasized the significant role that SSS can play in curbing the growth of truck traffic, rebalancing the modal split and bypassing land bottlenecks (Commission of the European Communities, 2001).

In the U.S., MARAD leads the way in promoting the idea of SSS with its Marine Highway Initiative. In December 2007, the U.S. Senate passed the Energy Law (H.R. 6) with a section dedicated to the promotion of SSS as a sustainable mode that can alleviate highway congestion (U.S. Congress, 2007). Under the latest Energy Law, the DOT will establish a new national network of marine highways for cargo transportation, in order to alleviate congestion from some of the nation's busiest highways. America's Marine Highways program calls for the selection and designation of key inland and coastal corridors as marine highways. Prospective services can be deployed in all of the five regions: U.S. East Coast, U.S. West Coast, U.S. Gulf Coast, Great Lakes, and in navigable rivers in America's heartland. These services will be eligible for up to $25 million in existing federal capital construction funds and will qualify for up to $1.7 billion in federal highway congestion mitigation and air quality (CMAQ) funds.

In the last few months of 2008, several private enterprises emerged offering short sea services in addition to the existing ones. Starting in December 2008, James River Barge Line plans to transport containers up the James River from the port of Hampton Roads to Richmond, shifting more than 4,000 trucks off the nearby I-64. In the Great

Lakes, Great Lakes Feeder Lines Inc., a Canadian company, launched a short sea service by a multi-purpose vessel linking the ports of Halifax, Montreal, and Toronto and plans to expand to U.S. ports. SeaBridge Freight, Inc. of Jacksonville, FL announced that it will launch its short sea container-on-barge service on December 1, 2008, between the Port of Brownsville, TX and Port Manatee, FL in Tampa Bay. The 600-TEU capacity barge (approximately 300 truckloads) will link the large and growing Texas/Mexico and Southeastern U.S. markets, offering complete intermodal, door-to-door services. More ambitious future projects are SeaBridge's proposal for the construction of high-speed, penta-maran, Ro-Pax vessels deployed on the U.S. East Coast and Greenships' proposed project for a fleet of feeder containerships with a battery-powered engine on the West Coast.

The advantages of SSS over the other surface modes are its environmental and societal benefits. These advantages are translated into lower external costs. In microeconomics, external costs or externalities are the hidden costs not borne by the parties involved in an economic transaction and thus they are not reflected in market prices. Transportation related externalities are air pollution and greenhouse gases, traffic congestion, noise, accidents, infrastructure repair and maintenance costs. Quantifying and monetizing these external costs is a challenging task. Several methodologies have been developed in the past few years aiming to put a monetary value on the negative side effects of transportation. Their results have revealed great uncertainties in the estimation of externalities. There are large variations, imprecision, and vagueness in the valuation of these damages. The causes for that are the scientific uncertainties of methodologies, lack of adequate data, and the high subjectivity in the evaluation of the impacts of transportation to the society and the environment. Furthermore, external costs depend highly on the location, the specific site and the population that is been affected. Transportation studies that include external costs usually apply average estimates from previous epidemiological studies and do not differentiate damage costs with location or mode. In addition, there is an increasing need for assessing the full costs of every transportation mode to the society and consequently make fair comparisons among transportation modes. Modal choice decisions should not be based exclusively on the low operating costs of every mode, but on its full costs to the society.

The vagueness, imprecision, and subjectivity of externalities can be treated rigorously by fuzzy logic. Fuzzy logic is a tool that can give a more precise, site-specific, estimation of the external costs in specific locations under certain conditions in a simple way. Therefore, instead of using average estimates for every location and mode, applying human approximate reasoning, we can make judgments about the severity of each externality factor at a certain location.

This dissertation starts with a broad overview of SSS in Chapter 2. Existing operations of the two major forms of SSS are described. The European experience on SSS and the research conducted both in the EU and in the U.S. is documented. In chapter 3, the advantages of SSS over the other surface modes and the current obstacles hindering its expansion are described. An assessment of SSS's competitiveness is performed by conducting a Strengths-Weaknesses-Opportunities-Threats (SWOT) analysis, listing the favorable and unfavorable, internal and external factors for the future growth of SSS. The major advantages of SSS are its significantly lower environmental and social costs. These costs are called external costs or externalities, as chapter 4 describes. In microeconomics, external costs are the hidden costs not reflected in transportation prices and are considered market failures. Chapter 5 presents the current estimation methodologies for transportation-related externalities. However, there are large uncertainties and variations, in the form of vagueness, imprecision, and subjectivity in the estimation of external costs. These uncertainties can be tackled by fuzzy logic, as chapter 6 describes. Chapter 7 formulates the problem of full marginal social pricing. Finally, we try to apply all the above cost estimations in realistic business cases involving SSS operations in chapter 8. Chapter 9 includes the conclusions, recommendations, and guidelines for future research.

CHAPTER 2

OVERVIEW OF SHORT SEA SHIPPING

In this chapter, the basic forms of SSS are described and several studies, reports, and promotional efforts in the U.S. and in Europe are reviewed. Finally, we assess the competitiveness of SSS and its prospects in the U.S..

2.1 Two Types of SSS Operations

There is no strict taxonomy of SSS. SSS can be categorized according to the type of transported cargo, the types of vessels, or the waterways that are being used. In the U.S., there are two major types of cargo units for the transportation of general cargo; the freight containers, conforming to the International Standards Organization (ISO) standards of construction and dimensions, and the truck-trailers or semi-trailers. The ISO containers appear primarily in two standardized sizes: twenty feet long or Twenty-foot Equivalent Units (TEU) and forty feet long or Forty-foot Equivalent Units (FEU). They represent the majority of international general cargo traffic at the U.S. ports. Trailers, mostly 53-foot long, are the dominant truck-mode cargo units on highways, used for the transportation of domestic cargo, i.e. cargo that originates from a U.S. source. SSS can provide transportation options for both of these types of cargo. Small containerships, i.e. feeders, with lift-on lift-off (Lo-Lo) capability or container barges are suited for container transportation on coastal or inland waterways. Respectively, vessels that can transport truck trailers and other form of wheeled cargo are the roll-on roll-off (Ro-Ro) ships. Table 2.1 presents a list of existing short sea services in the U.S. and the geographical area where they operate, which is also is depicted in Figure 2.1. Most of them, however, operate in non-contiguous trade lanes, where they have captured captive markets due to limited competition.

Table 2.1: Existing Short Sea Operations in the U.S.

Company name	Vessel type	Geographical area
Alaska Marine Lines	Container barges	Washington state - Alaska
Bridgeport Feeder Service	Ro-Ro ships, container barges	New York - Connecticut
Columbia Coastal Transport	Container barges	U.S. East Coast-Bahamas
Crowley Maritime	Lo-Lo, Ro-Ro ships	U.S. East Coast-Caribbean, Mexico
Foss & Tidewater Barge Lines	Container barges	Columbia/Snake river
Horizon Lines	Lo-Lo ships	WA-AK, CA-HI, U.S. East Coast-Puerto Rico
Osprey	Container barges	Gulf Coast, Mississippi river
Totem Ocean Trailer Express	Ro-Ro ships	Washington state - Alaska

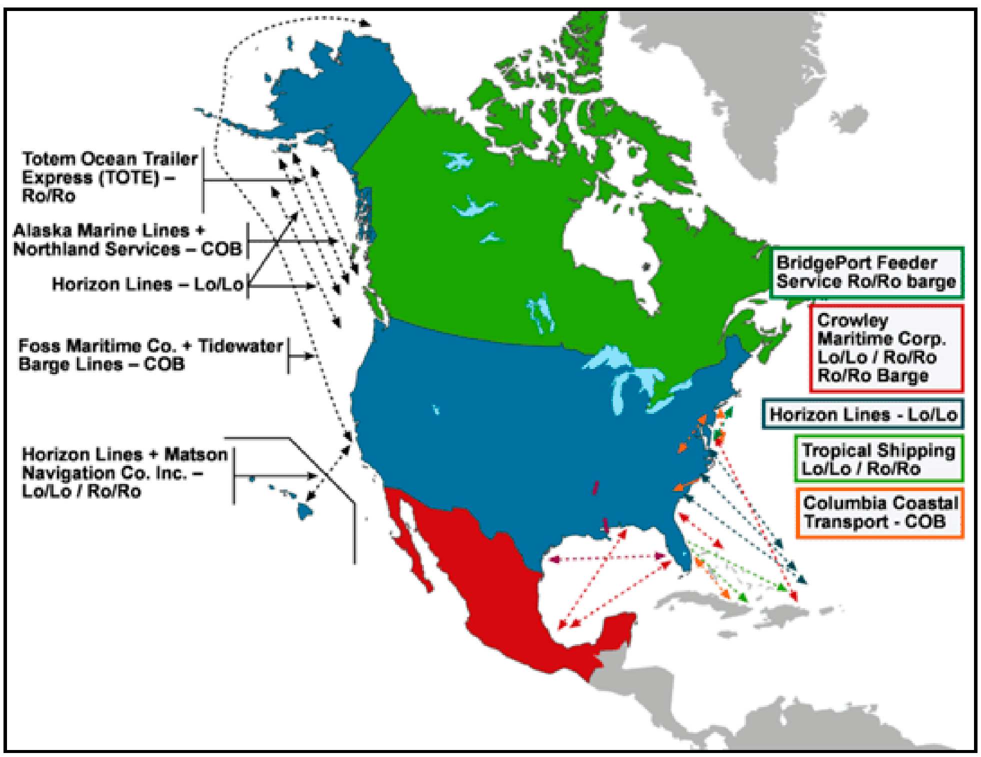


Figure 2.1: Short Sea Operations in the U.S.
(MARAD, 2006)

The following two general applications of short sea services are not an exclusive classification of SSS. These applications can provide realistic solutions for two major freight transportation problems, that of port capacity and of highway congestion. Successful examples of these waterborne freight transportation services can serve as models for future SSS operations.

2.1.1 Feedering International Containers

The rapid growth of the international container trade has created capacity problems and inefficiencies at the major U.S. container ports. The terminal productivity of the U.S. ports, in terms of annual container throughput per acre, is approximately three times lower than the productivity of the major Asian ports. There are also high delays for the trucks, which have difficulties reaching the port terminals due to traffic congestion and port inefficiencies. The upcoming arrival of the new post-Panamax mega-containerships will further deteriorate the situation. A solution to the terminals' efficiency problem is to use smaller feeder ports or satellite terminals and transship directly the containers there for distribution to their final destination. In other words, create a short sea hub-and-spoke system, where the major hub ports receive the international containers and transships them immediately to smaller ports using a fleet of smaller containerships or container barges. This is a form of SSS also known as 'feedering'. The cargo that can be transported this way is mostly international containers.

On the East coast, the Port Authority of New York and New Jersey (PANYNJ), facing port space limitations and an influx of international cargo, established the Port Inland Distribution Network (PIDN). PIDN is a public-private partnership that carries containers from the Ports of New York and New Jersey for distribution to an inland distribution network of satellite feeder ports, such as the ports of Bridgeport in Connecticut, Camden in New Jersey, Providence in Rhode Island, Albany in New York and Boston in Massachusetts using container barges and trains (Port Authority of New York and New Jersey, 2006). PANYNJ estimates that by 2020 container barges will transport almost 20 percent of the port's container traffic. In addition to relieving road congestion, the PIDN will lower the inland distribution costs and it will expand the port's throughput capacity. It will also reduce the truck trips (i.e. vehicle miles traveled), it will improve air quality, it will save energy through reduced truck fuel use and it will overall benefit the environment. The feeder ports can experience economic development by providing new port infrastructure for value-added warehousing and distribution opportunities. However, there are still significant financial and infrastructure challenges for the development of the PIDN.

Another example of container distribution is Columbia Coastal Transport, LLC, which operates a fleet of ten container barges in five sea routes linking major ports in the U.S. East Coast and in the Caribbean. Columbia Coastal is a part of a larger transportation company that offers complete freight transportation services, including truck transportation to the final destination. Annually, it moves approximately 100,000 containers on the U.S. East Coast. Similarly, Osprey Lines LLC operates container barges and offers transportation services in the U.S. Gulf Coast and in the Mississippi river system. Container barges connect Houston, Lake Charles, New Orleans, Memphis, Chicago, Mobile, Pascagoula, and other U.S. Gulf Coast and inland river ports. Several ports, such as the port of Canaveral in Florida and the port of Bridgeport in Connecticut, have already conducted their own feasibility studies in order to position their ports as future feeder ports or distribution centers, which will receive containers from the major hub ports of New York and Hampton Roads.

2.1.2 Transportation of Domestic Trailers

The increasing number of trucks on the major highways has created environmental and societal problems, such as road congestion, air pollution, road accidents etc. SSS offers an alternative method for the transportation of domestic cargo, mainly semi-trailers, using the waterways. Short sea operations can create an intermodal transportation network that will modally shift cargo from the highways to the sea for medium and long-haul distances. Roll-on Roll-off (Ro-Ro) ships can provide an economical and reliable way for truck-trailer transportation in geographical areas such as the U.S. East and West Coast, the Gulf of Mexico and the Great Lakes. For long distances, SSS can be very competitive due to economies of scale and its fuel efficiencies. Trucks will do the short-haul pick up and the delivery of the cargo to its final destination, i.e. ‘drayage’.

Examples of such short sea services, in the U.S., are the Totem Ocean Trailer Express Inc. (TOTE) and Crowley Maritime Corporation. TOTE operates a fleet of Ro-Ro cargo ships from the U.S. West Coast to Alaska, between the ports of Anchorage and Tacoma, Washington. Additionally, TOTE provides overland highway and intermodal connections throughout greater Alaska, the lower 48 States, and Canada. Crowley operates ocean cargo carrier services between the U.S. and the Caribbean. Its services include regularly scheduled liner operations for cargo shipped in containers or trailers.

Several other successful short sea services operate in the non-contiguous U.S. domestic trade lanes, such as between the continental U. S. and Puerto Rico, Alaska and Hawaii, which are considered as captive markets with limited competition. It is also noticeable that these successful short sea operations provide complete door-to-door, intermodal transportation services. Therefore, they can offer a business model that can be applied to future short sea ventures in coastal routes.

The Commonwealth of Massachusetts is investigating SSS options for its small- and medium-sized ports, in order to initiate short sea services along the U.S. East Coast and Canada. They focus mainly on domestic transportation of 53-foot trailers using Ro-Ro ships. A proposed short sea service will connect the ports of Fall River and New Bedford, Massachusetts with other major U.S. East Coast ports and will provide a modal shift for freight that is currently moving over the I-95 highway (Reeves & Associates et al., 2006). In Europe, one of the most successful short sea operators is Samskip with a comprehensive transport network, which spans all of Western Europe. Samskip offers frequent services between the European continent and various destinations in the UK, Ireland, Spain, Portugal, Scandinavian countries, Poland, the Baltic States and Russia. Furthermore, it is an intermodal provider that offers fast and reliable service by choosing the optimal geographical and economical routing. Its extensive fleet of containers can move via ship, road, rail or barge.

There is a lot of discussion about what will be the most successful trend for SSS; Ro-Ro ships carrying domestic 53-foot trailers or feeder ships and container barges carrying international containers? The majority of truck traffic on congested highways along the two U.S. coasts, such as the I-95 and I-5, is from truck-trailers. Advocates of

SSS propose a system that will use Ro-Ro ships, which will perform a ferry-type service and therefore will result in removing trucks from the coastal highways. The trucking industry can be a partner for such SSS operations (Leback, 2004). Many truckers have already become supporters of SSS and they view it as a bridge to new businesses rather than a direct competitor. Therefore, alliances or even direct investments from the trucking industry can be expected in the near future. On the other hand, the 'bottlenecks' at the container ports that were caused from the surge of international trade appear in the form of ISO containers. Consequently, port authorities have expressed their interest for short sea feedering services. The PIDN from the port of New York is such a typical concept. Based on the presented two types of SSS, Table 2 summarizes the main characteristics and the differences between a Ro-Ro trailer service and a Lo-Lo container transportation.

Table 2.2: Comparison of the Two Types of Short Sea Operations

Vessels:	**Ro-Ro ships**	**Lo-Lo Feeder ships or Container Barges**
Cargo carrying units:	Trailers (53')	ISO Containers (TEUs or FEUs)
Carrying capacity:	200-500 trailers	500-1200 TEUs
Cargo origin:	Domestic	International
Time sensitivity:	High	Low
Load & unload time:	Low	High
Port turnaround time:	Low	High
Infrastructure costs:	Low	High
Cargo handling costs:	Low	High
Projected required freight rate ($/unit):	High	Low
Potential alliances with:	Trucking industry	Ports

2.2 The European Experience

Since 1992, the European Commission (EC) has supported SSS under its common transportation policy initiatives. Three roundtable conferences dedicated to short sea shipping were organized from 1992 to 1996. These conferences identified the main policies and role of the EU in the development of SSS (Wijnolst et al., 1993 ; Peeters and Wergeland, 1997). In 1995, the Short Sea Shipping Concerted Action was established with the goal of compiling and synthesizing any published research done in the field of SSS. This effort, although it provided a framework for discussion on the major issues and promoted the idea of SSS, it also revealed the difficulties of applying SSS in the transportation reality. The main proposed strategy was the integration of SSS into Europe's intermodal transportation networks. The recommended steps were further cooperation among various transportation modes, alliances among ports, i.e. 'port pairing' and the development of a common system for freight transportation data (Psaraftis and Schinas, 2000). Rail and short sea projects have been financially supported since 1992 under the Pilot Actions for Combined Transport (PACT), a program that was designed to foster innovative actions that could improve the competitiveness of combined transport. From 1992 to 2000, the PACT program financed a total of 167 intermodal projects, with 92 of them funded after 1997. Several short sea operations, mostly in Northwestern Europe, using container barges on inland waterways are considered today as successful models for future SSS applications.

Regardless of these efforts, from 1990 to 1999, SSS increased at a slower rate, 30%, than the road freight transport, which increased by 41% in terms of ton-kilometers. In 2001, SSS had 40% of the total ton-km, while road transport had a share of 45%. In cargo tons alone, road transport is still the dominant mode of freight transportation with about 80% of total tons of freight. European SSS is deployed mostly in longer routes with an average distance of 1385 km, while trucks have an average distance of 100 km. Rail has a small share of freight transportation in Europe (Commission of the European Communities, 1999; 2004a). The lack of sufficient data of the cargo flows, which are necessary to define any modal shift that will create a SSS market, was mentioned as one of the main reasons for the lower than expected results. As another cause, European port authorities are blamed for outdated practices, lack of investments in port infrastructure and for preventing international private operators investing in their port terminal infrastructure.

Despite the lower than expected results, the EC is committed to its support of SSS. A major boost for the promotion of SSS in Europe was the establishment of the Marco Polo program in 2001, as a successor of the PACT program, with the broad objective to enhance intermodality. The program ran from 2003 to 2006, with a total budget of €102 million. Its main actions included the establishment of sixteen national promotion centers, the development of more accurate statistical cargo data, the reduction of the paperwork and improvements in port infrastructure. In July 2004, the EC presented the expanded Marco Polo II program, which includes new initiatives such as the Motorways of the Sea concept in four European regions. The program, which has a budget of €400 million for the 2007 to 2013 period, has also been extended to countries bordering the EU (Commission of the European Communities, 2004b). The EC estimates that every €1 in grants will generate at least €6 in social and environmental benefits. The program has specific targets of cargo volume to be shifted from road to sea mode. Intermodal projects that will contribute to that modal shift will be funded up to 35% from the program's budget. Five types of actions will be supported:

a. Modal shift actions, which will shift cargo from road to rail or SSS.
b. Catalyst actions, which will promote innovative ways in lifting barriers for intermodal transportation.
c. Motorways of the Sea actions that will achieve door-to-door service
d. Traffic avoidance actions that will reduce the demand for freight transportation.
e. Common learning actions that will enhance the knowledge in the freight logistics sector.

In another recent display of strong support for SSS, the EC has funded a research project, named CREATE3S, which aims to develop a new generation of standardized short sea vessels. Utilizing advanced design and manufacturing techniques, the proposed vessel is consisted of two modules, one ship hull module and one large cargo module, which allow it to unload its cargo in one move. The project brings together private and public companies and has a budget of €4.2 million.

The EC initiatives have also triggered scientific research on SSS. Paixão and Marlow (2002) presented the first analysis of SSS as an alternative mode of transportation. They evaluated the strengths and weaknesses of SSS in Europe. The weaknesses are mostly related to the port environment and the quality of service that SSS can provide. Barriers to its expansion are the lack of efficient port operations, unreliable vessel schedules, excessive paperwork and administrative costs. The advantages of SSS are its environmental benefits, the lower energy consumption, the economies of scale, and the lower costs needed for infrastructure expansion. If certain measures are introduced the disadvantages of SSS can be overcome. This was the first research approach, which defined the major issues. In 2005, the same authors published a second article about SSS (Paixao and Marlow, 2005). Given the lower than expected results by that time, they examined the competitiveness of SSS in comparison with the other transportation modes, in terms of the level of service that SSS provides to its customers. Based on a questionnaire sent to 332 industry participants, an analysis of the current short sea market environment was performed. The analysis revealed the low quality of service that SSS provides, but also its poor image compared to the other transportation modes. The short sea shipowners should change their corporate attitude and integrate their businesses to the modern just-in-time logistics as a way to improve the image of SSS. The study used marketing tools in order to determine the performance of SSS on customer service satisfaction.

A different approach on the competitiveness of SSS is presented by Musso and Marchese (2002). They provided an overview of SSS, its different markets and they examined its advantages and disadvantages. They also proposed an economic framework, based on the 'a la Hoover' approach, for the economic and geographical conditions that can make SSS competitive. These conditions define the critical thresholds for the optimal trip distances and the corresponding costs, under which SSS is more competitive than the other land modes. Although, it appears as a simple methodology, the interaction of transportation costs with trip distances is interesting. SSS competitiveness depends directly on the sea-leg distances. Under the term cost the authors mention that all the costs, both internal and external costs, such as environmental and social costs, should be included.

There are several successful and innovative examples of SSS in Northern Europe. At the Port of Rotterdam, about 25% of the container traffic is being carried by container barges on inland waterways. This operation was materialized with the application of modern logistics and integrated business practices among shippers and port operators. The success of container barges in rivers has shown that vessel speed may not be the most important factor for SSS success. On the contrary, investments in vessel capacity and cargo handling equipment may yield better returns and better level of service than investments in ship propulsion (Becker et al., 2004).

The Baltic region has also experienced a significant growth of SSS, where it offered shippers an alternative to deteriorating road conditions and an easy access to Russia's markets. Shipping companies providing short sea operations in the region saw their profits grow substantially in 2006.

There are however some distinct differences between the European and the U.S. freight transportation networks, beyond the given geographical differences. For example, rail mode in Europe is perceived mostly as a passenger transportation mode, while in the U.S. cargo trains have about 30% market share of the freight transportation in ton-miles. Roads in Europe are considered to be more congested and in some areas, like in the Alps and the Pyrenees, road expansion is extremely difficult. The main motivation behind the SSS promotion and expansion is its environmental advantages over the other modes of freight transportation. EU strongly supports SSS by financing projects that can initiate a modal shift from road to sea mode, because of the high external costs of truck transportation.

2.3 Studies Conducted in the U.S.

In the U.S., the Department of Transportation (DOT) has made SSS a high priority in its National Freight Action Agenda. The first SSS initiative was launched in November 2002. MARAD currently leads the way in promoting the idea of SSS with its Marine Highway initiative. MARAD's vision is using SSS to reduce freight congestion on road and on rail transportation networks by increasing intermodal capacity through the underutilized waterways. MARAD has organized four conferences on SSS from 2002 to 2006. The main purpose was to raise awareness on SSS and further stimulate short sea operations. Stakeholders, from public and private transportation sectors, acknowledged the viability of SSS as an alternative transportation mode, but also pointed out existing obstacles, such as port inefficiencies, lack of communication among shippers and shipowners and legal and administrative constraints. The Short Sea Shipping Cooperative Program (SCOOP) was established in October 2003 aiming to further promote SSS and support the cooperation among the transportation modes. Its members are public and private organizations with the goal to exchange information and ideas towards reducing congestion and improving freight mobility in the U.S.. In November 2003, Canada, Mexico and the U.S. signed a Memorandum of Cooperation on Short Sea Shipping. Under the Memorandum, the three countries will cooperate in sharing knowledge and information on SSS, and support any research or development efforts about SSS (Transport Canada, 2003).

All these promotional efforts have already led to some action. In 2007, the U.S. Congress passed the following bills that support the idea of SSS. The 'New Direction for

Energy Independence, National Security, and Consumer Protection Act', (H.R. 3221) and the 'Transportation Energy Security and Climate Change Mitigation Act of 2007' (H.R. 2701) direct the DOT to establish programs for short sea transportation and to designate short sea shipping projects in order to mitigate landside congestion on interstate highways (U.S. House of Representatives, 2007a ; 2007b). These bills would provide $100 million over four years for the financing of short sea operations. Additionally, loan guarantees, up to $2 billion will be available to maritime operators for their short sea projects. The Capital Construction Fund program was also extended and is now offered for the building of short sea vessels as well. Another bill that calls for the repeal of the Harbour Maintenance Tax (HMT) is the 'Great Lakes Short Sea Shipping Enhancement Act of 2007' (H.R. 1499) (U.S. House of Representatives, 2007c). This bill aims at eliminating the repetitive HMT tax imposed on containers each time a vessel enters a U.S. port. The latest Energy Law (H.R. 6) is also a major boost for SSS.

Most of the research that has been conducted so far in the U.S. has been in the form of preliminary and empirical studies that examined the major issues and the viability of certain proposed short sea operations. Their methodology relied on surveys of transportation stakeholders, either by interviews or questionnaires, in order to determine the factors for the success of prospective short sea services in a region. Few of these studies included a market research analysis using cargo flows and projected transportation costs.

The Short Sea Shipping Cooperative Program (SCOOP) has funded three studies on SSS so far. The first study, by the U.S. Merchant Marine Academy, presented an economic analysis of a proposed short sea service with a Ro-Ro vessel designed to carry

80 tractor-trailers (Lombardo et al., 2005). The estimation of the required freight rate revealed that this is lower than the truck's freight rate for distances longer than 200 miles. This analysis however, did not include the terminal costs and the port fees, which in the case of SSS can be a major part of the total transportation cost. The study also presents a survey/questionnaire that was sent to various industry stakeholders, such as port authorities, shippers, and shipowners. The results showed that the market size and transportation demand for short sea services are the most critical factors for them.

A comprehensive analysis of the external benefits of SSS is presented in the second study that was conducted by the National Ports and Waterways Institute at the University of New Orleans (UNO, 2004). These public benefits, such as relieving highway congestion, improving air quality and road safety, are identified and quantified for two cases of prospective short sea operations in the U.S. East Coast; a short route from New York to Boston and a longer route from New York to Miami. In both cases, the use of Ro-Ro ships appear to be very competitive compared with the truck mode in terms of the projected required freight rate, because of the high external costs of the trucks. In the third study by the same institute, these quantified external benefits are applied for the assessment of the Harbour Maintenance Tax (HMT), which is one of the obstacles to the expansion of SSS (2005). The HMT is a fee paid every time a vessel enters a U.S. port for any delivery of domestic or international cargo. The study examined the consequences of a possible elimination of the HMT. The conclusion is that the external monetary benefits of SSS outweigh the revenues from that fee.

Local and state authorities have also taken their own initiatives in promoting the idea of SSS. On the U.S. East Coast, the I-95 Corridor Coalition is an alliance of transportation agencies, twelve U.S. East Coast state departments of transportation, port authorities, private, and public organizations. Their main motivation is the alleviation of highway congestion and the negative environmental impact that the trade growth has caused in the region. The Coalition has developed several transportation projects with state and federal funding. A study, conducted by Cambridge Systematics Inc. for the coalition (Cambridge Systematics Inc., 2005), investigated the current situation and the future opportunities for a modal shift from road mode to sea mode on the U.S. East Coast. The study is based on existing SSS services and extrapolates their results for future operations. The most important contribution of the study however, is that it tries to estimate the commodity flows and thus to identify any potential short sea market in the region. The authors used the Freight Analysis Framework, developed by the U.S. FHWA, to quantify the commodity flows and highlight the trade corridors. The study did not include a cost-benefit analysis of the external and the total costs of such a modal shift. The authors also conducted a survey with interviews of transportation stakeholders in order to assess their interest on SSS. Overall, their findings show a positive attitude towards prospective short sea operations on the East Coast.

On the West Coast, Westar Transport, a trucking firm, investigated the possibility of establishing a short sea service on the U.S. West Coast. They proposed a National Water Highway System with six ships that can carry 20% of the region's general cargo volume. Their published white paper (Silva, 2005) is a description of the proposed operation, which consists of three short sea routes; a north to south Ro-Ro ship service, a southern and a northern barge service. All the services include commercial and military cargo. The paper gives no further information about the costs of these services.

Another study examined the potential of SSS on the Atlantic Coast of Canada and the Northeastern U.S. (Brooks et al., 2006). The authors investigated the demand for short sea services and the forecasted cargo flows in the region. They also surveyed a group of shippers in order to determine the critical service requirements that SSS must fulfill. According to their survey, SSS should provide door-to-door services at a competitive price. There is also a strong need for policy changes from the governments of Canada and of the U.S., in order to make SSS more attractive to shippers. The study revealed marginal opportunities for new SSS services in the region. The case of SSS in Canada was examined, by the same authors, in their 2004 paper as well (Brooks and Frost, 2004). The paper describes in detail the regulatory limitations on SSS in North America, from both Canada and the U.S., which impede the growth of SSS. It also stresses the fundamental issues to be addressed, such as the role of governments in supporting potential short sea operations.

Several port authorities have also conducted their own feasibility studies in order to test how suitable their ports are for future short sea businesses. The Port of Pittsburgh and the Port of Canaveral are two of them. In July 2003, the Port of Pittsburgh Commission completed an ambitious pre-feasibility study for a container-on-barge service that links river terminals from Pennsylvania to Brownsville, Texas and then to Monterey, Mexico. The University of Rhode Island conducted a study for converting a closed U.S. Navy facility at Quonset, Rhode Island into a new container port. The Canaveral Port Authority performed a study in order to determine the possibility of success of future SSS operations (Yonge and Henesey, 2005). This study includes a decision tool that sets weights on the various decision factors, which determine the possibility of SSS in the Port of Canaveral. The decision factors are level-of-service indicators that can facilitate or hinder the establishment of a new short sea service. These weights were determined from previous studies and from one-on-one interviews with SSS stakeholders, i.e. decision makers. Based on the above methodology, a score was estimated, which indicates the probability of success for a new service in the region. The results showed that the Port of Canaveral is in a favorable position for the development of SSS services in the near future.

One of the few published reports, which criticized the direct public funding of short sea services is the study from the U.S. Government Accountability Office (GAO) (2005). The GAO conducted an independent review of SSS and its role in the U.S. transportation system. Their area of interest is mainly the financing of SSS. GAO shows an unfavorable attitude towards the generous public funding of SSS and recommends a more systematic evaluation of public investments, based on detailed and rigorous cost-benefit analyses. GAO also proposes a variety of funding tools such as loans, loan guarantees, tax expenditures and joint private and public ventures for investing in port infrastructure and short sea ventures. The study raises one of the most important questions for the future of SSS, which is if federal funding is justified for the support of SSS.

In a study ordered by the U.S. DOT, the feasibility of SSS was examined in four candidate trade corridors: U.S. Gulf to Atlantic Coast, Atlantic Coast, Pacific Coast, and Great Lakes (Global Insight and Reeves & Associates, 2006). The study assesses the potential costs and benefits from a number of various perspectives, such as transportation cost, travel times and on-time reliability, capital investments, environmental impact, job creation and security issues. Transportation stakeholders were interviewed and they all, including the truckers, openly stated their interest for SSS. All corridors, except the Pacific corridor, appear to have great potential for viable short sea services. There is enough cargo density to support modal shift from truck mode to SSS, although the domestic coastal market is highly unbalanced, with northbound flows significantly higher than the southbound flows. SSS should provide reliable ‘best-in-class’, door-to-door transportation services in a competitive price. The study also recommends that the major U.S. container hub-ports should be avoided for new short sea services, in favor of smaller uncongested ports.

CHAPTER 3

BENEFITS OF SSS AND OBSTACLES TO ITS EXPANSION

The motivation behind the increased interest for SSS in the last few years is its advantages over the other transportation modes in the form of public benefits that it offers. In this chapter, the major benefits of SSS, but also the obstacles hindering its expansion are described. Finally, a Strength-Weakness-Opportunities-Threats (SWOT) analysis that assesses the competitiveness of SSS is performed.

3.1. Benefits of SSS

The rapid growth of trucking as the dominant domestic mode of freight transportation has caused significant environmental and societal problems. These problems can be alleviated though modal shifts to more environmentally friendly modes, such as SSS. SSS is a more sustainable mode of freight transportation that has environmental and societal advantages over the other surface modes. The main benefits of SSS are the following:

a. Improved energy efficiency. The transportation sector utilizes about 30% of all the energy used in the U.S. and freight transportation consumes about 43% of that. Ships are the most energy efficient transportation mode, while trucks are the least efficient (Table 3.1). Economies of scale are in favor of SSS. One 1500-ton barge can carry the equivalent load of 60 trucks or 15 rail cars. Based on the number of miles one ton can be carried per gallon of fuel, an inland barge can travel 576 miles, a train 413 miles, and a truck only 155 miles (MARAD, 1994). This can be translated to significant fuel cost savings.

Table 3.1: Energy Use in Freight Transportation

Mode of transport	Energy use in MJ/ton-km
Road	1.8 - 4.5
Rail	0.4 - 1
Maritime/ SSS	0.1 - 0.4
Inland navigation	0.42 - 0.56

(Source: Kamp, 2003)

b. Reduced air pollution. Petroleum-based transportation is responsible for air pollution, which has major negative impact on human health and the environment. Common air pollutants are the carbon monoxide (CO), nitrogen oxides (NOx), particulate matter (PM), volatile organic compounds (VOC) and sulfur oxides (SOx). In addition to harmful air pollutants, freight transportation accounts for approximately nine percent of the total greenhouse gas emissions in the U.S., of which 60% is attributed to truck transportation (EPA, 1996 ; EPA, 2005). Sea transportation is the most environmentally friendly mode in terms of fuel emissions per ton-mile of cargo. With the exception of sulfur dioxide, due to the existence of sulfur in heavier marine fuels, SSS is a much cleaner transportation mode than truck and rail in both air pollutants and greenhouse gas emissions, such as carbon dioxide (CO_2) (Table 3.2).

Table 3.2: Emissions of Air Pollutants in grams per ton-km for Surface Transportation Modes

g/ton-km	CO	CO_2	NOx	SO_2	CH_4	VOC	PM10
Road	0.2 - 2.4	50 - 333	0.24 - 3.6	0.03 - 0.4	0.2 - 0.9	0.025-1.1	0.005 - 0.2
Rail	0.02 - 0.2	9 - 102	0.07 - 1.9	0.04 - 0.4	0.02 - 0.9	0.01-0.1	0.01 - 0.08
Maritime	0.02 - 0.2	7.7 - 31	0.11 - 0.72	0.05 - 0.51	0.04- 0.08	0.01-0.02	0.002-0.04

(Source: Kamp, 2003)

It is clear that increasing the share of sustainable intermodal transportation, such as SSS, is a way in reducing air pollution. The International Maritime Organization (IMO) has implemented stricter regulation for air pollutant emissions from ships, as a way to make shipping more environmentally friendly, such as the Annex IV (Regulations for the Prevention of Air Pollution from Ships) of MARPOL, which sets limits on sulfur oxide (SOx) and nitrogen oxide (NOx) emissions from ship exhausts (IMO, 2008).

c. Mitigating highway congestion. SSS can alleviate traffic congestion by shifting freight from the highways to inland and coastal waterways. Major highways, along the three U.S. Coasts (East Coast, West Coast and the Gulf of Mexico), suffer from congestion. Trucks currently carry about 60% of the domestic general cargo tonnage and contribute significantly to this problem. Trucks delivering their loads compete with cars for space on highways. This congestion is costly as well. According to the annual urban mobility report from the Texas Transportation Institute ((Schrank and Lomax, 2007), traffic congestion continues to worsen in American cities of all sizes, creating a $78 billion annual drain on the U.S. economy in the form of 4.2 billion lost hours and 2.9 billion gallons of wasted fuel for 2007. The congestion cost of an additional truck trip is the added delay that it causes to other users of the highway. The added delay occurs because the average speed of the vehicles will begin to decrease progressively once the density of vehicles on the road reaches high volume to capacity ratios. This congestion, which is generally associated with peak-hour traffic, is referred to as recurring congestion. A solution to the highway congestion problem could be a change in transportation patterns from shippers, especially for long-haul trips, with distances greater than 500 miles. Shippers should explore alternative modes of transportation, such as SSS, and consider modal shifts from road to water. Trucks would do the short-haul, pick-up and delivery at the start and the end of the transportation chain.

d. Improved road safety. SSS can create modal shifts from truck mode to water mode. Thus, by removing trucks from the highways it can improve highway safety significantly. Trucks are responsible for many fatal highway accidents. On the contrary, shipping is one of the safest modes of transportation.

e. Reduced highway noise. Noise is generally perceived by urban residents as an important problem associated with road traffic, both on highways and local streets. In addition to being unpleasant annoyance, noise contributes to health problems. People feel more directly affected by noise than by any other form of pollution. According to EPA estimates, trucks are responsible for about two-thirds of the highway vehicle noise emissions. There are several characteristics that affect allowable noise levels, such as speed, traffic levels, vehicle weight, and population density. Currently, the EU has established a maximum noise limit of 70dB for urban areas. By removing trucks off the highway, SSS can alleviate noise pollution. Ships are superior with regard to noise pollution, since most of the time they operate away from residential areas, while trains are considered the worst. Noise is a big issue for rail transportation. However, since it is intermittent - not continuous- trucks are considered to cause higher noise problems than trains.

f. Lower infrastructure expenditures. The capital costs needed for the short sea terminal infrastructure are significantly lower then the infrastructure expenditures for the expansion and maintenance of highways. Currently, the cost for a new highway lane is around $32million per lane mile and a new interchange on average costs around $100 million (Cambridge Systematics, 2005).

3.2 Additional Advantages of SSS

In addition to the above environmental and societal benefits, SSS has the following advantages:

a. Expansion of the transportation network capacity. SSS can add more capacity to the stressed freight transportation network of the U.S. in an efficient way. Given that the sea lanes or 'marine highways' are in theory limitless, SSS is by far the easiest to expand transportation system.

b. Port productivity improvement. By swiftly transshipping containers out of a hub-port, using feeder vessels and container barges, SSS can increase the capacity of the port terminals, reduce the 'dwell time' for containers in the yard and overall improve the productivity of the port.

c. Revival of the U.S. maritime sector. The introduction of new waterborne transportation can revitalize the maritime sector in the U.S. There will be new shipbuilding opportunities for new short sea vessels and therefore employment opportunities as well. The new satellite terminals will also create more jobs for the local communities.

d. Corporate social responsibility. The significant environmental and social advantages of SSS over the other transportation modes can lead to different transportation patterns and a change in the attitude of the users of the transportation system, i.e. shippers. Under the corporate social responsibility (CSR) concept, businesses make their decisions considering the interests of other parties, such as the society and the environment, and therefore taking responsibility for the impact of their activities. Companies are taking further steps to improve the quality of life for the local communities and the society in general. Proponents argue that with CSR corporations gain in the long-term in multiple ways by operating with a perspective broader than their own immediate, short-term profits. Several studies have found a positive correlation between social/environmental performance and financial performance (Hardjono and Van Marrewijk, 2001). In the increasingly conscience-focused marketplaces of the 21st century, the demand for more ethical business processes and actions is increasing and additional pressure is applied on almost every industry to improve its business ethics. Often it takes a crisis to precipitate attention to CSR, such as the crisis in the U.S. freight transportation network. It is also suggested that stronger government intervention and regulation, rather than voluntary action, are needed in order to ensure that companies behave in a socially responsible manner.

The freight transportation industry is a competitive industry. Cost and time are the two main decision making criteria for the choice of mode. Transportation companies compete on cost and on the level of service been offered, operating under certain standards and regulations. However, the increased awareness of CSR may force them to move further than their compliance with environmental standards. Shippers will start looking at their environmental impact of their transportation activities and may turn their attention to greener modes. SSS has to promote its image as a sustainable mode of freight transportation and attract environmentally aware shippers. Recent surveys however have showed a lack of awareness about the advantages of SSS among shippers, shipowners, and the public as well (Fafaliou et al., 2006).

3.3 Obstacles Hindering the Implementation of SSS in the U.S.

Despite the wide acceptance of SSS among transportation stakeholders as an environmentally friendly alternative, there are various administrative, legal, operational and financial obstacles that delay the expansion of short sea services. These obstacles are:

a. Additional terminal handling costs and delays. SSS adds extra nodes or transshipment points in the transportation chain. Instead of trucks carrying the cargo directly from origin to destination, short sea vessels take over the longer haulage, and trucks make only the local pick-up and final delivery. At the transfer points or intermodal terminals, there are additional handling costs for the loading and unloading of the cargo.

b. Image problem. Traditionally, SSS has the image of a slow, unreliable and obsolete mode of transportation. Therefore, shippers are currently reluctant to use this new mode. Several surveys revealed that on-time reliability is the most important priority for shippers. Therefore, SSS should provide a high level of service in terms of on-time reliability, in order to compete with the rail and truck mode. An important task of the promotional programs is to alter that image by effectively promoting the advantages of SSS to the shippers and facilitating the cooperation among transportation modes.

c. Harbor Maintenance Tax (HMT). The HMT is assessed as a 0.015% *ad valorem* fee on the value of the commercial cargo, which is transported on vessels using the U.S. ports. Therefore, it is applied on both domestic and international containers that are been transported by vessels, but not on the cargo that is transported by trucks or rail. This is a major impediment to SSS, since it is applied on every transshipment point. Many transportation industry stakeholders are calling on the waiver of HMT for the domestic SSS transportation. The recent repeal of the HMT in the Great Lakes is major support for SSS.

d. Jones Act. In the U.S., as elsewhere, one of the major impediments to the development of coastal shipping is the restrictions of 'cabotage' laws. Certain provisions of the Merchant Marine Act of 1920, also known as Jones Act, which requires that any vessel operating between two U.S. ports must be U.S.-built, U.S.-owned, and manned by U.S. citizens, significantly increases the capital and the operating costs for any short sea operation. Thus, it makes SSS more expensive and less competitive. A study in 1993 suggested that the net cost of the Jones Act to the U.S. economy is $4.4 billion U.S. per year (Hufbauer and Elliot, 1993). As the idea of SSS is gaining ground, the debate over the Jones Act has been reignited. Defenders of the Jones Act claim that it is way to revitalize the domestic shipbuilding industry, by providing financial incentives for shipowners to build in the United States. Also, U.S. shipyard owners claim that they can be competitive for smaller standardized vessel designs with a shipbuilding program for a series of ships to be constructed over the next 15-20 years. On the other hand, shipowners argue that they can purchase SSS vessels from the international ship market for a fraction of what they cost in the U.S.

3.4 Competitiveness Analysis

We summarize the described advantages and obstacles of SSS and we further assess the competitiveness of SSS as a new emerging transportation service by applying the business tool of SWOT analysis. SWOT analysis is a strategic planning tool that evaluates the Strengths, Weaknesses, Opportunities, and Threats of a project, such as a new product, new service, or a new business venture. As new emerging transportation service, SSS has the objective of expanding and gaining modal share. The aim of the SWOT analysis is to identify the key internal and external factors, positive and negative, that are important to achieving the objective. Table 3.3 summarizes the major positive and negative points of SSS that were addressed above in a strengths-weaknesses-opportunities-threats (SWOT) analysis framework.

Table 3.3: Strengths - Weaknesses - Opportunities – Threats (SWOT) Analysis of the development of SSS in the U.S.

STRENGTHS	WEAKNESSES
• High fuel efficiency (per ton-mile of cargo), economies of scale • Environmental benefits: fewer emissions, less air pollution and greenhouse gases, noise • Highway congestion mitigation • Road safety improvement • Low infrastructure costs, port investment • Easy to expand	• Additional nodes (ports) in cargo flows • Terminal handling costs • Low vessel speed • Image problem, shippers' reluctance
OPPORTUNITIES	**THREATS**
• Container trade growth • MARAD and EU promotional policies • Intermodal integration, door-to-door, just-in-time practices, modern logistics • Truck drivers' shortage • Increasing fuel prices • Alliances with trucking industry and port authorities • Alleviation of port capacity problems, i.e. feedering	• Port fees, Harbor Maintenance Tax • More paperwork and bureaucracy • High vessel capital costs (Jones Act) • More sea traffic strain at ports, incompatible port terminals • Rail competition • High levels of sulfur in marine fuel

3.5 Successful Strategies for SSS

The various SSS conferences and several surveys in the U.S. and in Europe have revealed that integration of SSS into the intermodal transportation and logistics chains is imperative for its success. An empirical research study was conducted among short sea shipowners in the UK using the Delphi approach, i.e. a systematic collection of informed independent judgments from a panel of experts. They agreed that SSS should be integrated into the intermodal transportation (Saldanha and Gray 2002). Similar questionnaires among shippers in the U.S. showed that on-time reliability and door-to-door capability are the dominant factors in their choice of transportation mode. SSS should be an integral component of a multi-modal transportation network that will provide on-time reliable service and will meet modern door-to-door and just-in-time requirements. While short sea vessels will take over the long-haul leg of the freight transportation chain, trucks will pick up and deliver the cargo to the final destinations, i.e. drayage. The trucking industry can be an ally and a complementary mode for SSS. Trucking companies can become partners instead of competitors for the long-haul freight transportation and can further assist the growth of SSS. Facing a shortage of drivers, trucking companies have expressed their interest on cooperating with shipowners. Successful operations, such as Osprey Lines in the U.S. and Samskip in Europe showed that working with truckers and becoming intermodal providers were key elements of their success. The business strategies of ocean and rail companies, such as APL and CSX, which also became total intermodal logistics providers, should be examined. Furthermore, port authorities are increasingly interested in 'feedering' their international containers to smaller satellite ports, using SSS, as a way to increase their yard capacity.

The recent developments in supply chain management and the new trends of globalization, decentralized production and outsourcing of logistics to third party providers can benefit SSS even more. Modern logistics has become an essential part of the production process. Supply chain requirements focus not exclusively on speed, but on time reliability, with just-in-time transportation and zero inventory costs. Combined truck and SSS can take advantage of their efficiency, reliability and flexibility. Door-to-door cargo transportation requires the close cooperation of different modes. New technologies, such as cargo tracking, can facilitate that coordination and increase the level of service. The intermodal terminals as cargo transfer points are a crucial part of the intermodal transportation chain. Supply chain management has led to the creation of central trans-shipment facilities or hub terminals. SSS can exploit all these opportunities in logistics and become a modern form of intermodal transportation. Ports should operate as 'seamless' logistics nodes that will offer high level of service by facilitating the smooth transfer of cargo and the coordination among the different modes. Better communication and information exchange among the various modes is necessary. Itineraries and timetables among them should be synchronized. Fast and efficient cargo transfer is a key for the success of SSS.

The port-ship interface is a critical element in eliminating unnecessary delays and friction costs. For example, automation can reduce both the handling costs and the turnaround time of the containers. Concepts such as 'lean port' and 'crossdocking' can increase the terminal efficiency. Various information technology applications, such as Electronic Data Interchange (EDI) for the commodity flows or Intelligent Transportation Systems (ITS) for port traffic management can be applied as well. In the Saint Lawrence Seaway, an automated identification system has been used as a tool for better traffic control and navigation assistance. The Port of Rotterdam established a successful SSS operation using container barges and state-of-the-art cargo handling technology.

The idea of sustainable freight transportation is also gaining ground among its users, i.e. the shippers, the transportation stakeholders and the public. The negative effects of freight transportation can be reduced by introducing more efficient intermodal transportation, creating modal shifts from road to SSS and implementing efficient cargo transfers at port terminals, thus reducing cargo handling time and cost. Network techniques and consolidation of cargo flows can improve the overall efficiency and reduce the total transportation cost significantly. Innovative bundling, i.e. consolidation, networks have emerged as a way of taking advantage the energy efficiencies of rail and barge transportation for the long-haul part and the flexibility of road transportation for the collection and distribution parts. These intermodal transportation systems are broadly recognized as sustainable and environmentally friendly means of freight transportation.

SSS offers many public benefits. Removing trucks from the highways reduces congestion on major trade corridors, contributes to the decrease of road accidents and improves the air quality around the metropolitan areas. Additionally, SSS can alleviate capacity and efficiency problems at the U.S. ports, by swiftly dispatching containers to satellite feeder ports. However, there are administrative and operational barriers that should be addressed. Certain measures from the federal government, such as the waiver of the HMT, and from other stakeholders in the transportation industry could facilitate the expansion of SSS in the U.S.. The studies conducted in Europe and in the U.S. revealed many common issues and challenges that should be addressed, in order for SSS can be a successful alternative mode for freight transportation.

The negative effects of freight transportation, known as externalities, should be identified, quantified and managed with proper internalization approaches and policies designed to promote modal shifts to more sustainable transportation modes. Transportation decisions should be based on a fair and efficient pricing system that will reflect the marginal social cost and will also include all the external costs. SSS is a mode with significantly lower external costs than the currently dominant truck mode. Despite the uncertainties in the estimation of such externalities, SSS can prove that it is an efficient and sustainable mode for the long-haul freight transportation.

SSS should be integrated into the intermodal transportation networks. Vessels will take over the long-haul transportation while trucks will do the pick-up and delivery at the two ends of the transportation chain. Alliances with trucking companies and port authorities could facilitate such integration. In order to attract shippers and ship-owners, SSS must first prove that it is financially viable. Market research studies and cost-benefit analyses should examine the commodity flows on the main trade corridors and identify potential modal shifts, in order to establish successful short sea operations. Transportation cost parameters should be calculated, from start-up capital costs, to operating and cargo handling costs, in order to determine the total logistics costs. Given that the society gets the majority of the external benefits of a modal shift from road to SSS, the role of the government and also several options for financial support, from federal or other public resources, should be thoroughly examined.

The prospects of SSS in the U.S. are promising. Its many advantages can overcome the barriers hindering its growth. SSS offers many benefits to the transportation industry, the society, the national economy and the environment. A few successful existing operations make a strong case in favor of SSS. Its expansion as an integrated intermodal transportation system should be of national interest. Therefore, public and private organizations should collaborate in achieving this goal. SSS can be an efficient, reliable, and environmentally friendly option for relieving highway congestion and increasing the mobility and the capacity of the U.S. transportation network.

CHAPTER 4

DESCRIPTION OF TRANSPORTATION EXTERNALITIES

In this chapter basic elements of the theory of externalities from microeconomics are presented followed by a description of the major transportation-related externalities.

4.1 Fundamentals of Theory of Externalities

An externality is a cost or benefit imposed on people other than those who purchase or sell a product or service and occur when the economic activity of a person or group has an impact on others, who do not participate in that activity. The recipient of the externality is neither compensated for the cost imposed on him nor does he pay for the benefit bestowed upon him. These costs or benefits are named externalities, because the people who experience them are outside or external to the transaction of buying or selling the good or service. There are two types of externalities. Positive externalities exist when a person not involved in the production or consumption process receives a benefit for which he does not pay. The second type of externalities is the negative externalities, when a person who has nothing to do with the sale or purchase has a cost imposed on him for which he is not compensated.

In microeconomics, negative externalities or external costs are market failures that lead to non-optimal or non-Pareto production (Nicholson, 1997). Because of the existence of externalities the market will provide too much or too little of a particular good or service. Freight transportation activities provide benefits and costs to the society as a whole. The internal or private costs are costs that the user pays directly and are reflected in transportation prices and fares. External costs are the hidden costs imposed indirectly to the society and the environment and they are not included in the transportation prices. Therefore, externalities are not taken into account by the market pricing mechanism. As a result, the market's competitive system fails to allocate resources efficiently. In other words, there are market failures and distortions in favor of the more polluting, non-sustainable modes and technologies. This is the case with truck transportation, which has benefited from its low internal costs, aided by the very low fuel prices in the U.S. in the past, and has gained a large modal share.

The transportation market model in Figure 4.1 illustrates the market equilibrium conditions for a transportation mode under different scenarios. The demand for transportation services is given in ton-miles by curve D. The two supply curves, marginal private cost (MPC) curve and marginal social cost (MSC) curve, representing the marginal private (internal) costs and marginal social costs of trucking respectively, provide two market equilibriums at A and B, respectively. Social costs are the sum of private or internal costs and external costs and represent the total (full) cost to the society.

Social Costs = Private or Internal Costs + External Costs

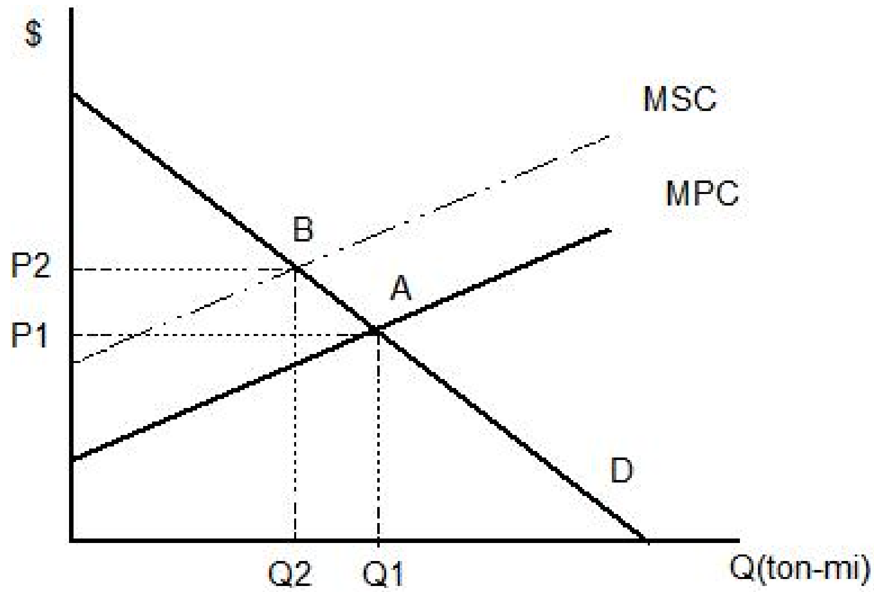


Figure 4.1: Equilibrium Model for Freight Transportation

While the market outcome at equilibrium point B, based on full social cost pricing principles, satisfy optimal resource allocation and economic efficiency criteria, the market outcome at A, based on private costs only, is sub-optimal and it leads to misallocation of transportation resources (i.e. output too large and costs are too low). Therefore, in order to determine the full social costs of a transportation activity we need to estimate both the private (or internal costs) and the external costs.

4.1.1 Fair Pricing

After identifying the negative effects of freight transportation, it is important to translate the negative effects into monetary terms as external costs. These costs should subsequently be internalized or incorporated into transportation pricing. The problem of incorporating externalities into the prices of goods was first identified by Arthur Cecil Pigou (1920), who introduced welfare economics into economic analysis. He made the distinction between private and external marginal costs and he originated the idea that governments can, via a mixture of taxes and subsidies, correct such perceived market failures—or "internalize the externalities,"—through taxes, known for that reason as Pigouvian taxes.

In transportation, the idea of internalizing the external costs is depicted in the fair and efficient pricing. Fair pricing is based on the “Polluter Pays” principle of environmental law. It is an environmental policy principle, which requires that the costs of pollution should be borne by those who cause it. The user responsible for producing pollution should also be responsible for paying for the damages done to others, such as the natural environment and to the society in general. It is regarded as a regional custom because of the strong support it has received in most Organization for Economic Co-operation and Development (OECD) and European Community (EC) countries.

As a result, transportation pricing is based on the full marginal social costs and in that way market failures, resulting from externalities, are corrected (Khinock, 2000). Under full social cost pricing of freight transportation modes, the true costs to society and the environment, after been estimated, are reflected in the prices paid by users. Hence, the modes would be able to compete on an equal basis. In transportation, modal choice decisions should ultimately be based on total marginal social costs. In a market economy, where prices are determined by supply and demand, it is essential that all costs are internalized in order to get efficient resource allocation. In that way, alternative, environmentally friendlier modes can become more competitive by internalization of the external costs. Internalizing external costs into transportation prices can create modal shifts towards more environmentally-friendlier and more sustainable transportation modes.

4.1.2 Internalization of Externalities

Governments can use several instruments to reduce negative externalities. In general, the three approaches are:

a. Command-and-control regulation. Government can set standards for the maximum allowable amounts (quotas) on externalities.

b. Pricing methods, such as taxes, fees and charges for the polluting modes or subsidies for the cleaner modes.

c. Cap-and-trade. An overall cap (limit) is set and property rights or credits are assigned and traded through free market negotiations among the various transportation modes. The idea of property rights trading allowances was first proposed by Ronald Coase (1960). A successful application of a cap-and-trade scheme is the program to reduce acid rain by reducing SO_2 emissions through tradable emission permits. This program was introduced through the Title IV of the 1990 Clean Air Act Amendments (Shmalensee et al., 1998).

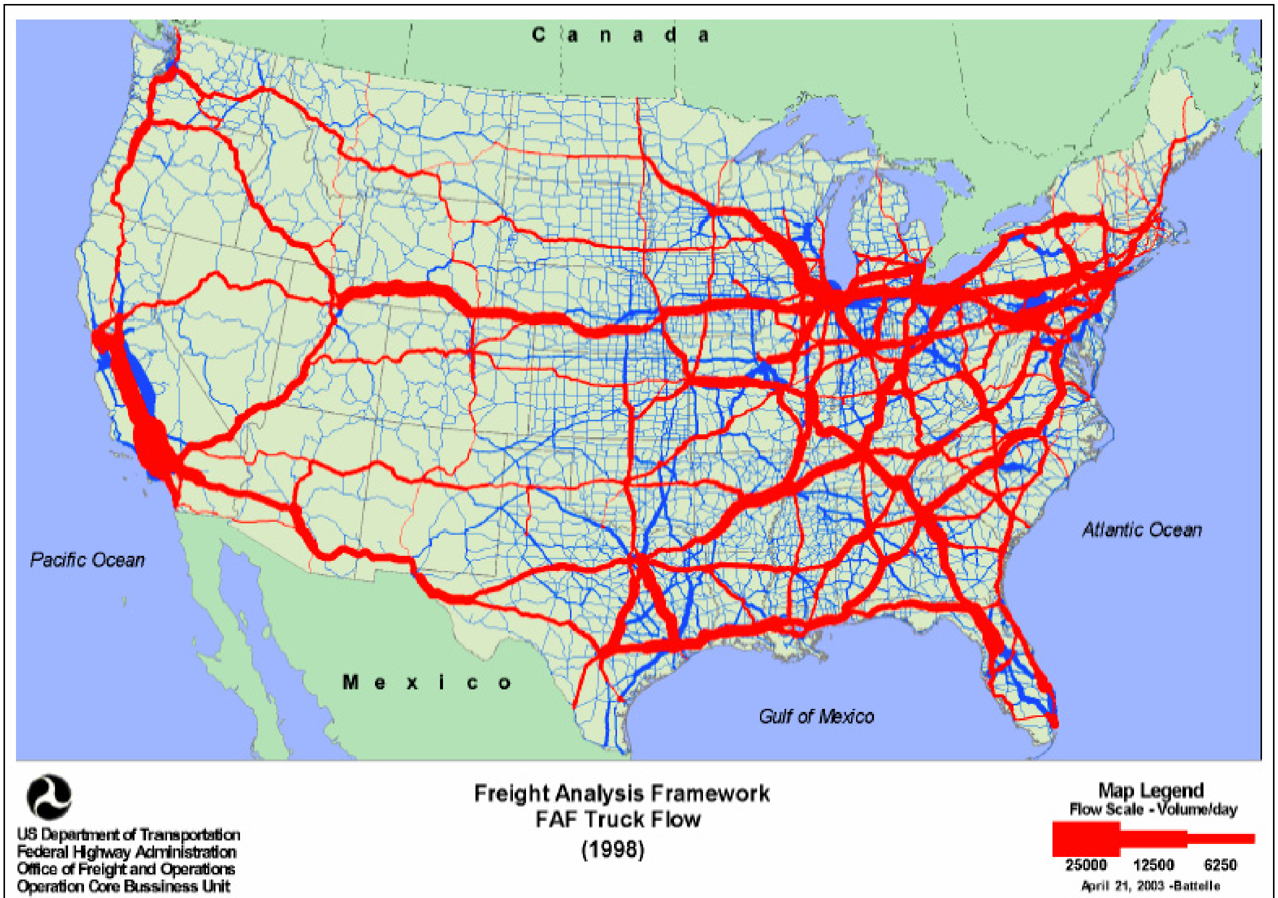
Command-and-control regulation, such as emissions standards, has failed so far to reduce the expansion of freight truck transportation. Also, the current taxes and fees imposed on trucks do not cover all the external cost of truck transportation (Delucchi, 2007). A fairer pricing system that will include all the environmental and social costs is required in order to reflect all the costs of transportation activities. Such efficient pricing should be based on the estimation of the marginal social cots of freight transportation for all the available modes and thus result in modal shifts to more environmentally friendly modes. The main principle should be that every mode should pay the total marginal social cost of its transportation activity.

4.2 Description of Major Transportation Externalities

The rapid expansion of trucking as the dominant mode of domestic freight transportation has caused environmental and societal problems, such as air pollution, traffic congestion, highway accidents, noise, road damage etc. These significant side effects are called negative externalities or external costs and are hidden costs imposed on the economy and the society in general. Despite the economic benefits of freight transportation, there are five major negative side-effects of freight transportation, mostly related with road transportation.

4.2.1 Traffic Congestion

The increasing share of trucking in freight transportation exacerbates highway congestion. Major highways along the U.S. Coasts suffer from congestion (Figure 4.2). Trucks compete with cars for space on highways. In the last 20 years annual vehicle miles traveled have increased by 78%, but road capacity have increased by just 1%. Road congestion causes additional time delays and wasted fuel. It is estimated that in 2007 traffic congestion costs the U.S. economy $78 billion in the form of 4.2 billion lost hours and 2.9 billion gallons of wasted fuel (Shrank and Lomax, 2007).



Red lines indicate Interstate Sections. Blue lines indicate all other roads.

Figure 4.2: Truck Flow and Highway Interstate Congestion
(Source: U.S. DOT, 1998)

4.2.2 Air Pollution

Freight transportation is a major source of air pollution. Residuals emitted as gaseous components and as particulate matter from the internal combustion engines are a major source of air pollution. The Clean Air Act of 1970 and its amendment in 1990, requires EPA to set National Ambient Air Quality Standards for six criteria air pollutants: particulate matter (PM), ground-level or tropospheric ozone (O_3), carbon monoxide (CO), sulfur oxides (SOx), nitrogen oxides (NOx), and lead (Pb). These pollutants can have harmful effects on human health, affect quality of life, the environment, and can cause property damage. Their effects are experienced at three geographical levels: local, regional, and global. Of the six basic pollutants, particle pollution and ground-level ozone are the most widespread health threats.

The main air pollutants related with freight transportation are: carbon monoxide (CO), nitrogen oxides (NOx), particulate matter (PM), volatile organic compounds (VOC), sulfur oxides (SOx). Transportation is responsible for almost 80% of the CO emitted, due to incomplete combustion in engines, for 50% of the total amount of NOx, and for 40% of VOC. NOx reacts with VOC to form ground-level ozone, the major cause of photochemical smog (U.S. EPA, 1996). Each air pollutant has serious health effects. Below, a description of major air pollutants according to EPA:

Carbon monoxide (CO). CO is a colorless, odorless, poisonous (toxic) gas. Carbon monoxide is produced from the incomplete combustion of fuel and is emitted directly from vehicle tailpipes. Nationwide, more than two-thirds of the carbon monoxide emissions come from transportation sources, with the largest contribution coming from highway motor vehicles. In urban areas, the motor vehicle contribution to carbon monoxide pollution can exceed 90 percent. Infants, elderly persons, and individuals with respiratory diseases are particularly sensitive. Carbon monoxide can also affect healthy individuals, impairing exercise capacity, visual perception, manual dexterity, learning functions, and ability to perform complex tasks.

Particulate matter (PM). PM is made up of a number of components, including acids (such as nitrates and sulfates), organic chemicals, metals, soil or dust particles, and allergens. The size of particles is directly linked to their potential for causing health problems. Particles less than 10 micrometers (PM10) in diameter pose the greatest problems, because they can get deep into the lungs, and some may even get into the bloodstream. Particle exposure can lead to a variety of health effects on the heart and cardiovascular system. Numerous studies link particle levels to increased hospital admissions and emergency room visits—and even to death from heart or lung diseases. Long-term exposures, such as those experienced by people living for many years in areas with high particle levels, have been associated with problems such as reduced lung function and the development of chronic bronchitis—and even premature death. Short-term exposures to particles (hours or days) can aggravate lung disease, causing asthma attacks and acute bronchitis, and may also increase susceptibility to respiratory infections. PM10 is closely associated with diesel engines, since their PM emissions are 30 to 70 times higher than from gasoline engines.

Non-methane Volatile Organic Compounds (VOC). VOC result from incomplete combustion and fuel evaporation. Transportation is responsible for 35-40% of VOC emissions. VOC gases react with NOx to form ground-level ozone.

Nitrogen Oxides NOx. NOx results from the combustion of fuels under high pressure (ratios) and temperature. It is one of the main ingredients involved in the formation of ground-level ozone, which can trigger serious respiratory problems. It reacts to form nitrate particles and acid aerosols, which also cause respiratory problems. It also contributes to formation of acid rain and to nutrient overload that deteriorates water quality. The transportation sector emits about 50%.

Sulfur Dioxide (SO_2). SO_2 is produced by the oxidation of sulfur present in fuel types. Transportation is responsible for 5-7% of SO_2. SO_2 contributes to respiratory illness, particularly in children and the elderly, and aggravates existing heart and lung diseases. It also contributes to the formation of acid rain. The pollutants formed from SO_2, such as sulfate particles, can be transported over long distances and deposited far from the point of origin. This means that problems with SO_2 are not confined to areas where it is emitted

Ozone is a secondary pollutant. It is not emitted directly into the air, but it is created, at ground-level, by a chemical reaction between nitrogen oxides (NOx) and volatile organic compounds (VOC) in the presence of sunlight. In the earth's lower atmosphere (troposphere), ground-level ozone is the main component of photochemical smog. Motor vehicle exhausts, gasoline vapors, and chemical solvents emit NOx and VOC that help form ozone. Sunlight and hot weather cause ground-level ozone to form in harmful concentrations in the air. Many urban areas tend to have high levels of ground-level ozone, but even rural areas are also subject to increased ozone levels because wind carries ozone and pollutants that form it even hundreds of miles away from their original sources.

In summary, air pollution from internal combustion engines has deleterious effects on health and the natural environment. It is caused by carbon and rubber particulates, heavy metals, carbon monoxide, and photochemical smog. Health problems, such as irritations to substances with carcinogenic qualities, contribute to mortality and morbidity of the affected population and are translated to higher health care costs and premature loss of lives (Table 4.1).

Table 4.1: Harmful Effects of Transportation-Related Air Pollutants

	TRANSPORTATION PERCENTAGE	DESCRIPTION	HEALTH EFFECTS	ENVIRONMENTAL EFFECTS
CO	80%	Colorless, odorless gas produced by incomplete combustion	Heart and cardiovascular problems	Toxic gas
PM10	27%	Solid and liquid particles less than 10 micrometers	Lung and respiratory diseases, bronchitis	Dirt, soot
NOx	50%	Pungent gas from fossil fuel combustion	Contributes to ground-level ozone, smog, respiratory problems	Creates smog, weathering erosion
SOx	5%	Colorless gas, irritant odor from fuel combustion	Respiratory problems	Major acid rain contributor
VOC	40%	From incomplete combustion and evaporation. Hydrocarbons	Contributes to ground-level ozone, smog	Depletes stratospheric ozone

(Sources: EPA, OECD)

4.2.3 Greenhouse Gases

For the past 200 years, the burning of fossil fuels, such as coal and oil has caused concentrations of heat-trapping greenhouse gases in the atmosphere. These gases prevent heat from escaping to space. Greenhouse gases (GHG) are necessary to life, because they keep the planet's surface warmer than it otherwise would be. However, as the concentrations of these gases increase in the atmosphere, the Earth's temperature increases. GHG emissions are linked with climate change.

In the U.S., energy-related activities account for three-quarters of our human-generated greenhouse gas emissions, mostly in the form of carbon dioxide emissions from the burning of fossil fuels. More than half GHG emissions come from large stationary sources such as power plants, while about a third comes from transportation (U.S. EPA, 2008). Transportation-related emissions contribute to global climate change–greenhouse effect. The most important GHG is CO_2 and to a lesser extent N_2O and CH_4. Climate change affects people, plants, and animals. Scientists are currently working to better understand future climate change and how the effects will vary by region and over time. Human health can be affected directly and indirectly by climate change in part through extreme periods of heat and cold, storms, and climate-sensitive diseases such as malaria, and smog episodes. The principal greenhouse gases that enter the atmosphere, because of human activities are:

Carbon Dioxide (CO_2). CO_2 is the largest source of U.S. greenhouse gas emissions. Carbon dioxide enters the atmosphere through the burning of fossil fuels (oil, natural gas, and coal), solid waste, trees and wood products, and also as a result of other chemical reactions (e.g., manufacture of cement). Carbon dioxide is also removed from the atmosphere (or "sequestered"), when it is absorbed by plants as part of the biological carbon cycle. CO_2 is 85% of total GHG. Since CO_2 is a natural constituent (0.03%), it is not technically considered as a pollutant. Transportation is responsible for about one third of the total CO_2 emissions. CO_2 emissions from transport are directly proportional to gasoline and diesel fuel consumption. CO_2 emissions from the transportation sector have increased by 29%, from 1990 to 2005. Over 60% of the emissions resulted from gasoline consumption for personal vehicle use. The remaining 40% emissions came from other transportation activities, including the combustion of diesel fuel in heavy-duty vehicles and jet fuel in aircraft (EPA, 2008). However, it is very difficult to measure the effects of a single vehicle or vessel to the overall global climate change. Predicting such consequences involves complex forecasting, and valuation of their costs requires an assessment of how these impacts will affect the well being of future generations.

Methane (CH_4). CH_4 is more than 20 times more powerful than CO_2 at trapping heat in the atmosphere. Methane is emitted during the production and transport of coal, natural gas, and oil. Methane emissions also result from livestock and other agricultural processes and by the decay of organic waste in municipal solid waste landfills. CH_4 is 8% of total GHG.

Nitrous Oxide (N_2O). Nitrous oxide is emitted during agricultural and industrial activities, as well as during combustion of fossil fuels and solid waste. N_2O is 310 time more potent than CO_2, but it represents 5% of total GHG emissions.

Fluorinated Gases. Hydrofluorocarbons HFCs, perfluorocarbons, and sulfur hexafluoride are synthetic, powerful greenhouse gases that are emitted from a variety of industrial processes. Fluorinated gases are sometimes used as substitutes for ozone-depleting substances (i.e., CFCs, HCFCs, and halons). These gases are typically emitted in smaller quantities, but because they are very potent greenhouse gases, they are sometimes referred to as High Global Warming Potential gases ("High GWP gases"). HFCs are 2% of total GHG.

The global warming potential (GWP)-weighted emissions of all direct greenhouse gases are presented in terms of equivalent emissions of carbon dioxide (CO_2), using units of teragrams of CO_2 equivalent (Tg CO_2 Eq.).

4.2.4 Transportation-related Accidents

Accidents are another negative side effect of transportation that can result in deaths, injuries, and property damage. The U.S. National Traffic Safety Administration (1998) estimated that 5,282 fatalities occurred in crashes involving large trucks in 1998. The majority, about 75% of people killed in large truck collisions, were occupants of other vehicles or non-motorists. In addition to the high private costs due to loss of life, road accidents cause additional costs to society, such as medical costs, police costs, material damages, which are only partially covered by the existing insurance systems. Furthermore, accidents may also generate additional non-recurrent congestion problems when traffic is dense.

Accidents are translated into external costs, to the extent that total accident costs are not reflected in insurance premiums. Accidental deaths are translated to real monetary costs. Putting a price on life is a sensitive issue, but such price can be approximated as what society is willing to pay to save lives or settlements in loss-of-life court decisions. Modern societies place a substantial value on human life as evidenced by their willingness to spend public money on transportation safety. Similar conditions apply to injuries with applicable costs for medical care, loss of productivity and pain – and suffering (Porter, 1999).

External accident costs of waterborne transportation can be considered as negligible. The number of accidents with personal injury is very low. For waterborne transportation another source of external accident costs is the potential environmental damage due to accidental oil or chemical spills. However, as we do not focus on oil or chemical tankers, the marginal external costs of maritime transportation due to accident risks are projected to be extremely low compared with the other modes.

4.2.5 Noise

Noise nuisance is closely related with road and rail transportation. Highway traffic is a major source of noise, particularly in urban areas. Noise pollution contributes to health problems, such 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. Local noise pollution from transportation activity can affect the productivity and personal enjoyment of neighboring communities. Furthermore, it affects the general quality of life and the value of property. It is estimated that housing values decline by 0.4% per dB increase (Forkenbrock, 1999).

Measuring the magnitude of noise pollution is complex. Volume is measured in acoustically weighted decibels [dB(A)]; a level above 65 dB (A) is considered unacceptable and incompatible with certain land uses in OECD countries; while above 45dB is considered to influence well-being (OECD, 1997). Heavy-duty trucks are a significant source of road noise, and are considered as having the larger noise impact than other modes of freight transportation.

4.2.6 Infrastructure Repair and Maintenance

Wear and tear of the road pavement and other infrastructure from transportation activities constitutes an externality, so long as infrastructure users are not faced with charges that reflect the total damage of their activities. Heavier vehicles cause greater wear and tear. For example, trucks and especially heavy axle trucks do significantly greater damage to roads than automobiles. One 80,000 lbs. tractor-trailer truck does as much damage to road pavement as 9,600 cars (U.S. Highway Research Board, NAS, 1962).

Infrastructure costs associated with trucking operations on highways include the wear and tear costs of pavement, reconstruction and rehabilitation of bridges, system enhancement costs, and other miscellaneous items. Costs for pavement reconstruction, rehabilitation, and resurfacing are estimated to represent 25% of the total Federal cost obligation. They are allocated to combination trucks on the basis of vehicle miles traveled (VMT) weighted by its passenger car equivalents. The user-fees paid by combination vehicles include Federal taxes on fuels used, excise tax on the sale of heavy trucks, a tax on tires and a heavy vehicle use tax.

The external road damage costs are discussed extensively in Newbery (1988). These costs occur mainly when heavy vehicles cause damage to the road surface, in the form of increased road repair costs and increased vehicle operating costs for the other road users. The damage a vehicle causes to the road pavement increases at the fourth power of the axle road. Therefore, pavement damage is caused almost entirely by heavy trucks.

4.2.7 Other Externalities

In addition to the above major externalities, freight transportation causes environmental damages not directly linked to human health, such as water pollution, damage to ecosystems, land alteration, visual intrusion, etc. Trucking has received great attention regarding its environmental impacts. It is considered to have the highest external costs per ton-mile. SSS share of environmental impacts is not only through atmospheric pollution and noise emissions, but through routine or accidental water pollution. Except for water pollution, the environmental performance of SSS is superior to trucking. Shipping causes water pollution, both on inland waterways and on the ocean. This may 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 by vessels. However, the majority of water pollution attributed to coastal short sea vessels is in form of accidental spills and not a recurring event.

CHAPTER 5

EXTERNAL COST VALUATION

5.1 Estimation Methodologies of Transportation Externalities

The negative side effects of freight transportation, described in the previous chapters, can be quantified and monetized as external costs. The sum of the private (internal) costs, those directly borne by the parties involved in the transportation activity, and of the external costs, those borne to parties outside the transportation activity, represents the full social costs of transportation. In this chapter, methodologies and studies that were developed for the estimation of specific externalities, are applied for assessing the external costs of trucking and compare them with SSS. Unfortunately, estimates of external costs are often based on quite different assumptions, making even comparisons difficult. Uncertainties and variations in such estimates are significant. Externalities are also highly situation-dependent. They vary significantly depending on the location and time of the transportation activity, the transportation network, and the vehicle type.

Various studies in Europe and in the US have addressed the problem of monetary valuation of externalities. These studies were primarily conducted for assessing the pollution impacts of the energy industry and were later expanded to the transportation sector. The several methodologies that were developed in the past two decades for quantifying and monetizing the external costs followed mainly two approaches: a top-down approach and the bottom-up approach.

For the estimation of the external cost by a top-down approach, the total external costs for a country or a region is allocated to the number of its polluting units, resulting in an average value of that externality per polluter. The basis of this type of calculation is a whole geographical unit, e.g. a country. The monetary damages have been estimated at an aggregate level, typically as national estimates. For such a unit, the total cost due to a pollutant is calculated and this cost is then allocated based on the share of total pollutant emissions, by vehicle mileage, etc. Whilst this top-down approach provides some useful information for transport and environment policy, it does not allow for more detailed cost differentiation, such as dependence on fuel, technology and source location, all of which can have significant effects on transportation externalities.

US Federal Highway Administration has conducted two highway cost allocation studies, in 1982 and in 1997, with the objective to assess the costs of highway use (FHWA, 1997). The objective of these studies was the estimation of the cost responsibility of various vehicle classes to be used by federal and state agencies. They tried to estimate how highway costs should be allocated among vehicles in order to promote economic efficiency. They provide reliable estimates for externalities, such as infrastructure, highway accidents, noise and congestion. The first 1982 Federal highway cost allocation study focused on estimating the responsibility of different vehicle classes for Federal highway program costs and evaluating whether different vehicle classes were paying a proportionate share of the highway program costs for which they were responsible. Similarly, the primary objective of the 1997 study was to analyze highway-related costs attributable to different highway users and to compare the responsibility of different vehicle classes for highway program costs paid by federal and state funds. This study however extends the analysis of highway cost responsibility to examine environmental, social, and other costs associated with the use of the highway system that are not reflected in highway improvement budgets. In recent years, there has been increasing interest in estimating the total costs of highway transportation, not just the direct agency costs. Data and analytical tools developed in other studies were adequate to assess costs associated with safety, noise, congestion, and many other social costs of highways, such as published studies on air pollution costs.

The cost allocation studies are based on a number of scientific research studies that have tried to determine specific external costs of transportation, caused mainly by road vehicles. Murphy and Delucchi (1997) presented a detailed review of the research that was conducted in the US on the social cost of motor vehicle use. These studies provide estimates of cost functions and data, which can help analysts and policy makers to evaluate various transportation policies. Nash et al. (2001) examined transportation pricing based on social costs. Such socially optimal, fair and efficient pricing could result in a shift to more environmentally friendly modes and thus have a positive impact on transportation related emissions. The main principle is that the user should bear the social costs, including the environmental costs. Since price, i.e. fare, in transport is a determining factor in modal choice; pricing should be an instrument that stimulates modal shift to more efficient and greener modes. Small and Kazimi (1995), focused on air pollution from motor vehicles in the Los Angeles area. The costs are dominated by the heath effect from particulate matter. Diesel powered trucks are proven to be the most costly. Proost et al. (2002) analyzed the gap between existing and efficient transport prices. Efficient transport prices are those that maximize economic welfare and take into account the external costs, such as congestion, air pollution and accidents.

In the estimation of the external cost by a bottom-up approach, the external costs are estimated by following the path from the cause or emitting source to the receptors of the negative effects. The first research effort that developed a bottom-up approach was the "External costs of Energy (ExternE)" project of the European Union. The ExternE project was the first comprehensive attempt to use a consistent bottom-up approach to evaluate the external costs of air pollution of the energy industry. The European Commission launched the project in collaboration with the U.S. Department of Energy in 1991. Since 1991, the ExternE project has involved more than 50 research teams in over 20 European countries (Bickel and Friedrich, 2005). The centerpiece of the ExternE's research is the Impact Pathway Approach (IPA).

In the past twenty years, the EC has funded research on the subject of valuation of the environmental damages of energy and transportation. Such projects are the Real Cost Reduction of Door-to-door Intermodal Transport (RECORDIT) and the Unification of accounts and marginal costs for Transport Efficiency (UNITE) project. The RECORDIT project focused on the estimation of the private and external costs of intermodal freight transport in Europe. The UNITE project compares user payments of tolls, vehicle taxes, and fuel taxes with the external costs in several European countries (Link, 2005; Nash, 2003; Black et al., 2003).

5.2 External Costs of Air pollution

The main methodology that was used extensively in most of the latest European studies estimating the external costs of air pollution was the Impact Pathway Approach (IPA), which was developed during the ExternE project. According to that methodology, the external costs are calculated by an Impact Pathway Analysis (IPA) following the pathway from the polluting source to receptor. The external costs are estimated from the calculation of emission at the polluting source, followed by atmospheric dispersion modeling of air pollutants, then estimation of physical impacts, and finally monetary valuation of these impacts (Figure 5.1). In more detail, the analysis follows the chain of causal relationships starting from the pollutant emissions and chemical conversion in the atmosphere to their impact on various receptors, such as humans, ecosystem, buildings, etc. The outcome is a detailed estimation of the marginal – incremental - external costs caused by one additional polluting unit.

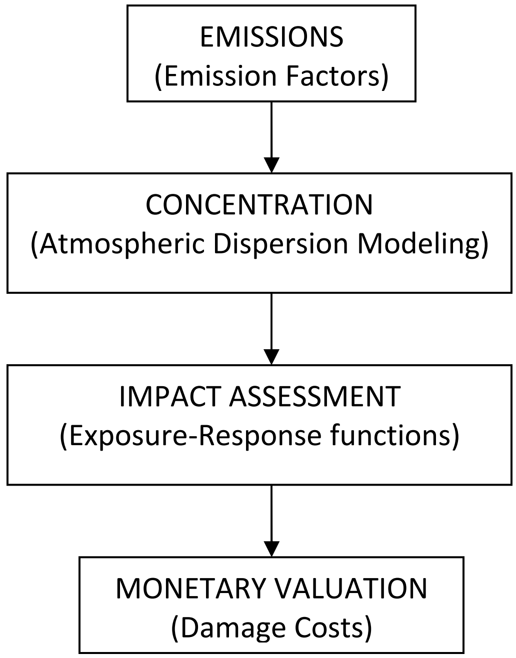


Figure 5.1: Impact Pathway Approach

IPA is considered today as the most reliable approach for environmental impact assessments that allows the estimation of site-specific external costs following the chain of causal relations from the source to the receptor. The four steps in detail are:

Step 1: Estimation of the emissions produced at the source. Based on the fuel consumption and the type of fuel, the emissions of air pollutants are calculated. The estimation of transportation emissions is a complex issue due to the multitude of parameters involved. These parameters may be propulsion technology oriented, such as vehicle type, motor and fuel type, emission control technology, engine capacity, and age or related to operational conditions, such as traffic, speed profile, vehicle load, driving behavior, routing, and spatial planning characteristics. All can have significant impacts on the quantity and the relative share of each pollutant emitted, and similarly on the noise emitted, on the probability of accidents and on congestion.

Step 2: Concentration of pollutants in a geographic area. The relationship between changes in the emissions and resulting concentrations is established by atmospheric dispersion models calculating the annual average incremental concentration of the pollutants on local and regional scale.

Step 3: Impact assessment. The impact assessment procedure is performed by estimating the physical effects of the several externalities, such as air pollution, noise, accidents, and congestion to human health, building materials and crops. The approach involves the use of dose-response (or exposure-response) functions and follows the pathway from source emissions via quality changes of air, soil and water to physical impacts.

Step 4: Monetary valuation. This is the most crucial step. Where appropriate, damage assessment can be based on market prices that are affected by externalities and therefore damage costs can be estimated directly. In that case, market values determine the damage costs. Alternatively, abatement costs are applied, where prevention methods estimate the costs of mitigating the effects of an externality. However, for non-market goods, such as clean air, health, etc., different valuation techniques can be applied. These techniques are mostly based on the subjective Willingness-to-Pay (WTP) approach and are classified under three categories:

1) **Contingent Valuation Method** or stated preference approach, which attempts to determine the value from direct surveys, by posing hypothetical questions to a representative sample of individuals.
2) **Hedonic method** or revealed preference approach, which attempts to deduce the value that individuals place on a characteristic from their market decisions.
3) **Implied preference**, which derives societal values from regulatory and court-derived costs.

The ExternE project has been expanded to the transportation sector. The detailed IPA methodology was applied to several European cities. Epidemiological and toxicological studies revealed the great variations of the damage costs in Euros per ton of pollutant. Although it is clear that PM is the most harmful pollutant, its damage cost depends highly on the location and the population affected.

Several European intermodal transportation projects, such as RECORDIT and REALISE-SSS, which involve the estimation of external costs, use average values of damage costs for every pollutant, which were previously calculated using the IPA method (Table 5.1) (Alliance of Maritime Regional Interests in Europe (AMRIE), 2003). These average values give a sense of the relative magnitude of the harmful effects of each pollutant. It is clear that particular matter dominates the external costs of air pollution, due to it harmful effects to human health. However, it is very approximate or even problematic to use these values in every case.

Table 5.1: Average Damage Costs of Air Pollutants

Pollutant	Euros per ton
SO_2	11,243
NOx	4,020
CO	3
VOC	1,119
PM	302,739

Source: (AMRIE, 2003)

5.3. External Costs of Congestion

The annual mobility study from Texas Transportation Institute estimates every year the total costs of congestion for US urban and rural roads as time lost, due to added delays, and fuel wasted. For 2007 the total costs of congestion in US roads was $78 billion. FHWA allocates congestion costs to various vehicle classes according to the added delays that they cause to highway users. These time delays are associated with changes in traffic levels estimated by speed-flow relationships. FHWA analysis includes both recurring congestion and the added delays due to incidents such as crashes and disabled vehicles. Costs of congestion are estimated over a range of traffic volumes and vehicle mixes, and include both peak period and non-peak period conditions. The results presented are weighted averages, based on estimated percentages of peak and off-peak travel for different vehicle classes. For combination trucks of 80,000lbs gross weight, the costs of congestion in 2000 prices are in Table 5.2.

Table 5.2 External Costs of Congestion (cents per mile)

	Rural highways			Urban highways		
Cents/mile	Low	Middle	High	Low	Middle	High
Combination Trucks	0.98	3.70	10.87	4.44	16.78	49.34

(Source: FHWA, 2000)

5.4 External Costs of Noise

The negative health and psychological effects of noise is very difficult to monetize. However, the most widely used method of estimating the external costs of noise is the hedonic method. Since noise has a negative impact on residential property values, a decrease in house values per dB emitted over the threshold of 55-60dB, is a good estimator for the external costs of noise. Most of the studies conducted compared trucking to rail transportation. In general, the literature suggests that a given level of noise produced by a train is usually perceived as less annoying than noise produced by vehicle traffic on a highway. Especially, combination trucks have the highest external noise costs. One semi-trailer produces at 55mph a noise level of 90 dB at 50 feet distance, equivalent to 28 automobiles. The highway cost allocation study (FHWA, 1997) estimated noise costs using information on the reduction in residential property values caused by decibel increase for highway vehicles. Estimates of noise emissions and noise levels at specified distances from the roadway were developed using FHWA noise models in which noise emissions vary as a function of vehicle type, weight, and speed (Table 5.3).

Table 5.3: External Costs of Noise (cents per mile)

	Rural highways			Urban highways		
Cents/mile	Low	Middle	High	Low	Middle	High
Combination Trucks	0.07	0.26	0.68	1.05	3.73	9.86

(Source: FHWA, 2000)

5.5 External Costs of Infrastructure and Road Pavement

Trucks cause significant wear and tear of road pavement. Federal and state highway costs include pavement reconstruction, rehabilitation, and resurfacing. These costs are allocated to vehicle classes through charges and fees. Pavement costs in dollars per mile represent the contribution of a mile traveled by an additional combination truck. For combination trucks total pavement costs are for rural highways 12.7 cents/mile and for urban highways 40.9 cents/mile (FHWA, 1997).

Furthermore, FHWA and other state agencies estimate the equity ratios or revenue/cost ratios, i.e. the ratio of total charges paid by a vehicle class to its cost responsibility. When the charges paid by a vehicle class are less than the costs that it causes then a de facto subsidy occurs. This equity ratio for combination trucks of total gross weight 80,000 lbs is approximately 0.5. That means that trucks underpay by 50% the highway costs they cause.

5.6 External Costs of Highway Accidents

External costs of highway accidents, caused by trucks and expressed in cents per mile, are the uncompensated costs of fatalities, injuries, and property damages caused by unit increase in highway travel. They include medical costs, lost of productivity, pain and suffering, and other costs associated with highway crashes. These costs are the uncompensated costs not covered by insurance premiums. The external costs of highway accidents are thus lower than the average total cost of highway crashes.

FHWA estimates these costs for various vehicle classes taking into account their involvement rates. Trucks have a high fatal accident rate. Urban highway traffic has a positive effect in reducing fatal crashes. Forkenbrock (1999) estimated that the uncompensated external accident cost is 60% of the total average accident cost of trucking to the society. For combination trucks, these costs for rural and urban highways have the following variation.

Table 5.4: External Costs of Accidents (cents per mile)

	Rural highways			Urban highways		
Cents/mile	Low	Medium	High	Low	Medium	High
Combination Trucks	1.02	2.20	6.90	0.56	1.16	3.67

(Source: FHWA, 2000)

5.7 External Costs of Greenhouse Gases

The external costs of greenhouse gas emissions are the hardest to monetize. The uncertainty over the valuation of the damage costs of climate change, due to greenhouse gases, is very large. The phenomenon of climate change is global and therefore its impacts are very hard to be measured and allocated to specific greenhouse gas emitters. Therefore, the valuation methods used for estimating the external costs of local air pollution do not apply. Greenhouse gases, such as CO_2, have global effects, thus their impact on the environment is irrelevant of the location of the emitter.

The Intergovernmental Panel on Climate Change (IPCC) does not suggest any particular range of values for the marginal damage of CO_2 emissions on climate change. The IPCC emphasizes that estimates of the social costs of climate change have a wide range of uncertainty because of limited knowledge of impacts, uncertain future of technological and socio-economic developments, and the possibility of catastrophic events or surprises.

Nevertheless, it is clear that greenhouse gas emissions are directly proportionate to energy consumption. Transportation is a significant emitter of CO_2. Several studies tried to estimate the damage costs of CO_2. First estimates were presented by Nordhaus (1991), Cline (1992), and Titus (1992). Estimates of the costs of one ton of carbon emitted range between 5 euros (Capros and Mantzos, 2000) to 135 euros (INFRAS, 2000).

However, greenhouse gas allowances or credits can be traded as commodities in emissions trading markets, such as the European Union Emission Trading Scheme. The price of one metric ton of CO_2 is set by bids and offers in these markets. These prices can serve as abatement costs, i.e. the cost of eliminating an additional unit of greenhouse gases. Therefore, they can virtually represent the economic damage costs of greenhouse gases. From the European reporting web site www.pointcarbon.com, the price of a ton of CO_2 was 15 euros per ton in December 2008.

5.8 Uncertainties in the Estimation of Externalities

From the described valuation methods, it is obvious that there are great variations in the estimates of the external costs. All the studies mentioned stress the fact that their external cost estimates have significant uncertainties. These uncertainties have many causes (Rabl and Spadaro, 1999). Most of them are related to the difficulty of calculating monetary values in the absence of markets for externalities and to the imprecise understanding of the physical impacts and harmful effects of transportation. In addition, some uncertainties are also due to data inefficiency, but many are also embedded in the scientific methodologies applied.

For example, air pollution uncertainties lie in the exposure-response (E-R) functions in step 3 of the IPA method, but also in the valuation part of damage costs, such as mortality and morbidity risks, with the use of Value of Statistical Life (VSL) estimates (step 4). There are also large differences due to the specific circumstances, i.e. geographic location, time, equipment technologies etc. Quinet (2004) summarizes the main reasons for the large uncertainties in the estimation of external costs.

- **The specifics of the situations**. The situations differ according to the location, the time, and the population density of the region studied. Similarly, the precise type of vehicle or vessel technology used, which affects the external costs through its fuel consumption, emissions, noise levels, etc.

- **The type of cost taken into consideration**. Some methodologies calculate average costs while other estimate marginal costs. Both concepts have an interest in economic analysis; however, their outcomes may vary significantly.
- **Impacts relations (E-R functions)**. For each of the effects, the calculation of costs includes physical laws and models that link the cause of damages to the effects; for instance air pollution estimates generally use a chain of relations going from gas exhausts to dispersion in the atmosphere, then to exposure of human beings, and finally to health damages. Similarly, the costs of the danger of accidents associated with transport are based on relationships between the level of traffic and the number of fatalities. It happens that these relations include a large degree of uncertainty, and that alternative relations exist for many of them. For instance, air pollution in Europe has been analyzed using two main methodologies—stemming from the ExternE study and a World Health Organization, 1999 study—that give very different results.
- **The secondary hypotheses used by the modeling framework.** It is well known that large-scale models such as those that are used to estimate air pollution, congestion or global warming include, besides the general hypotheses which characterize them, a lot of semi-hidden secondary assumptions that do not appear at first glance. These secondary hypotheses often relates to data handling and to the adaptation of the data to the needs of the theoretical framework of the model. Though difficult to assess without a deep insight in the model, these secondary hypotheses can often have dramatic impacts on the numerical results.
- **Unit values.** Cost estimates use unit values such as value of time and value of statistical life (VSL). These subjective estimates may significantly differ from one

study to another. In the US, the latest Value of Statistical Life, used by EPA, is \$6.9 million, while in Europe the respective value that used was used in the ExternE project was \$4.1 million. Furthermore, these values are determined by Willingness-to-Pay methods that are highly subjective.

However, despite the uncertainties, external cost estimates can serve adequately as a reference point. They provide the relative magnitude of each externality, so we can elaborate the most important external costs for each case. Furthermore, we can make comparisons among transportation modes. Therefore, they are considered relatively reliable for policy-making purposes, which was the main objective of most externality studies.

CHAPTER 6

ESTIMATION OF SITE-SPECIFIC EXTERNAL COSTS USING FUZZY LOGIC

6.1 Assessment of the Negative Environmental Impacts of Transportation

The key problems in estimating the external costs of freight transportation are the uncertainties and the large variations in the evaluation of damage costs. Uncertainty in this case is in the form of imprecision and vagueness. Furthermore, because of lack of defined markets, damage costs of air pollution or congestion are evaluated using methodologies described in Chapter 5, which have an inherent subjectivity. Evaluating the negative impacts of transportation to the society and the environment is based on stated or revealed preferences (contingent valuation). Typical method is the "Willingness-to-Pay" to avoid or accept a certain negative impact. These valuations techniques are based on individual or group surveys and questionnaires about the tolerances and acceptability of people on various environmental and societal problems. These surveys try to price resources, such as clean air, value of time, accident risk etc. The negative impacts of transportation are evaluated by people using subjective terms and language and are described with linguistic variables and words, such as unacceptable or acceptable level of pollution, heavy traffic, loud noise etc. Therefore, estimation of externalities involves the acquisition and processing of information that is inherently subjective, imprecise, and fuzzy.

Humans have the advantage over computers in handling vast, partial, imprecise information and making decisions quickly, using approximate reasoning. Whereas traditional approaches face the above problems, modern methods, such as fuzzy logic and approximate reasoning, are well suited for a modern approach to estimating external costs. For example expressions such as:

- "If emissions are high and the area is densely populated then the health damage costs are high," or
- "If it is rush-hour and I am taking I-95 then the traffic congestion will be significant."

The above rules with the linguistic expressions can be treated rigorously using fuzzy logic and give us estimates of the external costs of air pollution and congestion respectively.

6.2 Elements of Fuzzy Logic Theory

A method for solving the above problems of vagueness, complexity, imprecision, and subjectivity in the evaluation of the external costs of transportation is using fuzzy logic. Lofti Zadeh created fuzzy logic as the mathematical theory that quantifies linguistic variables and words that are inherently imprecise, vague, or fuzzy. Zadeh invented the concept of fuzzy sets to demonstrate the handling of fuzziness exhibited by humans to solve complex problems (Zadeh, 1965). Unlike Boolean logic and crisp sets that have no ambiguity—an element either belongs or does not to a set—fuzzy sets are sets whose elements can belong to more than one set. Fuzzy set theory permits the gradual assessment of the membership of elements in a set. A fuzzy set A is defined by a membership function that is used to determine that grade of membership. The grade of membership μ ranges from 0 to 1, $\mu : A \rightarrow [0,1]$

For each member $x \in A$, $\mu(x)$ is the grade of membership of x. However, μ is not a measure of probability, but it represents possibility. Fuzzy sets describe mathematically non-stochastic uncertainty, which is based on subjectivity judgments or imprecision and vagueness information. Fuzzy sets are used to convert linguistic variables into numbers and fuzzy logic manipulates these numbers in a rigorous, scientific way. Using fuzzy linguistic terms is a way people think and describe environmental conditions and other externalities. Fuzzy sets can quantify the vagueness and imprecision of externalities. Using linguistic variables and approximate human reasoning, we can evaluate complex systems and problems and make decisions in a systematic and simpler way. The motivation for the use of words or sentences rather than numbers is that linguistic characterizations are, in general, less specific than numerical ones. Fuzzy logic is reasoning with fuzzy sets, fuzzy truths, operators, and fuzzy rules of inference. It attempts to emulate human reasoning in a natural systematic and mathematical way. Fuzzy logic deals with not only truth and fault but also partial truth and partial fault.

A fuzzy system involves four major operations (Li, 1997) as shown in Figure 1:

1. **Fuzzification** that transforms crisp inputs into fuzzy sets according to the membership functions.
2. **Rules activation**. Fuzzy rules are the linguistic expressions which interpret the input information and provide the output value information. They are in the IF-THEN form:

"IF x is A THEN y is B," where A and B are the linguistic variables. The IF part is the antecedent or premise, while the THEN part the consequent or conclusion.

3. **Fuzzy Inference System (FIS)**. The FIS is the process of formulating the mapping from a given input to an output using fuzzy logic. There are two common types of FIS in the MATLAB fuzzy logic toolbox: Mamdani-type and Sugeno-type. The FIS performs logical operations in order to determine the activation of the fuzzy sets in consequent. The most common approach, which was applied here, is the correlation-minimum inference. In correlation-minimum inference, the antecedents of a rule combined with the operator AND use the minimum truth value to activate the consequent (Mathworks, 2008).
4. **Defuzzification** interprets the information from the output fuzzy set to a crisp value. The most common approach of defuzzification is the centroid method, which determines the crisp output R as a weighted average of the activated areas.

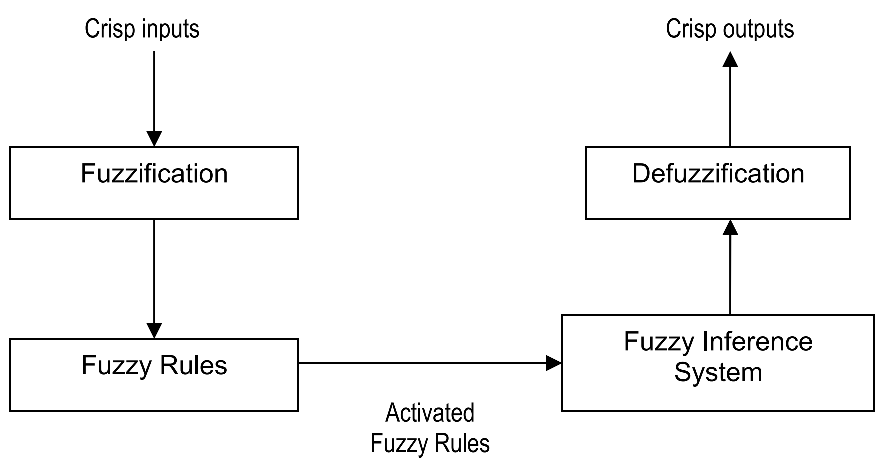


Figure 6.1: Schematic of a Fuzzy System
(Li, 1997)

6.3 Fuzzy Logic Models

Modeling externalities using fuzzy logic provides math-free estimators that are simpler than complex epidemiological, meteorological, and atmospheric dispersion models. The two main externalities to be investigated here are air pollution and congestion. The other transportation externalities can be evaluated accurately from top-down allocation methods. Highway repair and maintenance and accident costs are estimated and allocated to various vehicle categories. The cost responsibility of combination trucks in road maintenance and their involvement in accidents are assessed by FHWA. On the contrary, environmental costs require the valuation of goods, such as clean air or health effects of pollution. In the lack of defined markets for these goods, methodologies rely on subjective valuation. Similarly, congestion costs involve the valuation of time and its estimates vary significantly among groups of people with different income.

Using certain factors of an externality as input variables, the damage costs of that externality are estimated for a specific situation as outputs. However, an additional challenge is the lack of data for the monetary quantification of the damage costs. Various environmental and other studies conducted in Europe and in the U.S. were delineated in order to get the most reliable data of external costs. The fuzzy models are adaptive and they can be easily modified to incorporate new research studies and data. Valuing environmental externalities in transportation is a relatively new and emerging research area.

6.3.1 Air pollution – Particulate Matter

The IPA methodology, described in Chapter 5, revealed the complexity and subjectivity in the estimation of external costs. With a Fuzzy Inference System (FIS) and the appropriate rules, crisp answers for the estimation of external costs of air pollution in specific locations under certain conditions can be derived. This is a lot easier and simpler than applying complex methodologies, such as toxicological and epidemiological studies. Furthermore, a fuzzy logic model can also provide situation-specific estimates instead of using average estimates. Air pollution is a local problem and average values do not provide reliable estimates. There are large differences between the health damages in urban areas to rural areas. Damages are multiplicative and not additive processes; therefore, air pollution is a nonlinear complex phenomenon (Rabl and Spadaro, 2002).

The two input variables to be fuzzified are: emission factor and population density. The output variable is the damage cost estimate for every pollutant. Damage costs are output as non-dimensional indices that range from 0 to 100.

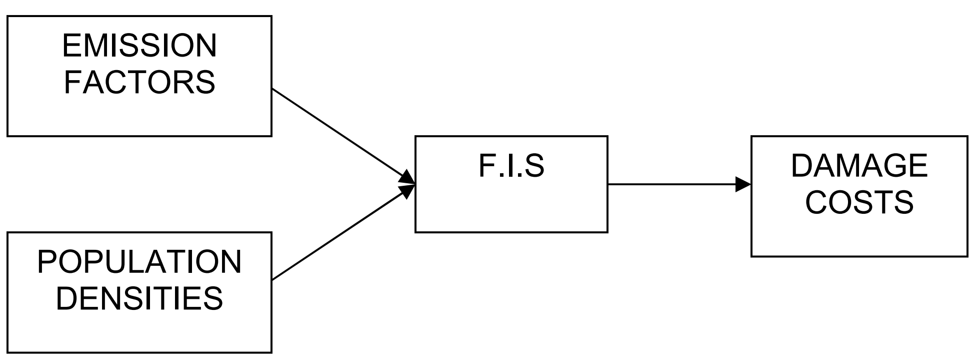


Figure 6.2: Fuzzy System for Air Pollution

a. Emission factors

An emission factor is defined as the average emission rate of a given pollutant for a given source, relative to the intensity of a specific activity. Air pollutant emission factors are representative values that attempt to relate the quantity of a pollutant released to the ambient air with an activity associated with the release of that pollutant. These factors are usually expressed as the weight of pollutant divided by a unit weight, volume, distance, or duration of the activity emitting the pollutant. (e.g., kilograms of particulate matter emitted per ton of fuel burned).

Emission factors facilitate estimation of emissions from various sources of air pollution. In most cases, these factors are simply averages of all available data of acceptable quality, and are generally assumed to be representative of long-term averages. Emission factors depend on the fuel type, fuel consumption, engine type, driving patterns etc. These values can be determined from emission estimation models, such as the MOBILE6 model of EPA, or can be used directly as inputs from emission factor tables. For maritime transportation, the following values of emission factors, shown in Table 6.1 were used.

Table 6.1: Emission Factors for Maritime Transport (kg/ton of fuel)

Engine speed	HIGH	MED	SLOW
SO_2 - (2.7%S fuel)		54	54
SO_2 - (1.5%S fuel)	10	10	10
NOx	57	57	87
CO	7.4	7.4	7.4
VOC	2.4	2.4	2.4
PM	1.2	1.2	7.6
CO_2	3170	3170	3170
CH_4	0.3	0.3	0.3
N_2O	0.08	0.08	0.08

(Source: Endersen et al., 2003; Corbett, 2000)

For truck transportation, FHWA has estimated emission factors for several U.S. road types as grams of pollutants per miles. These values are converted to kg per ton of fuel, assuming combination truck mileage 5.2 mpg (FHWA, 2002) as shown in Table 6.2. Additionally, truck emissions data from European sources (Table 6.3) were used.

Table 6.2: Emission Factors for Truck Transport – U.S. (kg/ton of fuel)

	Local	Arterial	Urban Highway	Rural Highway
NOx	26.0	27.5	41.5	54.9
CO	12.3	5.1	4.0	5.1
VOC	2.0	1.0	0.7	0.7
PM	0.7	0.7	0.7	0.7

(Sources: FHWA, 2002)

Table 6.3: Emission Factors for Truck Transport – EU (kg/ton of fuel)

Driving conditions	Highway	Congestion
SO2	0.8	0.5
NOx	29	45.8
CO	6.7	12.1
VOC	2.9	7.1
PM	1.8	3.4
CO2	3323	3534
CH4	0.3	0.5

(Source: AMRIE, 2003)

The membership functions of the input variable emission factors (EF) of particulate matter (PM) are shown in Figure 6.3.

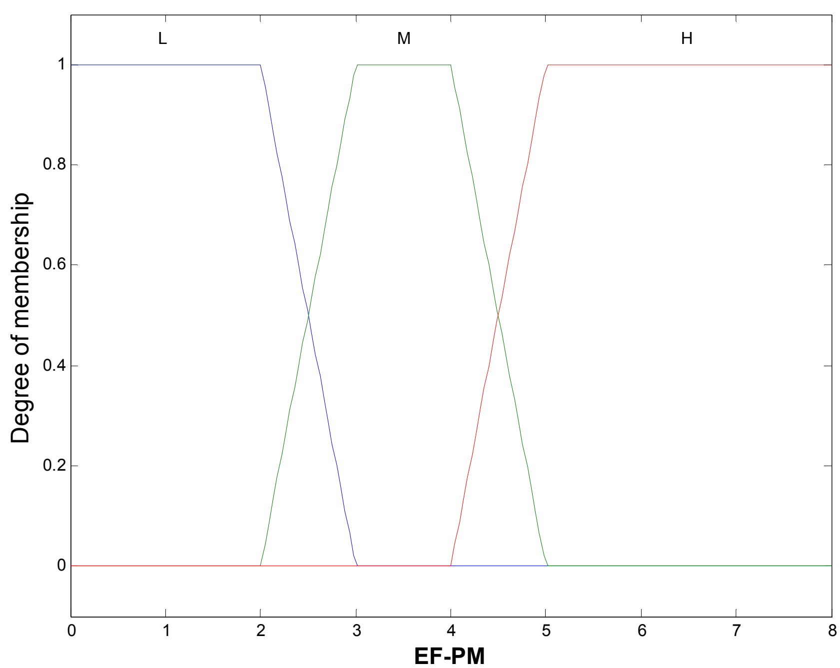


Figure 6.3: Membership Functions for the Fuzzy Input Variable Emission Factors of PM (EF-PM)

b. Population Density

The health effects of air pollution depend on the population affected at a specific geographic location, as this is characterized by its population density (number of inhabitants per square kilometer). Urban and metropolitan areas have the greatest problem and therefore the external costs of air pollution there will be much higher. Table 5.3 demonstrates the high variations of the damage costs for different populated areas in Europe. In the U.S., a populated area is defined as urban, if it has population greater than 50,000 and population density of at least 1,000 people per square mile (U.S. Census Bureau, 1994). Population density data are obtained from United Nations' population data tables (available at: http://esa.un.org/unpp/) and from the study Demographia (Demographia, 2008).

The input variable population density (PD) has membership functions defined as rural (R), urban-low (UL), urban-medium(UM), urban-high(UH), urban very high(UVH), as depicted in Figure 6.4.

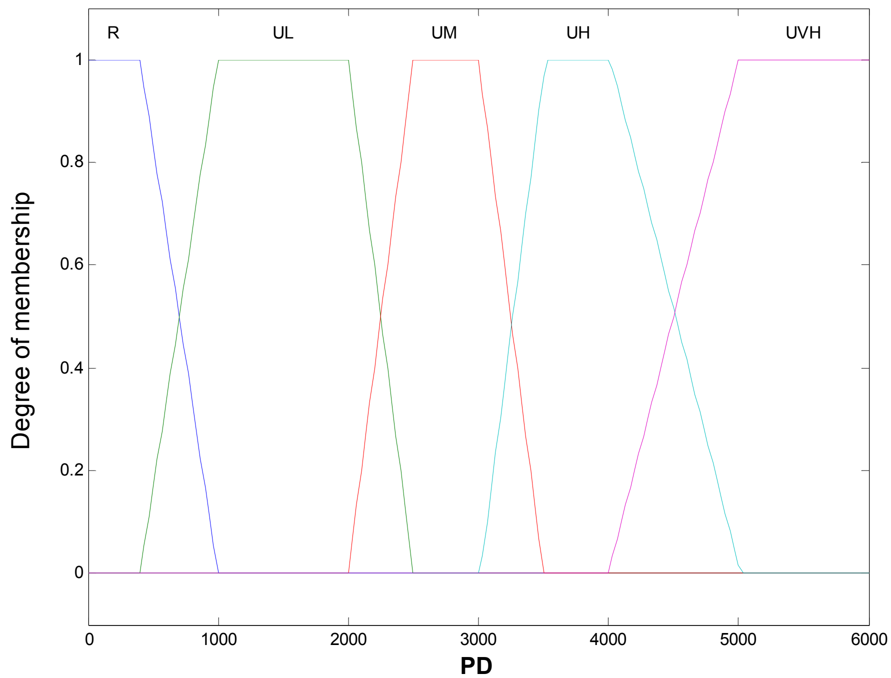


Figure 6.4: Population Density (PD) Membership Functions

c. Damage costs

The output of the fuzzy inference model is the damage cost for every pollutant. Several studies that have estimated monetary estimates of damage costs per ton of pollutant were reviewed. They vary significantly depending on the location examined, the methodology followed, and the data availability. The all however agree in the high damage cost of particulate matter (PM), due to its severe health effects.

The results of the ExternE project, described in Chapter 5, as it was applied in several European cities for various engine technologies and emission factors, are considered the most reliable, as of today. Figure 6.5 presents these damage costs as indices relative to Paris as maximum 100. On the graph, the correlation of damage costs of PM with population density is also depicted. Damage costs are expressed in a non-dimensional index, from 0 to maximum 100.

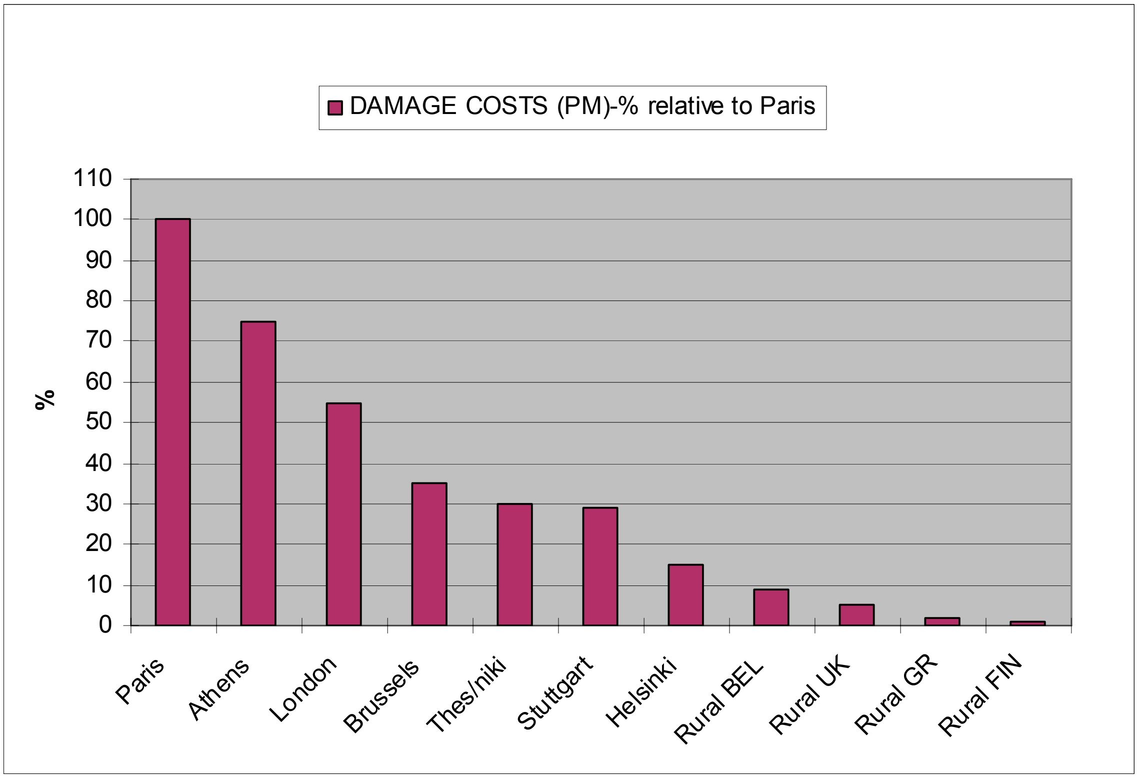


Figure 6.5: Damage Costs of PM in Selected European cities, relative to Paris

(Friedrich and Bickel, 2001)

The membership functions of the output variable damage costs (DC) are shown in Figure 6.6.

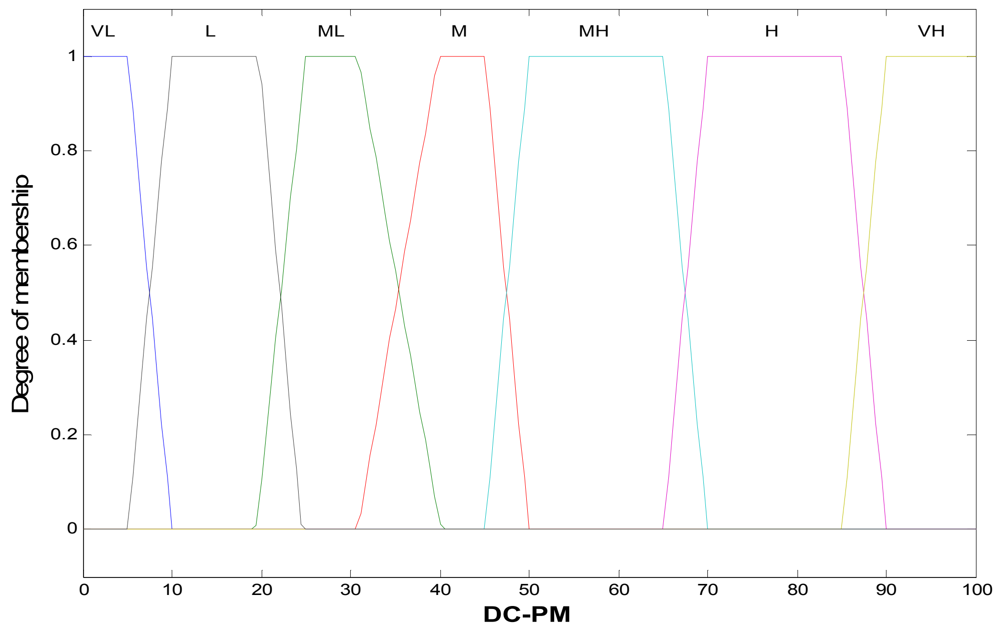


Figure 6.6: Damage Costs of PM (DC-PM) Membership Functions

The fuzzy rules are depicted in the following matrix Table 6.4.

Table 6.4: Fuzzy Rules Matrix for PM

EF	LOW	MED	HIGH
RURAL	VL	VL	L
URBAN –LOW	L	ML	ML
U-MED	ML	M	M
U-HI	M	MH	MH
U-VH	MH	H	VH

There is lack of adequate data for damage costs of different transportation modes and engine technologies. These EU studies have used two diesel technologies emission factors, both for heavy-duty diesel truck engines: uncontrolled and EuroII standards.

The fuzzy logic model outputs of the PM's damage costs for the European cities' population densities and emission factors shown in Table 6.5 are close to data on the graph (Figure 6.5). Furthermore, the fuzzy logic model provides estimates for the whole range of population densities and emission factors. The full results for the whole range of population densities and emission factors are depicted in the 3-D surface in Figure 6.7. The nonlinearity of the PM's damage costs with emissions (EF) and population density (PD) is illustrated in the generated 3-D surface.

Table 6.5: Damage Costs - Results of Fuzzy Logic Model

	Pop. density (inh./km^2)	Emission Factors – PM in (g/kg)	Damage Costs Index (MATLAB results)
Athens	**5400**	3.4	80.1
London	**5100**	1.8	60.9
Thessalonica	**4100**	1.8	31.5
Brussels	**3000**	3.4	41.8
Stuttgart	**3000**	1.8	28.2
Helsinki	**2250**	1.8	18.6
Rural EU areas	**400**	1.8	7.9

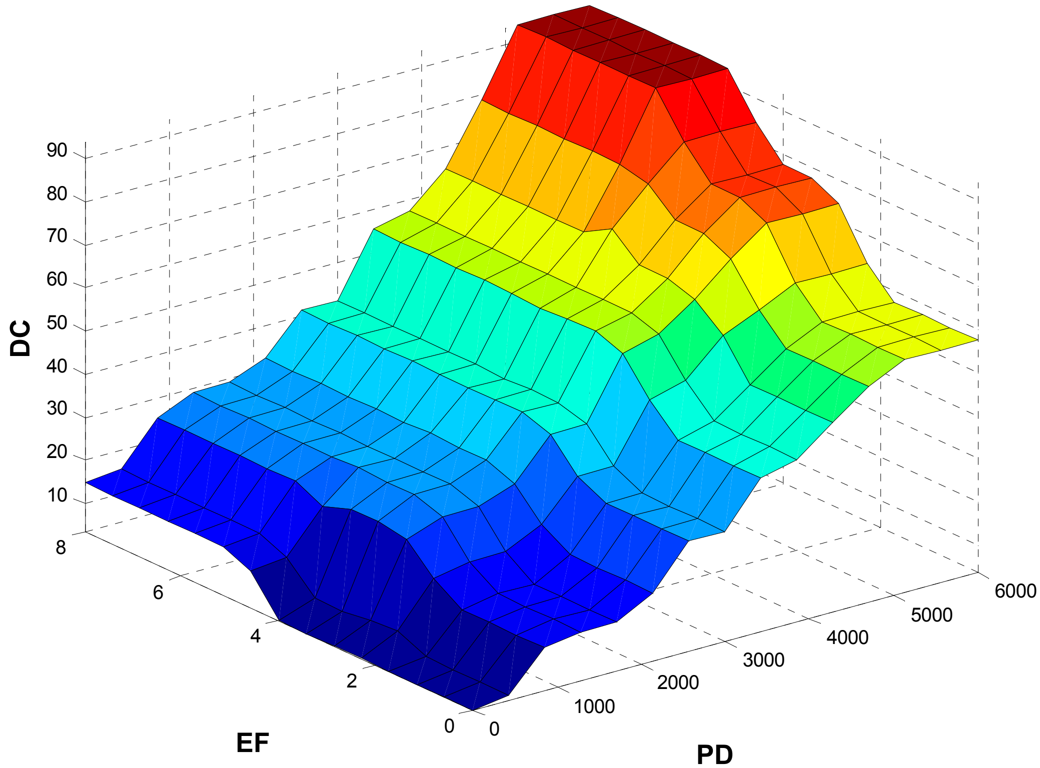


Figure 6.7: 3-D Surface for PM

6.3.2 Air pollution – Other Pollutants

Unfortunately, similar detailed studies of air pollution damage costs of specific cities or populated areas for the other air pollutants NOx, SO_2, VOC, CO are not available. The REALISE project (AMRIE, 2003) has published the damage costs for several transportation modes and traveling conditions. Representative locations are assumed for each mode, as shown in Table 6.6.

Table 6.6: Damage Costs for Three Transport Modes under Different Traveling Conditions in euros per ton

Mode	ROAD		Rail	Sea
Conditions	congestion	highway		
Location	Urban	Rural	Rural	Open sea
NOx	4,995	2,504	2,006	1,552
VOC	1,390	697	558	432
SO_2	13,967	7,002	5,609	4,342

(Source: AMRIE, 2003)

After converting the above costs to non-dimensional indices with max 100, we attempt to match the above relative damage costs indices with the outputs of our fuzzy logic models.

Fuzzy Logic Model for NOx

The membership functions for the fuzzy input variable emission factors of NOx (EC-NOx) are shown in Figure 6.8.

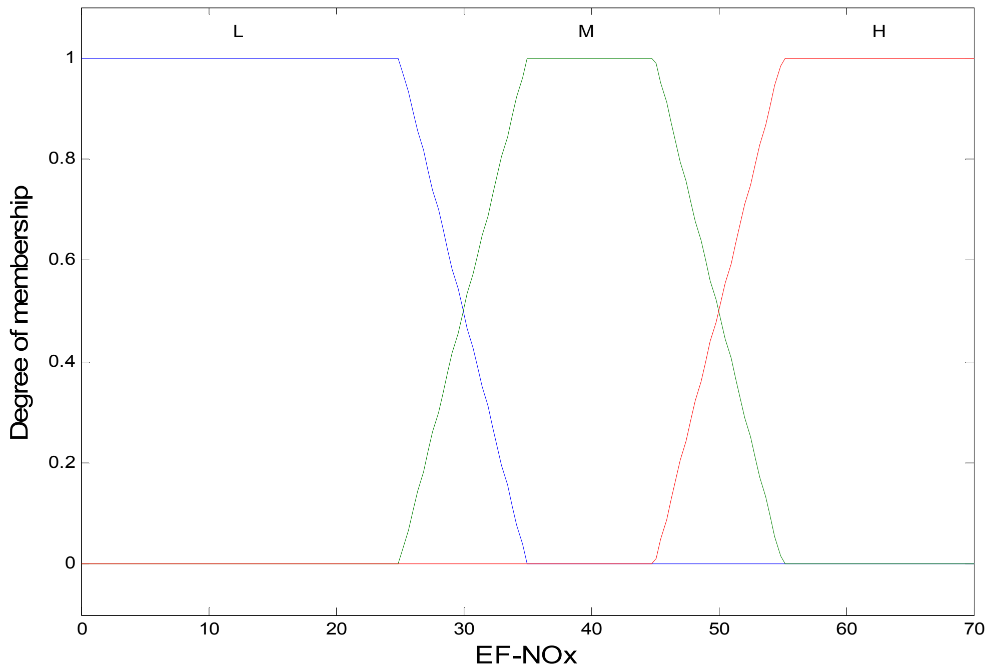


Figure 6.8: EF-NOx Membership Functions

The population density (PD) membership functions are shown in Figure 6.9. For the rest of pollutants, fewer membership functions were used, since there is not enough data of the damage costs of these pollutants.

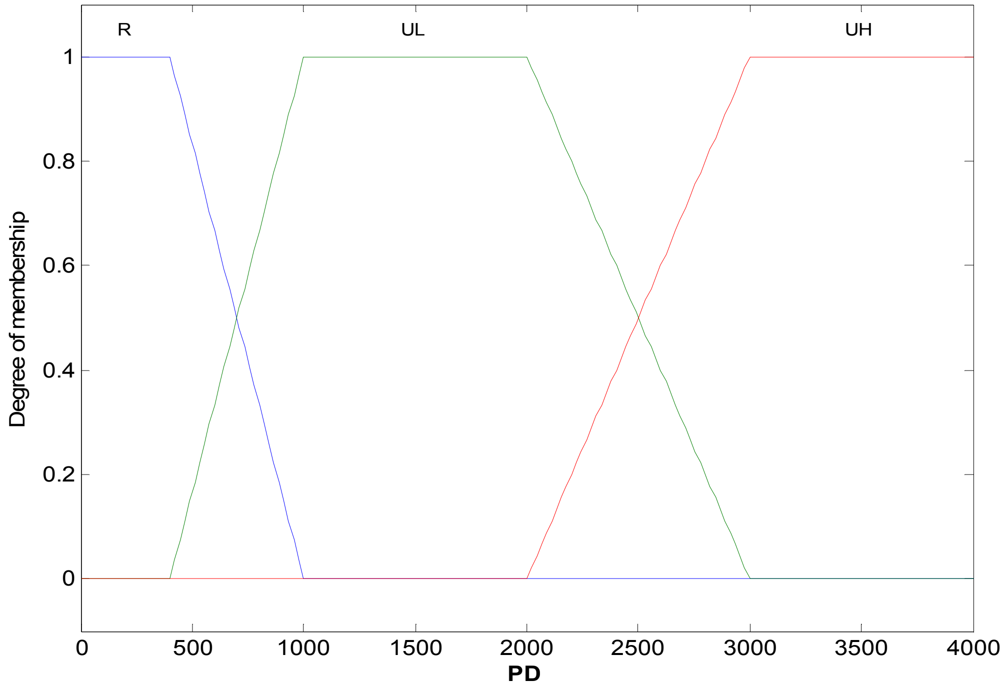


Figure 6.9: Population Density (PD-NOx) Membership Functions

The membership functions of the output variable damage costs of NOx (DC-NOx) are shown in Figure 6.10

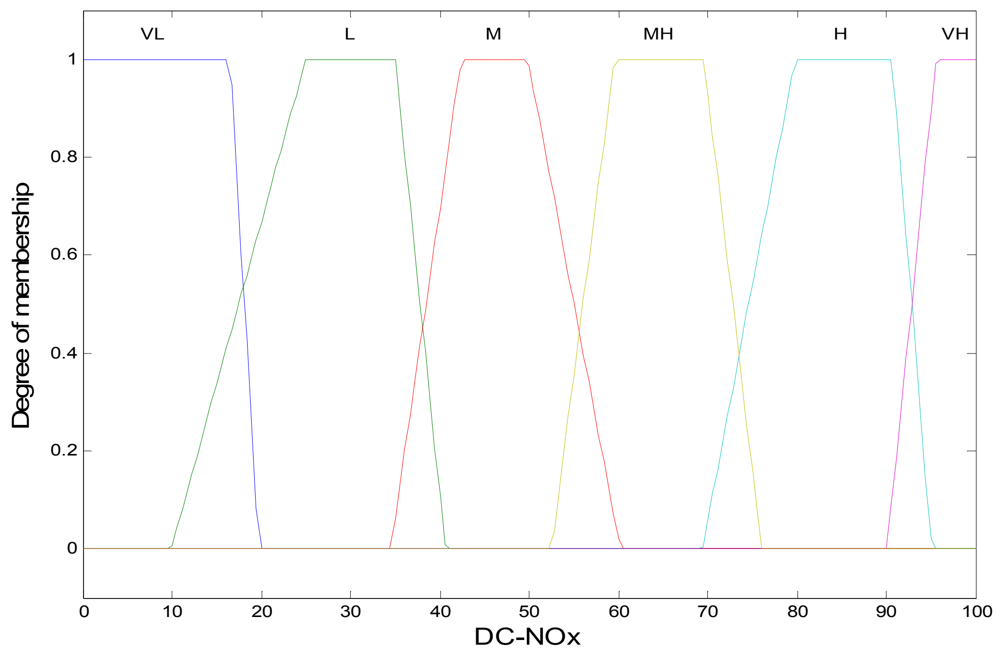


Figure 6.10: Damage Costs (DC-NOx) of NOx Membership Functions

The IF-THEN fuzzy rules matrix is shown in Table 6.7

Tables 6.7: Fuzzy Rules Matrix for NOx

	LOW	**MODERATE**	**SEVERE**
R	VL	L	L
UL	M	M	H
UH	H	H	VH

The surface in Figure 6.11 maps the results of the fuzzy logic model. Similarly to the PM damage costs results, the population density is an important factor of the damage costs.

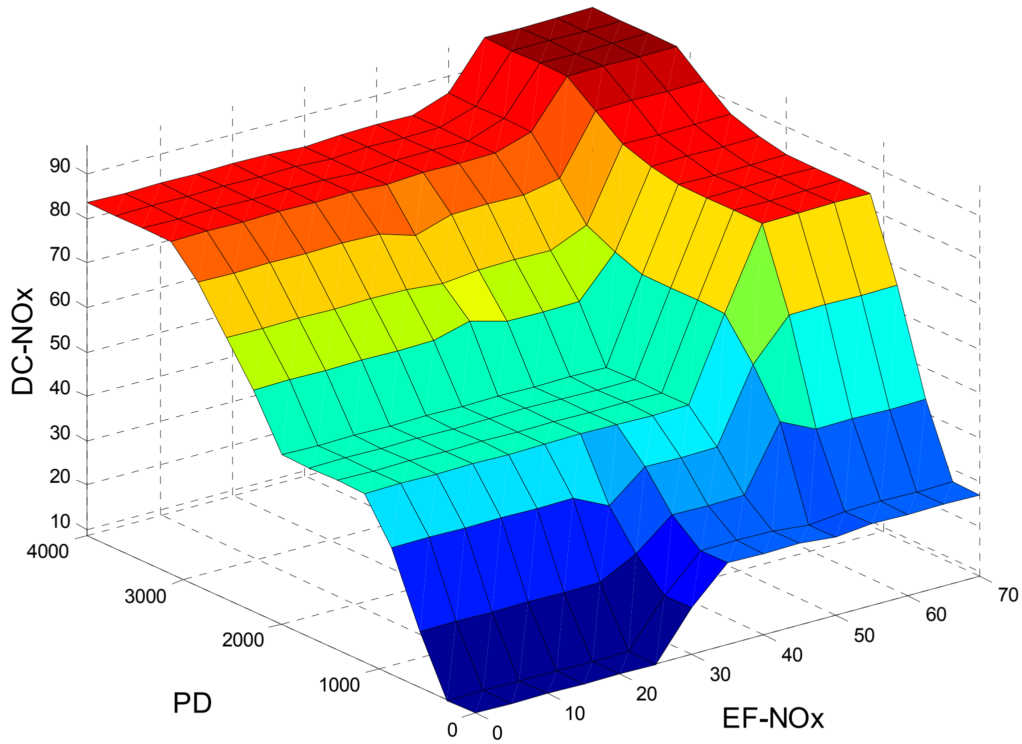


Figure 6.11: 3-D Result Surface for NOx

Similarly, for VOC the population density input variable is the same. The emission factor ranges are taken form Table 6.1-6.3 and the fuzzy input variable EF-VOC membership functions are shown in Figure 6.12

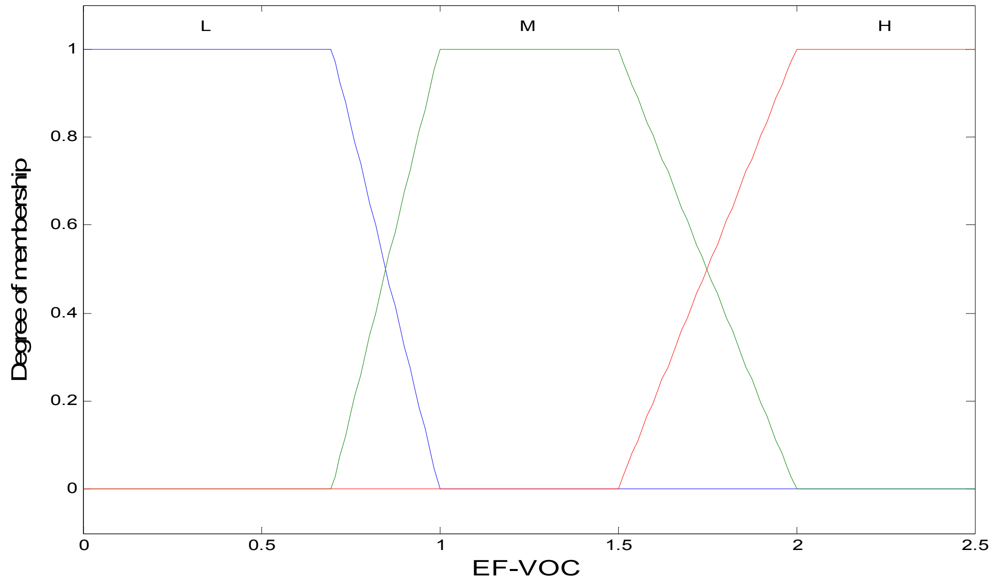


Figure 6.12: Membership Functions for the Fuzzy Input Variable EF-VOC

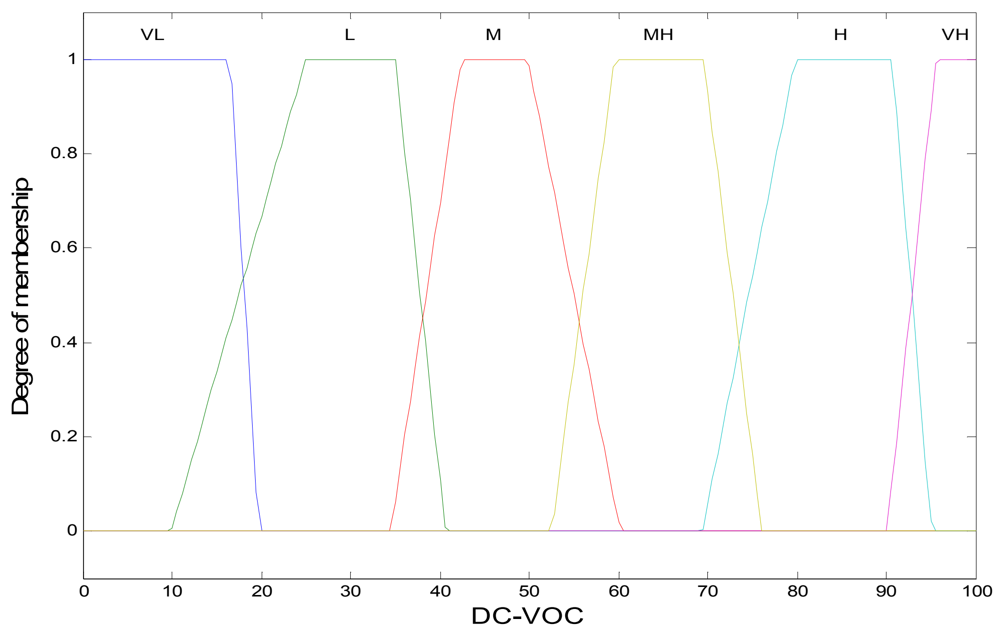


Figure 6.13: Membership Functions for the Fuzzy Output Variable Damage Costs of VOC (DC-VOC)

Similar rules were made for VOC. The rules matrix is shown in Table 6.8.

Tables 6.8: Fuzzy Rules Matrix for VOC

	LOW	MODERATE	SEVERE
R	VL	L	L
UL	M	M	H
UH	H	H	VH

The result surface in Figure 6.14 show that the damage costs increase both with emissions and with population density increases. The results and are in good compliance with Table 6.6.

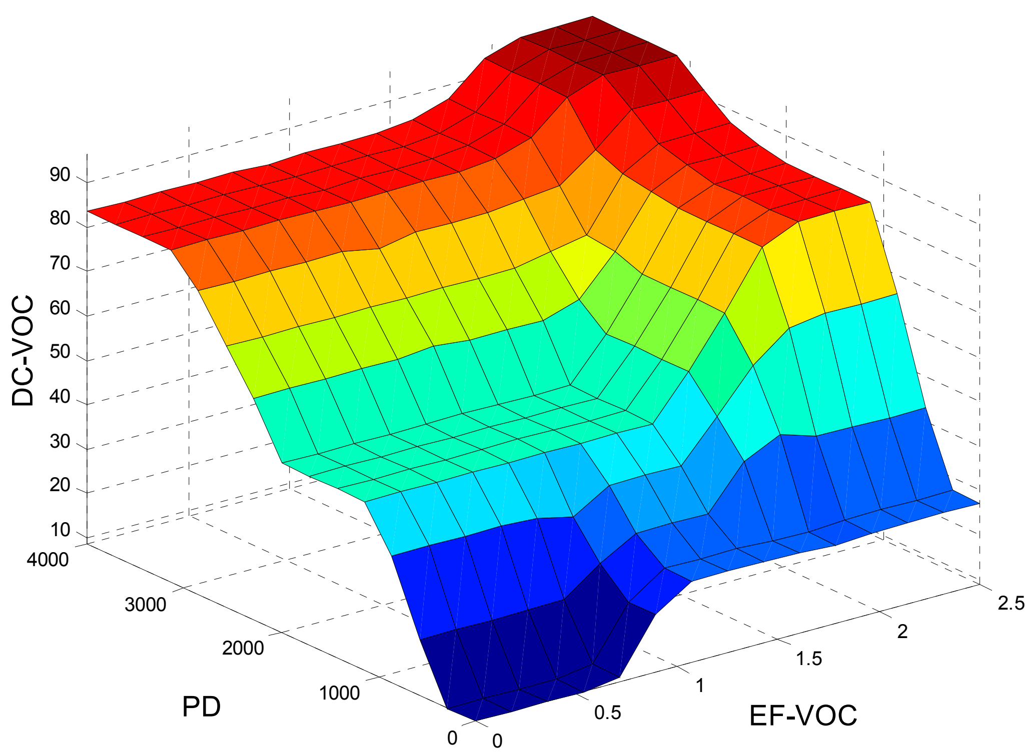


Figure 6.14: 3-D Surface for VOC

Similar results were obtained for the SO_2 damage costs, shown in Figure 6.17. The input variable EF-SO_2 and the output variable DC-SO2 are shown in Figures 6.15 and 6.16, respectively. The CO damage costs are very small, approximately €3 per ton, so they are omitted.

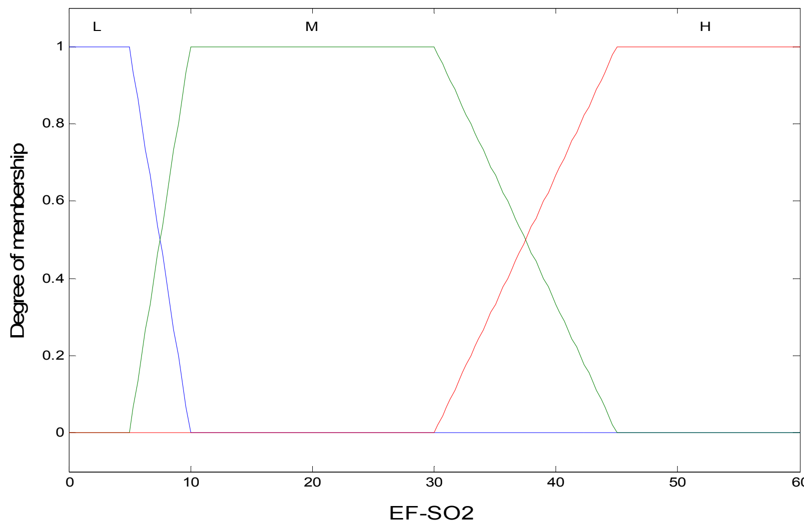


Figure 6.15: EF-SO_2 Membership Functions

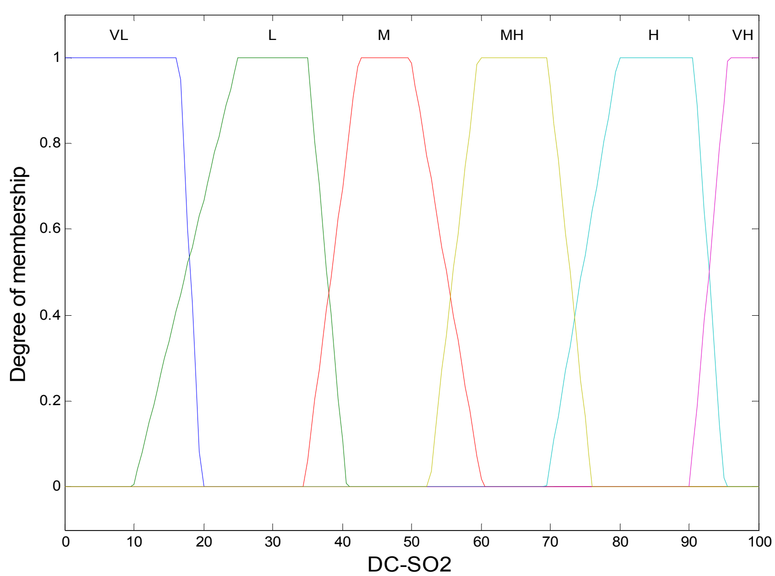


Figure 6.16: Damage Costs of SO_2 (DC-SO_2) Membership Functions

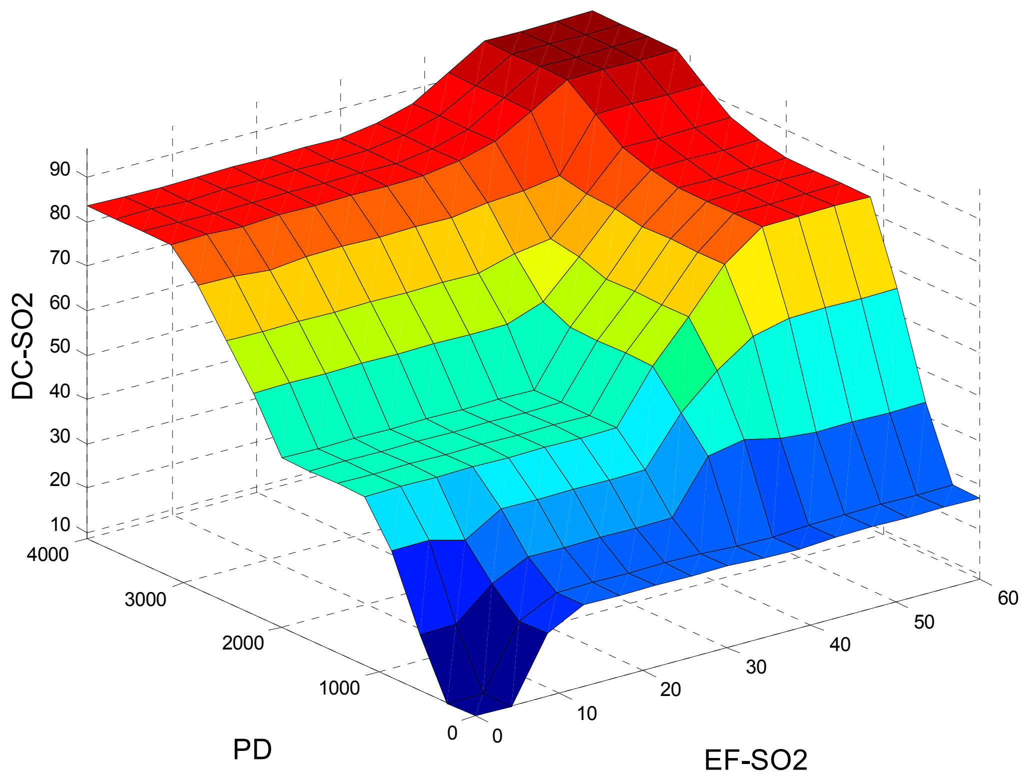


Figure 6.17: 3-D Surface for SO_2

6.3.3 Congestion

In Chapter 5, congestion costs for combination trucks are given as weighted averages for urban and rural roads, but also for peak and off-peak hours. Using fuzzy logic, a mode adaptive, customized estimation of the external costs of congestion is estimated, by taking into account the specific road traffic characteristics and the time of the day. Figure 6.18 shows the fuzzy logic system for estimating congestion external costs.

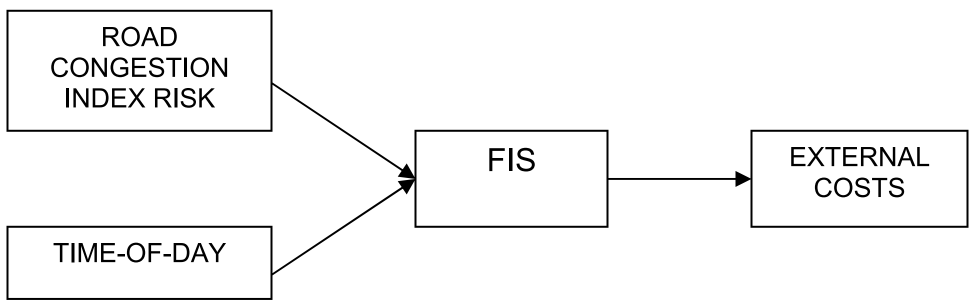


Figure 6.18: Fuzzy System for Congestion

The two input variables are:

Input variable 1: Congestion Risk Index (CRI)

CRI is defined as the road characteristic that determines the possibility of that road to be congested. CRI is a function of both the road type as defined by FHWA—freeway, rural expressway, urban expressway, or two-lane—and of the average annual daily traffic (AADT) per lane. Table 6.9 shows the threshold values of CRI for typical U.S. roads in a scale from 0 to 10.

Table 6.9: Congestion Risk Index

	AADT per lane	CRI	
Freeway	<15,000	LOW	1 - 4
	15,000 - 20,000	MODERATE	2 - 8
	>20,000	SEVERE	6 - 10
Rural Expressway	<8,000	LOW	1 - 4
	8,000 - 11,000	MODERATE	2 - 8
	>11,000	SEVERE	6 - 10
Urban Expressway	<5,000	LOW	1 - 4
	5,000 - 7,000	MODERATE	2 - 8
	>7,000	SEVERE	6 - 10
Two-lane	<4,500	LOW	1 - 4
	4,500 - 7,500	MODERATE	2 - 8
	>7,500	SEVERE	6 - 10

(Sources: Kritzky, 2004)

CRI as fuzzy input variable has thee trapezoidal membership functions.

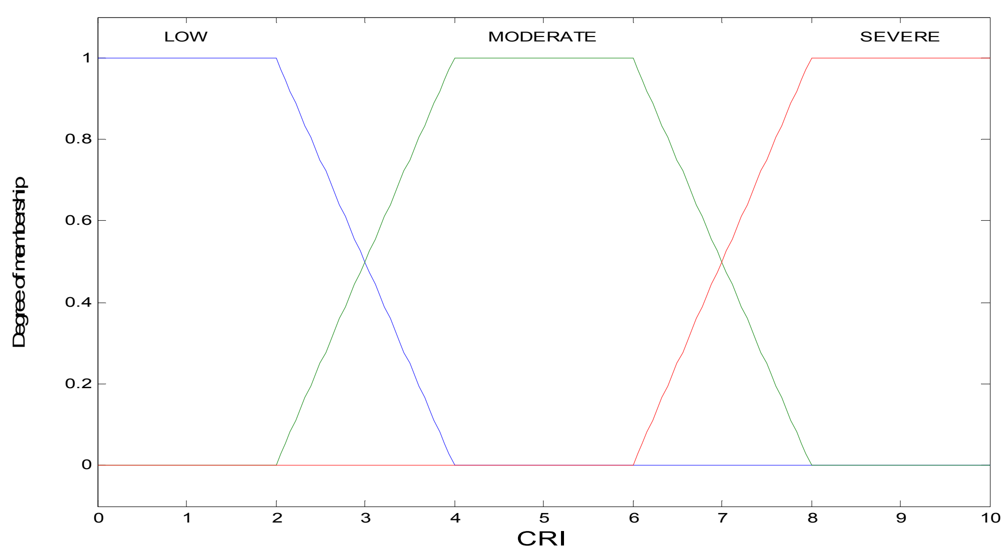


Figure 6.19: Congestion Risk Index (CRI) Membership Functions

Input variable 2: Time-of-Day

The time of the day plays a crucial role in traffic congestion. DOT defines as peak-time of rush hours form 6MA to 10AM and from 3PM to 7PM. The 24-hour day is divided into 5 segments, where the two peak hours, morning and afternoon, are around 8AM and 5PM. NT: 00:00 – 08:00, Morning peak (MPK): 06:00 – 10:00, Off-peak (OFFPK): 08:00 – 17:00, afternoon peak (APK): 15:00 – 19:00, Evening (EV): 19:00 – 24:00. the resulting membership functions are shown in Figure 6.20.

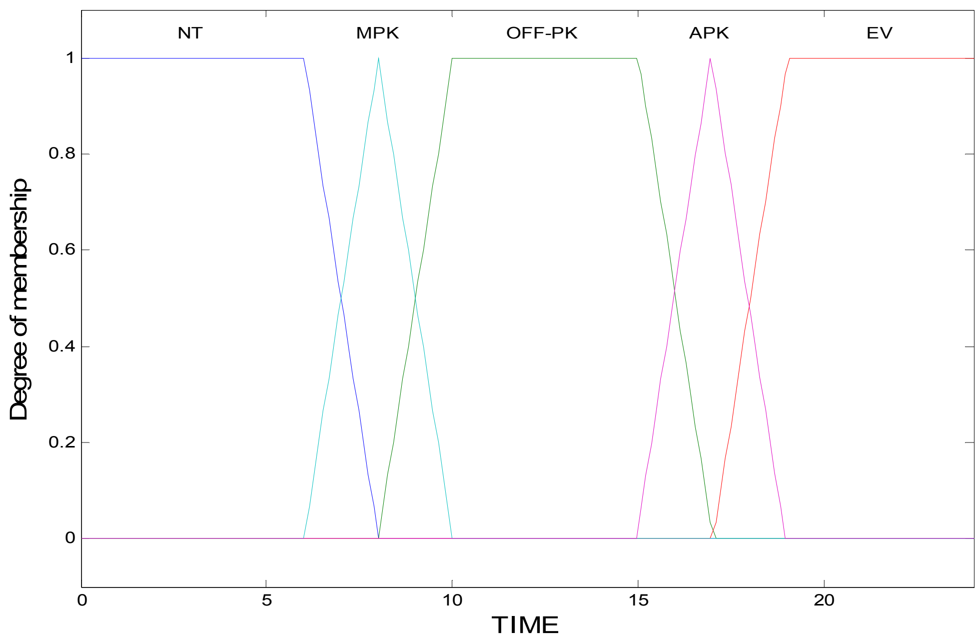


Figure 6.20: Time-of-Day (TIME) Membership Functions

The fuzzy rules are determined from the common knowledge that a congestion-prone road, such as I-95, during peak hours will produce very high external congestion costs.

Output variable: External Costs of congestion

The updated values for external costs of congestion from the FHWA study with ranges from 5 cents per mile to 70 cents per mile. The resulting output membership functions are shown in Figure 6.21.

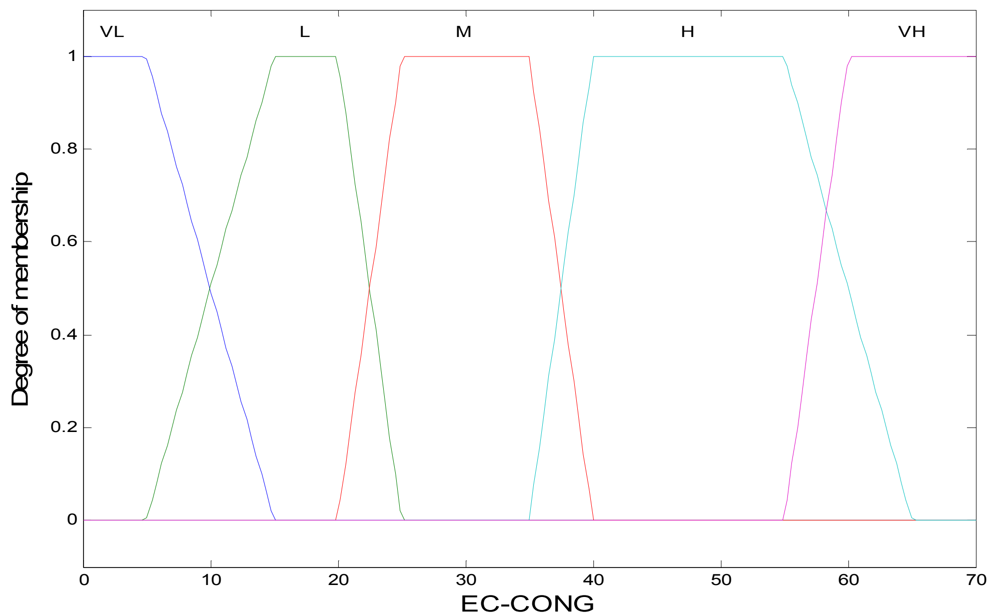


Figure 6.21: External Costs of Congestion (EC-CONG) Membership Functions

The fuzzy rules matrix is shown in Table 6.10.

Tables 6.10: Fuzzy Rules Matrix for Congestion

CRI	LOW	MODERATE	SEVERE
NIGHT	VL	VL	L
MORNING PEAK	M	H	VH
OFF-PEAK	L	M	H
AFTERNOON PEAK	M	H	VH
EVENING	VL	L	M

The surface shown in Figure 6.22 shows how congestion costs vary with time, where there are two peaks, in the morning and afternoon peak-hours, and also the role of the specific road characteristic (CRI) in the external cost of congestion.

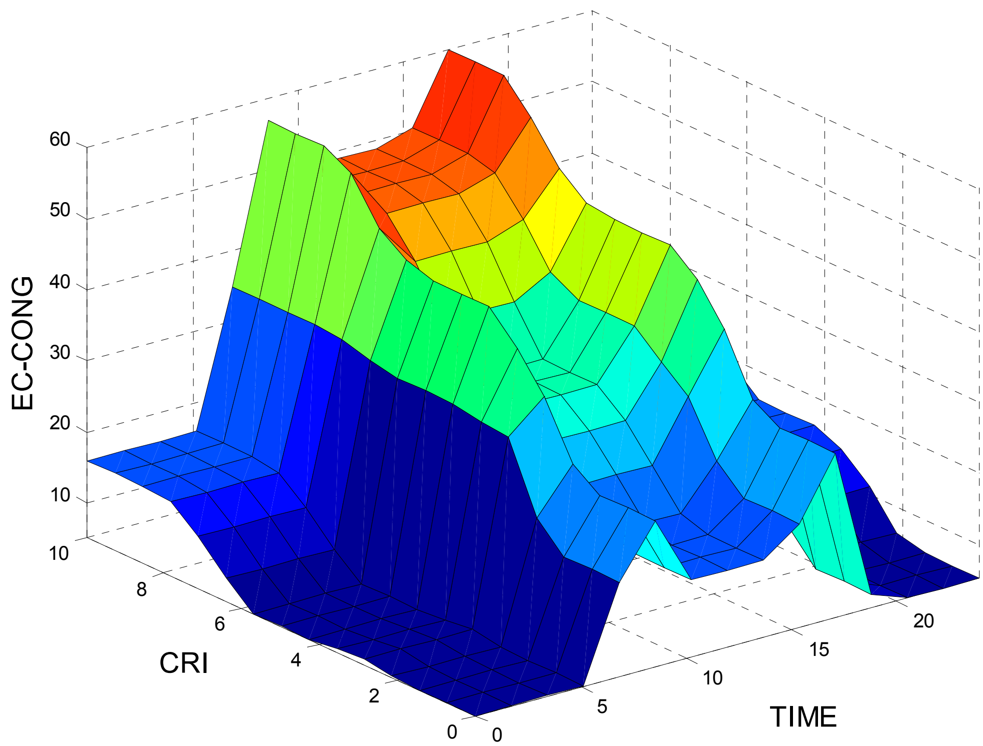


Figure 6.22: 3-D Surface for Congestion

CHAPTER 7

MODELING THE FULL SOCIAL COSTS OF SSS AND TRUCK MODE

In this chapter, an analytical model for the calculation of the full social costs of SSS and trucking is developed. The full social cost of a transportation mode is the sum of its internal and external costs. Fair pricing, based on the "polluter/user-pays" principle, determines transportation prices of a mode from its social costs, i.e. the full cost that this transportation mode produces. The internal costs of SSS consist of the sum of vessels' operating and voyage costs, plus drayage and inventory costs. The external costs for every mode of transportation consist of the categories described in the previous chapters: air pollution, congestion, infrastructure repair and maintenance, accidents, and noise. The analytical model includes the calculation of both the internal and external costs.

7.1 Internal costs of SSS

As mentioned in the previous chapters, SSS is an intermodal transportation system that provides door-to-door services. Ships perform the long-haul transportation between two ports, whereas trucks perform the short-haul pick-up and the delivery of cargo to the final destination (Figure 7.1).

Figure 7.1: SSS Intermodal System Configuration

According to the above configuration, the long-haul waterborne transportation leg is performed by a vessel employed between two ports located at distance d. The following vessel and route characteristics are given:

k = Cargo in number of TEUs or trailers

c_k : Unit weight per TEU

N : Number of trips per year

SHP : Ship's Engine Power (kW)

SFC : Specific fuel consumption (g/kWh)

f : Fuel price ($/ton)

d : Distance at sea (nm)

v : Speed (knots)

Internal or private costs C_{INT} are the costs allocated between the parties involved in the transaction and are reflected in the transportation prices. In intermodal SSS, these costs include the ship's capital recovery costs C_{CR} and the ship's running costs, which are the fixed operating expenses C_{OPEX} and the variable voyage costs C_{VOY} . We also add the trucks' drayage cost for the two road segments C_{DRAY} too.

$$C_{INT} = C_{CR} + C_{OPEX} + C_{VOY} + C_{DRAY} \tag{7-1}$$

a. Capital Recovery Costs *(C_{CR})*

The annual capital recovery costs C_{CR} are estimated according to the (7-2) formula:

$$C_{CR} = CR \cdot P \tag{7-2}$$

where CR is the capital recovery factor and is been calculated from the (7-3) formula and P is the purchase price.

$$CR = \frac{i(1+i)^N}{(1+i)^{N-1}} \tag{7-3}$$

where i is the investor's rate of return.

It must be noted however that the capital recovery cost was applied only to the purchase price of a ship or a truck, i.e. equipment, and does not include the infrastructure costs, such as highways or terminals, which in the case of trucking is substantial.

b. Fixed operating expenses (C_{OPEX}) are the costs of the day-to-day running of the ship. These costs include crew, insurance, stores and lubricants, and repair and maintenance. The operating costs are determined in $ per year and are the sum of the following components:

$$C_{OPEX} = CR + RM + SL + I + AD \qquad (7\text{-}4)$$

where:

CR: crew and manning costs

RM: repair and maintenance costs

SL: store and lubricants

I: insurance costs

AD: administration

c. Variable voyage costs (C_{VOY}) are the ship's costs associated with a specific voyage and include fuel costs, port fees, including HMT, and cargo handling charges.

C_{VOY} are determined per roundtrip. The two components are the fuel costs C_{FUEL} and the port costs C_{PORT}:

$$C_{VOY} = C_{FUEL} + C_{PORT} \qquad (7\text{-}5)$$

where:

$C_{FUEL} = SFC_m \cdot SHP_m \cdot (d/s) \cdot f$ are the fuel costs and

$C_{PORT} = 2 \cdot P_k \cdot k$ are the port costs, with

P_k: unit port costs per TEU

d. Drayage costs (***C_{DRAY}***) are the truck costs that occur at the two short-haul road segments. The drayage costs from and to the two port terminals are:

$$C_{DRAY} = D_k \cdot (k/2) \quad (7\text{-}6)$$

where:

D_k : the cost of drayage per trailer or per FEU = 2TEU

The total average unit internal cost (c_I) in \$ per ton-miles is:

$$c_I = (C_{CR} + C_{OPEX}) / (2N \cdot k \cdot c_k \cdot d) + (C_{VOY} + C_{DRAY}) / (2 \cdot k \cdot c_k \cdot d) \quad (7\text{-}7)$$

7.2 Truck Internal Costs

There are two basic types of freight truck service in the U.S.: truckload (TL) and less-than-truckload (LTL). TL services generally transport a shipment from a single shipper to one receiver. LTL trucking serves many shippers to multiple receivers. LTL companies maintain strategically located terminals, where cargo is consolidated. The deregulation of the trucking industry in 1978 has led to a steadily increasing portion of the TL sector. The main competitor of SSS is the long-haul TL trucking sector.

Trucking companies do not publicly publish cost or rates. The most common measurement is the Rate Per Mile (RPM) that a truck company charges. The basic RPM varies by regions and direction. RPM is lower for longer distances. RPM has a fuel surcharge part as adjustment to diesel prices. These fuel surcharges changed from $0.34 per mile in August 2007 to $0.61 in August 2008 (www.truckloadrate.com). More precise RPM quotes were obtained for private trucking companies' websites. These quotes reveal the following variation with distance: for long-haul distances, greater than 1,000 miles, the RPM is approximately at \$2.1 to \$2.3 per mile; for short haul distances, less than 300 miles, RPM is at \$3.5 per mile.

FHWA collects data on the average operating expenses of trucking in the U.S. on a per mile rate basis. The average cost per mile, extrapolated to 2008 prices, is **\$2.0/veh-mi**, as shown in Figure 7.2.

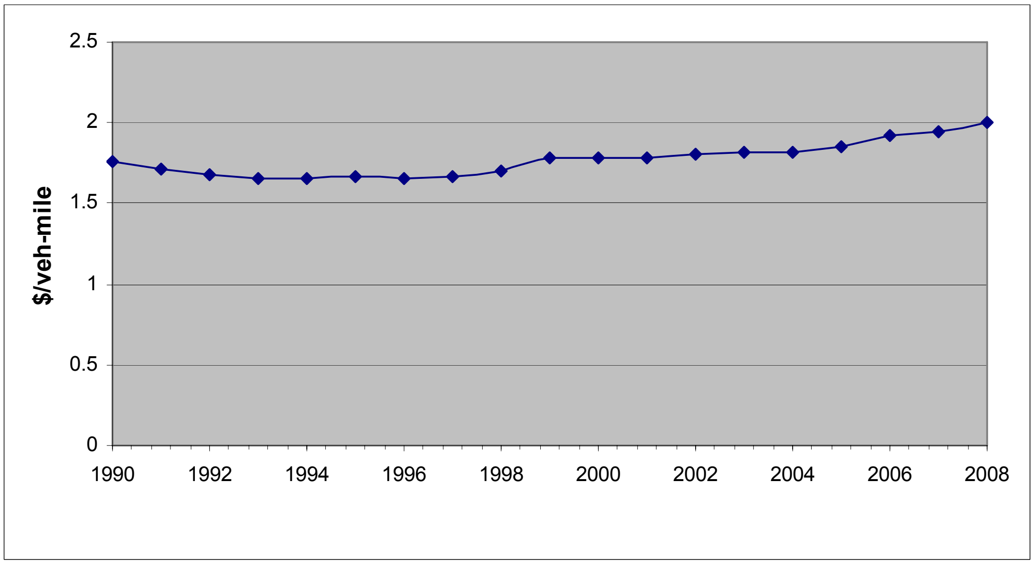


Figure 7.2: Trucking Average Cost Per Mile
(Source: FHWA, 2000b)

7.3 Inventory costs

Time can be a crucial factor for general cargo, especially when the goods are time sensitive. Typical examples are perishable and consumer goods with a short life cycle or high economic or technological depreciation (fashion, computers, etc). An extra day at port creates opportunity costs linked to fixed capital and could lower the economic value of the goods concerned. Therefore for the mode comparison to be complete, the inventory costs that a shipper experiences from delays are included (C_{INV}). The average value of containerized goods differs substantially among trade routes: \$15,000/TEU at the China-U.S. routes, \$28,000 at the Europe-U.S. routes, \$70,000/TEU to the U.S.-Japan routes (Cowie, 2007).

A delay of one day incurred by a container loaded with a value \$40,000 typically results in the following costs (Notteboom, 2005):

1. Opportunity costs (3%–4% per year): \$3 – \$4.5 per day and
2. Economic depreciation (typically 10%–30% per year for consumer products): \$10–\$30 per day.

We assume average value per trailer or FEU, V = \$40,000. The inventory cost C_{INV} per day equals the container value V times the daily interest rate i that represents the depreciation and the opportunity cost.

$$C_{INV} = V \cdot i \tag{7-8}$$

7.4 External Costs

The external cost of a transportation mode is the sum of the various external cost categories: air pollution, congestion, infrastructure repair and maintenance, noise, accidents, greenhouse gases.

$$C_{EXT} = C_{AP} + C_{CONG} + C_{INFR} + C_{NOISE} + C_{ACC} + C_{GHG}$$

Air pollution

Five air pollutants and their respective damage costs are considered: PM, SO_2, NOx, CO, and VOC. The external cost of an air pollutant p, $C_{AP\text{-}p}$ is calculated as the product of the quantity of the air pollutant emitted per trip with the damage costs in $ per ton of pollutant. The quantity of air pollutant is calculated by multiplying the total fuel consumption Q_{FUEL} with the emission factor EF_p of that pollutant from the tables in Chapter 5. Dividing by the total ton-miles provides the average external cost of that air pollutant ($MC\text{-}AP_p$) for a certain mode. Therefore:

$$c_{APp} = Q_{FUEL} \cdot EF_p \cdot DC_p \ / (k \cdot c_k \cdot d) \qquad (7\text{-}9)$$

where:

Q_{FUEL} : total fuel consumption per trip

EF_p : emission factor of pollutant p

DC_p : damage costs of air pollutant p

For SSS, two operating conditions are considered: cruising at sea (C) and hotelling condition (H):

$$C_{AP\text{-}p} = Q_C \cdot EF_C \cdot DC_C + Q_{FUEL} \cdot EF_H \cdot DC_H \qquad (7\text{-}10)$$

where:

$Q_{FUEL} = SFC \cdot SHP \cdot (d/s)$ is the amount of fuel (tons) and

EF : emission factors from Table 6.4

DC : damage cost is the output of the FL models from Chapter 6.

$DC = f\,(PD, EF)$

where the two inputs are: the population densities PD of the affected locations and the emission factors EF.

The external costs of trucks are calculated for two operating conditions: highway conditions, at 55 mph speed, and congestion conditions, at less than 30 mph speed.

FHWA estimates the fuel mileage for combination trucks at $MPG_H = 5.2$ and $MPG_C = 2.8$ mpg, respectively. Therefore, the quantity of fuel consumed per truck on a specific route, where d_H is the un-congested highway segment and d_C the congested segment:

$$Q_{FUEL} = d_H / MPG_H + d_C / MPG_C \tag{7-11}$$

Congestion

The average unit external costs of congestion (C_{CONG}) are estimated as outputs of the Fuzzy Logic Congestion model, described in Chapter 6, with inputs the Congestion Risk Index (CRI) of a specific road and the percentage of peak and off-peak traveling.

$C_{CONG} = f\,(CIS,\ TIME)$

Infrastructure

The infrastructure repair and maintenance external costs C_{INFR} are estimated from the top-down cost allocation tables of the FHWA Highway Cost Allocation Study (HCAS) (FHWA, 1997) for current 2008 values, depending on the type of roads used on a specific route, both for drayage and long-haul trucking.

Accidents

Similarly, the non-compensated external costs of highway accidents C_{ACC} attributed to combination trucks are given from FHWA Highway Cost Allocation Study (FHWA-HCAS) (FHWA, 1997).

Greenhouse Gases

The external cost of greenhouse gases are estimated by multiplying the amount of CO_2 emitted with the abatement cost, as this is determined from the price of a ton of CO_2 that is traded at the emissions trading scheme of the EU. For December of 2008, this value was at 15 euros per ton of CO_2 (www.pointcarbon.com).

The total average external costs c_E per ton-mile are:

$$c_E = c_{AP} + c_{CG} + c_{INFR} + c_{NS} + c_{AC} + c_{GHG} \tag{7-12}$$

Adding the external costs to the internal costs provides the full social cost of a transportation mode (in $ per ton-mile).

$$c_S = c_I + c_E \tag{7-13}$$

CHAPTER 8

APPLICATION OF SOCIAL COST PRICING IN TWO PROSPECTIVE SHORT SEA OPERATIONS

The analytical model, presented in Chapter 7, is applied to two transportation operational scenarios in representative U.S. East Coast routes in order to compare the two competing two modes: intermodal SSS and all-road truck mode. This comparison provides an indication about the relative magnitude of the various cost factors, both internal and external, and demonstrates the “fair pricing” principle in real business case studies.

Furthermore, the fuzzy logic models, for air pollution and congestion, presented in Chapter 6, are applied for the estimation of more precise, site-specific external costs in the proposed routes, under certain conditions. The first case study is a container feeder service between the Port of New York/New Jersey and the Port of Canaveral, FL. The second case is a Ro-Ro operation transporting trailers between the ports of Fall River/New Bedford, MA and Jacksonville, FL. The differences between these types of SSS operations were also discussed in Chapter 2, thus their economic aspects are examined here.

8.1 Feeder Short Sea Service from Port of NY/NJ to Port Canaveral, FL

The first short sea operation is a container feeder service between the Ports of New York/ New Jersey and the Port of Canaveral, FL. The Port of New York/New Jersey is the largest container port on the U.S. East Coast with an annual throughput that exceeded 5 million TEUs in 2007. The Port of Canaveral has examined the potential to become a short sea feeder port in cooperation with other major hub ports on the East Coast (Yonge and Hesey, 2005).

Description of service:

Route: Port of NY/NJ – Port of Canaveral, FL

Distance: 860 nautical miles

Drayage: 100 miles at the two ports assumed

Frequency: weekly, 50 roundtrips per year

Cargo: TEU and FEU ISO containers (1FEU = 2TEUs)

Vessel: Containership, Feedermax size

Capacity: 1,000 TEUs

Speed: 19 knots

Engine: SHP= 10,000 kW, medium speed

Fuel consumption: SFC= 175 g/kWh

The ship is fully-laden in both trips. Average weight of 1 TEU = 10 tons. Average value of 1 TEU = $40,000

8.1.1 Internal Costs of Feeder Service

The estimation of internal costs is conducted according to the procedure outlined in Chapter 7. The capital recovery cost C_{CR} of the feeder is determined for a new-building price of a feedermax container ship built in the U.S. Under the Jones Act requirements the price of U.S.-built ship is almost three times higher than of a foreign-built. The useful life of the feeder is assumed to be 25 years and the investor rate of return *i* is assumed at 8%. In 2002, Matson commissioned two 2,600-TEU containerships, built at Kvaemer Philadelphia Shipyard at a price of $110 million each (Tirschwell, 2000). Vessels of similar size and capabilities cost around $40 million at foreign shipyards. The price of a feedermax in December 2008 was $25 million, according to Clarksons (Clarksons, 2008). Therefore, the price of a new U.S.-built feedermax containership was assumed at $70 million.

Vessel operating cost data are obtained from Moore Stephens' OpCost estimates (Moore Stephens, 2007). Also, the price of HFO that was used is $300 per ton (as of December, 2008). Average internal unit cost for the feeder service is: **$1,504** per FEU or **$0.0645** per ton-mi.

Table 8.1: Feeder Internal Costs

Cost	Per roundtrip voyage	%
Capital Recovery	131,180	8.7%
Operating	89,288	5.9%
Port	500,000	33.3%
Drayage	700,000	46.5%
Fuel	83,425	5.6%
TOTAL	**1,503,893**	**100.00%**

8.1.2 External Costs of Feeder service

Air pollution

The customized fuzzy logic model is used to determine the air pollution damage costs for the specific routes under specific operating conditions for ship and truck drayage.

Input variable 1: Emission Factors (EF)

The vessel operating conditions are separated into the following two states: at sea, cruising (S) and at port or hotelling condition (H). The fuel type at sea and at maneuvering state is heavy fuel oil (HFO-IFO180), while at hotelling state only the auxiliary genset operates using marine diesel oil (MDO). The emission factors are taken from Table 5.2.

Input variable 2: Population Density (PD)

The NJ/NY is assumed as urban-high area with population density of 3000 inhabitants per square kilometer (inh/km^2). The coastal route on the open sea is taken equivalent with low rural population density less than 100inh/km^2. The 100-mile drayage at the two ends of the route is performed under 50% free-flow highway conditions at 55 mph and under 50% congested conditions in urban-high population density (PD). The total quantities of air pollutants are estimated for the sea part, the hotelling part, and drayage as shown in Table 8.2.

Table 8.2: Quantities of Air Pollutants Emitted - Feeder Service (kg)

	AT SEA	AT PORT	DRAYAGE	Total
Sulfur dioxide (SO_2)	4,536	184	44	4,764
Nitrogen oxides (NOx)	4,788	1,049	2,298	8,135
Carbon Monoxide (CO)	621	136	1,087	1,844
Volatile Organic Compounds (VOC)	202	44	177	423
Particulate matter (PM)	101	22	62	185

Output variable: Damage costs (DC)

Running the two fuzzy logic models—for PM and for the other pollutants—for the locations' population densities and the various emission factors, we get the following damage cost indexes (DCI) shown in Table 8.3.

Table 8.3: Feeder Service Damage Cost Indices

	SEA	PORT	DRAYAGE
SO_2	27.2	46.9	83.5
NOx	27.2	46.9	83.5
VOC	27.2	46.9	83.5
PM	14.8	59.7	77.5

Using maximum values for each pollutant's damage cost in $ per ton from the ExternE studies, the following total damage costs are estimated as shown in Table 8.4. The average external unit cost of air pollution for the feeder service is: **$0.088**/ton-mile.

Table 8.4: Total Air Pollution Damage Costs - Feeder ($ per voyage)

Pollutant	AT SEA	AT PORTS	DRAYAGE	TOTAL
SO2	30,845	2,157	923	33,925
NOx	11,070	4,181	16,310	31,561
VOC	137	52	369	558
PM	7,459	6,591	23,975	38,025
Total $ per voyage	48,616	12,552	41,577	**104,069**

Congestion costs of drayage

The fuzzy logic model for the external costs of congestion is applied for the two 100-mile drayage legs. It is assumed that 50% of drayage is performed under 50% free flow highway conditions, between 10:00AM to 14:00PM at 55mph, and under 50% congested conditions at peak-hours around 08:00AM or 17:00PM in urban-high population density. This also applied for the arterial road segment of drayage. The congestion risk index (CRI) for I-95 is chosen as high or CRI=9, since I-95 is a highly used road on the East Coast. For the two input variables CRI and TIME the fuzzy logic model gives the external costs (EC) of congestion in $ per truck-mile traveled for the drayage part, shown in Table 8.5. The $47.25/truck-mile is converted to $/ton-mile for SSS. The external cost of congestion for the feeder service is **$0.0040/ton-mile.**

Table 8.5: Congestion Costs of Drayage – Feeder Service

Road	TIME	CRI	$/VMT	%	$/mile
I-95	PEAK	9	62.1	25%	15.525
	OFF-PK	9	48.9	25%	12.225
Arterial	PEAK	5	48	25%	12.000
	OFF-PK	5	30	25%	7.500
				Total	**47.250**

Greenhouse gases

The external cost of GHG is determined by calculating the amount of CO_2 emitted from the ship and drayage operations. This amount is multiplied by the price of CO_2, which is obtained from the Emissions Trading Market of the EU (15 euros for December 2008).

The rest of the external costs are estimated based on the Highway Cost Allocation Study (HCAS-FHWA) (FHWA, 2000) values, adjusted for 2008 prices (http://data.bls.gov/cgi-bin/cpicalc.pl). Table 8.6 shows the total external costs of the short sea feeder operation.

Table 8.6: External Costs – Feeder Service

External Cost	$/ton-mi
Air pollution	0.0088
Congestion	0.0040
Noise	0.0010
Infr. r&m	0.0021
GHG	0.0008
Accidents	0.0007
Total External Costs	**0.0174**

Adding the internal and external costs gives the full social costs of the feeder intermodal service shown in Table 8.7.

Table 8.7: Social Costs – Feeder Service

Costs	$/ton-mi
Internal Costs	0.0645
External Costs	0.0174
Full Social Costs	**0.0819**

The feeder service is very energy efficient and has significant economies of scale, which are translated into lower internal and external costs. Its main disadvantage is the two cargo transfers at intermodal terminals, where additional cargo handling costs and delays occur. By transporting ISO containers, feeders will operate at hub ports where port congestion and capacity constraints were an issue for the major coastal U.S. ports.

8.2 Ro-Ro Short Sea Operation from New Bedford, MA to Jacksonville, FL

The second SSS operation is a Ro-Ro service between the twin ports of New Bedford/Fall River, MA and Jacksonville, FL. MassPort Authority has examined potential Ro-Ro services from these ports. In Chapter 2, the advantages and the limitations of such service were discussed. Because of the relatively low cargo capacity, a Ro-Ro vessel should be employed on longer short sea routes. The DOT's four-corridor study has recommended a Ro-Ro vessel for the Atlantic corridor with the following characteristics (Global Insight and Reeve & Associates, 2006).

Description of service

Route: New Bedford, MA – Jacksonville, FL

Distance: 840 nautical miles plus 100 mile of drayage at the two ports

Frequency: weekly, (50 roundtrips per year)

Cargo: 53-foot trailers (1 trailer = FEU)

Vessel: Ro-Ro ship

Capacity: 140 trailers

Speed: 25 knots

Engine SHP= 16,000 kW, medium speed

Fuel consumption: SFC = 175 g/kWh

The Ro-Ro capital recovery cost is calculated for a 30-year useful life, assuming a purchase price of $120 million for a U.S.-built, 2300 lane-in-meters Ro-Ro vessel. The price of a similar vessel built at foreign shipyards was $60 million in December 2008, according to Clarksons. The internal operating and voyage costs are calculated from data obtained from the four-corridor and SCOOP study, according to the procedure described in Chapter 7 (Global Insight and Reeve & Associates, 2006; UNO, 2004). The internal costs are summarized in Table 8.8. Average internal unit cost for the Ro-Ro service is: **$2,946** per trailer or **$0.1239** per ton-mi

Table 8.8: Ro-Ro Internal Costs

Cost	Per roundtrip voyage	%
Capital Recovery	213,120	25.8%
Operating	105,850	12.8%
Port	240,800	29.2%
Drayage	196,000	23.8%
Fuel	69,132	8.4%
TOTAL	**824,902**	**100.00%**

Similarly, the customized fuzzy logic model is used to determine the air pollution damage costs for the specific route under specific operating conditions. Emission factors are taken from Table 5.2. The total quantities of air pollutants are shown in Table 8.9.

Table 8.9: Quantities of Air Pollutants Emitted – Ro-Ro (kg)

	AT SEA	AT PORT	DRAYAGE	Total
Sulfur dioxide (SO_2)	5,435	147	12	5,594
Nitrogen oxides (NOx)	5,737	838	644	7,219
Carbon Monoxide (CO)	745	109	304	1158
Volatile Organic Compounds (VOC)	242	35	50	327
Particulate matter (PM)	120	18	17	155

Damage costs

The New Bedford/Fall River area is assumed to be an urban-medium area with population density of 2000 inh/km^2. Running the fuzzy logic models for the location's population density and the various emission factors, for certain operating conditions, the damage cost indexes shown in table 8.10 are obtained. Multiplying by the maximum values of the damage costs the total air pollution damage costs shown in Table 8.11are obtained.

Table 8.10: Damage Cost Indexes – Ro-Ro Service

	SEA	PORT	DRAYAGE
SO_2	27.2	46.9	83.5
Nox	27.2	46.9	83.5
VOC	27.2	46.9	83.5
PM	14.8	41.2	77.5

Table 8.11: Total Air Pollution Damage costs – Ro-Ro Service

Pollutant	AT SEA	AT PORTS	DRAYAGE	TOTAL
SO2	36,959	1,724	258	38,941
Nox	13,264	3,340	4,567	21,171
VOC	164	41	103	308
PM	8,938	3,634	6,713	19,285
Total per voyage	**59,325**	**8,739**	**11,641**	**79,705**

The external costs of congestion for the drayage 100-mile part are similar to the feeder service: $**0.0040** per ton-mi. Similarly with the feeder case, the external costs of GHG are calculated from the total quantities of CO_2 multiplied by the price of CO_2. The rest of the external cost categories were calculated from the FHWA-HCAS study data and these are summarized in Table 8.12. Adding the internal and external costs, the full social costs of the Ro-Ro intermodal service shown in Table 8.13 are obtained.

Table 8.12: External Costs – Ro-Ro Service

	$/ton-mi
Air pollution	0.0222
Congestion	0.0040
Noise	0.0010
Infrastructure r&m	0.0021
GHG	0.0019
Accidents	0.0007
Total MEC	**0.0319**

Table 8.13: Social Costs – Ro-Ro Service

Costs	$/ton-mi
Internal Costs	0.1239
External Costs	0.0319
Full Social Costs	**0.1558**

Ro-Ro service is a fast and reliable mode. Its easy loading and unloading procedures decreases significantly the port turnaround time and its terminal handling costs are lower. However, its low capacity and increased fuel consumption reduces its competitiveness against the all-truck mode. Another advantage of Ro-Ro vessels is that they can serve smaller ports and secondary terminals avoiding the congestion of the big hub ports. Given that the majority of truck traffic is semi-trailers, there is great potential for Ro-Ro services along the U.S. Coasts.

8.3 Comparison of SSS Services with All-Truck Mode

Based on the data compiled in section 7.3, the internal cost of a semi-truck is assumed to be at $2 per truck-mile for long distances, similar to the short sea services described. Therefore the internal cost of the all-truck option is $0.1 per ton-mile, assuming a 20-ton trailer.

In order to estimate the external costs of air pollution of a single truck, the procedure described in Chapter 7 is followed. The basic assumption is that 70% of the total distance is performed at highway free-flow conditions at urban-low population density and 30% at congestion conditions at urban-high population density. The respective emission factors are taken from Table 6.2. The external costs for congestion is estimated from the fuzzy logic model with the assumptions for road CRI and time percentages as shown in Table 8.14.

Table 8.14: Congestion Costs of All-Truck Mode ($/vehicle-mile-traveled)

	TIME	CRI	$/VMT	%	$/VMT
I-95	PEAK	9	62.1	15.0%	9.315
	OFF-PK	9	48.9	15.0%	7.335
	NIGHT	9	24	30.0%	7.200
Arterial	PEAK	5	48	15.0%	7.200
	OFF-PK	5	30	15.0%	4.500
	NIGHT	5	24	30.0%	7.200
				Total	**42.750**

The external cost of GHG is calculated by multiplying the total amount of CO_2 emitted by the price of CO_2 that is been traded in Emissions Trading Scheme of the EU. The external costs of noise, infrastructure and accidents are estimated according to FHWA values for combination trucks. A comparison of the external costs of the three described services: feeder, Ro-Ro, and all-truck mode is shown in Table 8.15. The full social costs of the three services are shown in Table 8.16 and in Figure 8.1.

Table 8.15: Modal Comparison of External Costs ($/ton-mi)

	Feeder	Ro-Ro	All-Truck
Air Pollution	0.0088	0.0222	0.0185
Congestion	0.0040	0.0040	0.0214
Noise	0.0010	0.0010	0.0062
Infrastructure	0.0021	0.0021	0.0123
Accidents	0.0007	0.0007	0.0043
GHG	0.0008	0.0019	0.0020
TOTAL $/ton-mi	**0.0174**	**0.0319**	**0.0647**

Table 8.16: Modal Comparison of Full Social Costs ($/ton-mi)

	Feeder	Ro-Ro	All-truck
Internal Costs	0.0645	0.1239	0.1000
External Costs	0.0174	0.0319	0.0647
Full Social Costs ($/ton-mi)	**0.0819**	**0.1558**	**0.1647**

Inventory Costs

Since time is valuable for general cargo, the mode comparison would be incomplete without estimating the inventory costs as the opportunity cost that the shipper faces. With average value per trailer or FEU V = $40,000 and daily interest rate i = 0.20/365 the daily cost is $21.92 per day per FEU. Given that it takes 3.3 days for the feeder, 2.15 days for the Ro-Ro, and just 1.2 days for that all-truck mode, for an average distance of 1,200 miles the inventory costs in $ per ton-mile are shown in Table 8.17.

Table 8.17: Modal Comparisons of Inventory Costs ($/ton-mi)

$/ton-mile	Feeder	Ro-Ro	All-Truck
Inventory Costs	0.0033	0.0020	0.00082

Comments on Results

The results of the social cost comparison, shown in Figure 8.1, demonstrate the true competitiveness of SSS, both in terms of internal and external costs. The high energy efficiencies of the sea leg can overcome the additional port and drayage costs that occur at the two intermodal terminals, especially when there are economies of scale similar to the 1000-TEU feedership. Although SSS has higher emissions of certain pollutants, such as SO_2 and PM, given its different damage costs, due to location, its performance in terms of monetary impact of those emissions is superior. A large part of SSS's external costs occur at ports and during drayage. This fact shows that SSS can further improve its environmental performance by reducing emissions at ports.

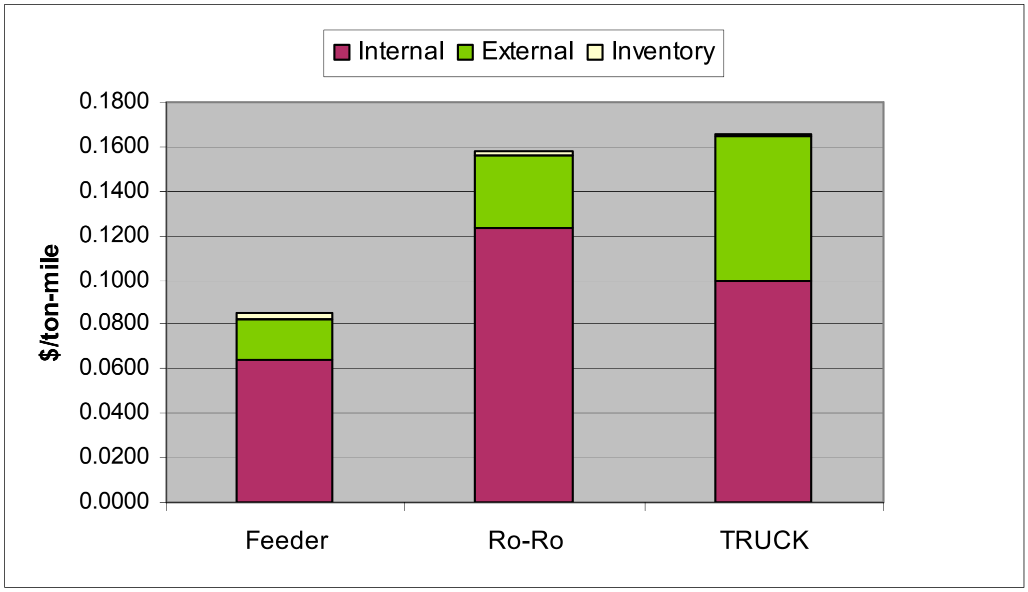


Figure 8.1: Mode Comparison of Full Social and Inventory Costs

CHAPTER 9

CONCLUSIONS

9.1 Conclusions

Estimating the monetary costs of externalities is a challenging task. Traditional top-down or bottom-up methodologies revealed the vagueness, imprecision, and subjectivity in the valuation of environmental externalities. Transportation research so far used average estimates of external costs from previous environmental studies, without taking into account the differentiation of externalities with location or time.

Fuzzy logic treats the vagueness and subjectivity of externalities in a rigorous, but also simple way. Using approximate human reasoning, fuzzy logic models provide reliable estimations of the external costs of air pollution and congestion, for a specific site and certain spatial or temporal conditions. Emissions in urban locations with high population densities produce significantly higher damage costs due to extensive health effects of air pollution. For the same reason, ships operating in the open sea generate considerably lower air pollution external costs. Therefore, although SSS has higher emissions with regard to certain pollutants, such as SO_2 and PM, given its lower pollution costs, due to location, its performance in terms of monetary impact of emissions is superior. This fact, in combination with the high energy efficiencies of SSS and its congestion mitigation benefits, proves the superiority of intermodal SSS in terms of lower external costs compared to the unimodal all-truck transportation. Furthermore, the significant energy efficiencies of SSS make it competitive for large distances, as the two case studies revealed.

9.2 Contributions

This dissertation made the following contributions:

- It demonstrated the principle of full social cost pricing in freight transportation. The external costs were identified, monetized, and included in the determination of the total transportation costs. By internalizing external costs to transportation prices, modes are compared on a fair basis and modal decisions would be based on true costs.
- Applying fuzzy logic, site-specific, more precise estimates for air pollution and congestion costs are derived. These externalities depend highly on the location affected. Therefore, their site-specific estimation provides better estimates of their negative effects.
- The economic feasibility and competitiveness of SSS was examined in two real case studies. It was shown that SSS is a competitive and environmentally-friendly mode. SSS has significant energy efficiencies that can overcome the additional costs at port terminals.

9.3 Recommendations

Policies, such as "cold ironing" for ships on-dock and LNG trucks for drayage, which have been proposed by major California ports, can drastically improve the environmental performance of SSS. In Europe, certain areas, such as the North and the

Baltic Seas, where SSS vessels operate are declared emission-control areas. SSS has great potential for further reducing its external costs, because a large share of its externalities occurs at ports, due to the high sulfur content in marine fuel, and also during the drayage leg. The latest regulations by IMO (MARPOL Annex VI) and by EPA that restrict sulfur levels in marine fuel oil will significantly reduce the air pollution external costs of SSS.

A reliable and simple estimation of the external costs can also facilitate the comparison of the various transportation modes on a fair basis, as the two case studies have demonstrated. Fair pricing in transportation, based on the "polluter-pays" principle, means that the transportation prices of a mode should reflect its full social costs. Therefore, external costs should be internalized. The estimation of SSS's external costs and thus its environmental superiority over trucking can act as an argument for its promotion and support. Modal shifts from trucks to ships can produce significant monetary savings to the society and the economy.

In order to succeed, SSS should be an integral part of an intermodal system that offers reliable door-to-door transportation. Alliances with trucking industry and port authorities and several successful operations from both sides of the Atlantic demonstrate the positive prospects of SSS in the US. SSS is a sustainable and environmentally-friendly mode of transportation. Its energy efficiencies and economies of scale are so significant, compared to trucking, that for large distances, SSS can even be cheaper than trucking, in terms of internal costs also. The disadvantages of SSS occur at the two intermodal terminals, where additional delays and costs occur. Therefore, operational strategies that facilitate the cargo transfer and interoperability with intermodal terminals and drayage trucks can further improve its competitiveness.

9.4 Future Research

The fuzzy logic models for externalities can be extended to include more factors as input variables. For instance, meteorological—weather—conditions can also influence the air pollution's external costs. Also, instead of trial-and-error, the fuzzy logic models can include a tuning phase that will provide more accurate estimates. Fuzzy logic can also be applied to examine the direct outcome of certain environmental policies, as they are described as alternative fuzzy inputs. The crisp outputs can directly guide policy decisions. Thus, the effectiveness of specific internalization policies, such as command-and-control regulation, taxes, or cap-and-trade market mechanisms can be compared.

SSS is an emerging mode of transportation. As part of a marine transportation system, it requires additional research in areas ranging from marine engineering and ship design to modern logistics and transportation science. Existing types of vessels are already been deployed in short sea operations worldwide. Additional vessel types, such as container barges deployed from hub ports to satellite terminals over short distances can be examined.

However, new technologically advanced solutions should emerge that will further increase the competitiveness of SSS. As it has been observed in the cost calculations, the cargo transfer at port terminals is the largest obstacle for SSS in terms of cost and time delays. Terminal-friendly ships and SSS-dedicated innovative terminals can significantly improve SSS's performance.

Operational strategies from successful intermodal networks, such as the bundling or trunk-consolidation-and-distribution railroad networks can also be studied and applied to SSS intermodal networks.

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