Comprehensive Framework for Sustainable Container Ports Development of US East Coast in the 21st Century - Year Three

Environmental Issues in Container Port Planning: Application of an Integrated Framework to Assess Air and Noise Externalities from a Hypothetical Hub Port at Quonset Point, RI

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16. Abstract

We extend prior research on environmental issues in port development by estimating *ex ante* external costs from air emissions and noise because of container port development for a planned port. First, we simulate demand for port services and the least-cost multimodal (train-truck) split and routing. Then, we use coefficients to estimate emissions of key air pollutants from major port sources: dredging, trucks, rail, vessels and on-dock vehicles. Annual emissions reflect growth in traffic, least-cost road routing, road speeds, and phased implementation of EPA regulations. Emissions are estimated for Washington County and for Rhode Island as a whole. Benefit transfer is used to estimate damage for the illustrative case study. The Federal Highway Administration's noise model is used to estimate incremental noise from port-related traffic along the port connector road. Then, exposure of single-family homes along the road to noise is estimated by section of the road and by tiers for each section. Given the estimated noise, the results of a hedonic property value model (done for single family homes in a nearby town) are used to estimate potential noise damages. For both external costs, sensitivity analyses and mitigation options are assessed. The estimates of damages are relatively small for the range of effects considered and assumptions used. Future refinements should assess noise externalities on multi-unit housing and on undeveloped land, and the range of exposure to noise should be extended beyond what was considered in this study. External costs from incremental air emissions focused on NOx; future research should be expanded to include PM and SOx, which were not considered because they were not included in the EPA model (Mobil5b) used for this study.

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INTRODUCTION

I.A. Background and Issues

Environmental concerns – both real and perceived – are a major factor in container port development (Transportation Research Record, 2001; Transportation Research Board, 2002). These concerns stem from the nature of modern container ports, which require deep channels, berths and turn around basins to accommodate the increasing size of container ships, adequate land for terminal facilities, and ready access to interstate road and rail systems. These requirements often mean substantial dredging of subtidal lands and filling in of intertidal and coastal waters during the development stage, and once on line, the daily movement of thousands of containers through and at the port with a resultant potential for air emissions, noise, and other external costs. Environmental concerns also reflect societal ambivalence toward often ill-understood, large-scale development projects which offer economic benefits but are thought to pose serious but uncertain environmental risks.

In short, port development raises a host of *potential* environmental issues. These issues differ between projects and from location to location, but typical environmental concerns include:

- the scale, timing, and effects of dredging and dredge disposal,
- the loss of shoreline and bottom wetlands habitat because of the filling in of coastal waters and inter-tidal lands,
- noise and congestion on roads near the port and added maintenance costs because of the daily movement by truck of thousands of container boxes,
- air pollution from mobile sources,
- the introduction of nonnative species to marine ecosystems via contaminated ballast water,
- interference with fish spawning routes,
- the loss of open space amenities in nearby communities,
- the adverse effects on nearby neighborhoods due to intense lighting
- stormwater runoff of oil, grease, and other substances from port facilities.

Recent experiences at ports along the East Coast underscore the significance of environmental issues in contributing to delays, modifications, and cancellation of major port proposals. Examples include:

- *Daniels Island, Charleston, So. Carolina*: cancelled due to environmental impacts on nearby communities, with development plans shifted to an abandoned Navy facility in the harbor.
- *Quonset Point-Davisville, RI*: proposal by Quonset Point Partners for a mega port abandoned due largely to environmental issues, as well as questions about economic feasibility. Later Environmental Impact Statement (EIS) and marketing studies intended to provide improved information on the environmental effects of a proposed port and alternatives and the potential demand for container port services were cancelled due to pressures from coastal communities concerned with the possibility of adverse environmental effects.
- *Delaware Bay and River*: the federal main channel deepening project substantially delayed and temporarily withdrawn due to a host of environmental concerns raised by the public concerning horseshoe crabs, migratory birds, spawning of endangered and threatened fish species, and marine mammals and inadequate analyses of the economic feasibility of the proposed operation as a whole and the distribution of the benefits and costs between the states involved (US Army Corps of Engineers, 1998; Grigalunas and Opaluch, 2002).

- *Providence River and Harbor*: dredging was significantly delayed largely due to concerns about the perceived impacts of dredging and marine dredge disposal on commercial and recreational fisheries.
- *Port of New York-New Jersey (PNYNJ)*: Dredging to accommodate deep draft vessels significantly delayed with vastly increased costs for dredging and dredge material disposal because of a prohibition on marine disposal of sediments and lack of onsite disposal options. Air emissions during dredging are a concern due to non-attainment status of project area (US Army Corps of Engineers, 2003). Ongoing plans will introduce a rail and barge distribution system to move boxes from the PNYNJ to distribution centers throughout the Northeast to avoid congestion and air emissions in the port area and along highway routes to major regional markets (Riklefs and Ellis, 2001).

Simply stated, unless anticipated and avoided through design changes or mitigation, environmental issues can cause major port modifications, delays, and cost increases -- and often all three. Outright cancellation of proposed projects also can occur.

In light of the potentially critical role of environmental concerns, planning for port development must proceed with an eye toward not only the financial feasibility of the port operation itself but also with a hard assessment of environmental concerns. If these concerns are not allayed or addressed, experience shows that environmental issues will generate substantial public resistance and call into question the economic (and equally important, the political) feasibility of a proposed port, as the above examples amply demonstrate.

This report focuses on environmental issues in container port development and is part of a larger, multi-year effort to develop and apply a "comprehensive" framework for container port development. Our research is driven by the notion that (1) financial, economic, and environmental concerns are inextricably linked; (2) who gains, who pays, and by how much are key concerns in public debates; and (3) an integrated framework encompassing financial, economic, environmental, and distributional issues illuminates the importance of these links and, thereby, can provide valuable insights for port planning.

In practice, however, few studies carefully integrate financial, economic and environmental issues to estimate net benefits and the distribution of benefits and costs, including environmental effects. Instead, port assessments typically are compartmentalized. Environmental issues are addressed at length in an Environmental Impact Statement, but largely in purely scientific terms. Benefit-cost ("B-C") analysis of proposed port projects is presented in a separate document with little -- usually, no – attention given to quantifying environmental costs (and conceivably, benefits) in monetary terms or to the *distribution* of benefits and costs between affected groups or states. Financial assessments of the proposed port operation typically are left to the private sector and its largely confidential negotiations with a port authority so that, again, the distribution of financial benefits and costs is largely shrouded in mystery.

Absent an integrated approach, important interactions in port development are difficult to grasp. For example, it is no trivial undertaking to weigh how prospective differences in development (e.g., in the scale of activity, the share of container moves by truck versus train or barge, in compliance with regulations or adoption of mitigation measures) would affect traffic, air emissions, noise, or benefits and costs. Intuition, subjective assessments, and good judgment are necessary; but at some point quantitative linkages – a model – are needed. Our development of a comprehensive framework forges some of these links and is meant to address key environmentally-related factors in port planning.

This research builds upon our previous efforts and focuses on environmental issues in port development, and in particular, on air emissions and vehicular noise. A rich literature deals with environmental issues in transportation in general and port development in particular.[1] Here we mention other environmental issues addressed in earlier research by the authors and colleagues in order to provide background for this report. Prior research by the authors and other colleagues include economic studies of the cost to recreational and commercial fisheries because of port dredging and dredge disposal and valuation of intertidal and subtidal wetlands and of open space (see, Grigalunas, *et al.,* 2001; Grigalunas, Luo and Chang, 2001; Johnston, *et al.*, 2002). More recent efforts include a case study of the distribution of the benefits and costs of port development (Grigalunas, Opaluch, and Chang, 2003)

This project has involved several investigators resulting in a suite of inter-related studies over a multi-year period. In the course of our work, we have drawn upon concepts and methods from environmental and natural resource economics, benefit-cost analysis (applied welfare theory), operations research, and computer science. Some of our related analyses of fisheries losses due to dredging and dredge disposal also rely upon results of engineering studies and biological research, which provide the important non-economic foundations of our economics research.

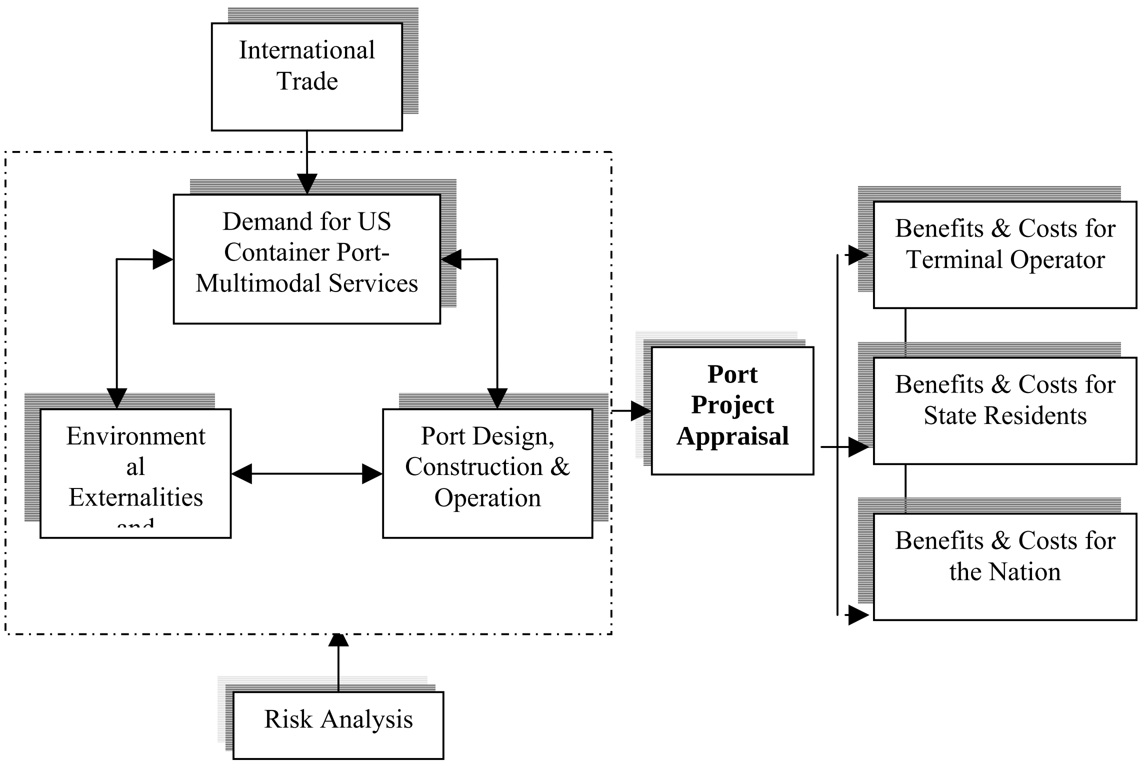
I.B. Prior and Ongoing Research on This Project

Research to date has proceeded along several paths. Our general strategy was, first, to build an integrated, "comprehensive" framework for sustainable container port development encompassing important financial, economic, and environmental elements. Then, we began to apply the framework one piece at a time, with each part subject to peer review and publication in refereed journals. Specifically:

- Year one research involved development of the comprehensive framework. We set out key financial, economic, and generic environmental issues in container port development (Figure I.B.1) and concepts and methods to address these major issues (Grigalunas, Luo, and Chang, 2001, 2002; Grigalunas, Chang, and Luo, 2002). Briefly:
    - *Financial* factors included a discounted cash flow model to assess the financial feasibility of, and risk to, a potential container terminal developer. Readily available, generalized data from prior studies of a proposed port at Quonset Point, Rhode Island were used to illustrate the estimation of the potential net present value (NPV) for a *hypothetical* port, given investment and operating costs, the start-up and annual growth in the volume of container throughput, and productivity (measured as moves/crane/hour). Sensitivity or "What if?" analyses and more formal risk analyses (Monte Carlo methods and use of a discrete, dynamic events model) also were used. These results of these models illustrate risk (for example, the variation in NPV and the percent chance of a loss) and also identify the principle sources of risk (Grigalunas, Chang and Luo, 2002).

[1] See, for example, recent *Proceedings* of the Transportation Research Board (TRB) annual meetings.

FIGURE I.B.1. Comprehensive Framework for Sustainable Container Port Development.



o *Economic* factors concern the development of a logically consistent, benefit-cost framework for assessing economic gains and losses. This is done not only from the perspective of a private terminal operator (described immediately above), but also to a host state or region, and to the nation as a whole. Briefly, economic benefits to a host state – defined as the *pre-development residents* of a state -- include transportation cost savings, net gains to labor (wages received over the value of a worker's time in its next-best use), receipt of fees over and above costs of administration, from which we subtract the net offsite and net environmental costs after mitigation. National benefits encompass transportation cost savings, net gains to labor, and net environmental costs after mitigation.

o Generic *environmental* issues often raised in connection with port development were noted, concepts for estimating the associated external costs of environmental issues were explained, and examples and case studies were given. These illustrate how non-market economic valuation methods can be employed in quantifying environmental costs in common units, dollars (Grigalunas, et al., 2001a,b)), or in terms of resources, as in resource-based restoration (Mazzotta, Opaluch, and Grigalunas, 1994; Opaluch et. al., 1999).

- Year two research concentrated on the development and application of a container port and related multimodal transportation *demand* simulation model for major US container ports (Luo, 2002; Grigalunas and Luo, 2003; Luo and Grigalunas, 2003a,b,c). The model was used to simulate:

    - International moves of full twenty-foot equivalent unit containers ("TEUs'), for two-digit Standard Industrial Classification categories, from sources to markets through major US ports. Given our primary interest on the Northeast, Halifax and Montreal are included because they are important competitors with US East Coast ports for mid-west US cargoes. The simulation model takes international trade as given and assumes shippers select routings and modes that minimize total general costs of transporting goods from point A to B: the costs of using multi-modal facilities (vessel-port-rail-truck) plus the interest on the value of investment tied up in cargo.

    - The *conditional demand* (that is, demand for port services, all else held equal) for the selected existing ports of New York-New Jersey and Boston and a *hypothetical* new port at Quonset Point.

    - Aspects of *inter-port competition* by providing estimates of cross-price demand effects – that is, how the demand services of substitute ports change in response to a price change at selected ports, again with all else being the same.

    - The *initial annual demand* at a hypothetical port at Quonset Point, RI and – of major importance for the present report -- the least-cost multi-modal mix (truck versus train) and truck routes between sources and markets. A preliminary econometric study (Jung, 2001) and review of estimates in the literature (Grigalunas, Luo, and Jung, 2002) were used to forecast demand for a new container port and for revising the port feasibility and risk analysis illustrative study done in our initial year 1 report for this project.

I.C. Purpose and Scope of This Year-Three Report

This report summarizes our year-three research program. Prior analyses of port-related environmental issues by the authors (see, Grigalunas, Luo, and Chang, 2001; Grigalunas, et al. (2000)) are expanded to include potential externalities because of (1) air emissions from mobile sources and from dredging and (2) noise from heavy trucks used to transport containers over connector roads.

Why an *economic* analysis of environmental issues? Why not just rely upon science-based assessments of port environmental issues? Science studies clearly are critical for quantifying potential sources of risk and indeed provide the foundation for environmental economics studies. However, the present study examines the potential external costs of port development, that is, impacts on *people*. This requires that we establish the series of cause-and-effect links between potential environmental stressors and the ultimate consequences for individuals or the public at large. This economics/social science perspective recognizes the "people" dimension of port activity: the potential benefits and costs from port development and how these benefits and costs are distributed.

Assessments of the private or financially profitability of port projects involves an evaluation of its financial benefits ("B_F") and costs ("C_F"). Projects do not proceed (without a subsidy) unless the financial benefits exceed costs, that is $B_F - C_F > 0$.

However, assessments of social profitability must incorporate all costs and benefits, not just financial effects. Omission of environmental costs, or of the costs of their mitigation, would exaggerate the true net benefits to society of proposed projects. Hence, a key question is whether a project which might be financially profitable (that is, $B_F - C_F > 0$) also is "socially profitable", when environmental costs and benefits and mitigation are considered:

$$\text{Social Profitability} = \text{Net Benefits} = (B_S - C_S) - (E_{CS} - E_{BS}) - M_S) > 0 \ ?$$

where $(B_S - C_S)$ is the benefits and costs of port development to society, M_S is the cost of mitigation or avoidance of external costs, and $(E_{CS} - E_{BS})$ is the environmental costs (E_{CS}) and benefits (E_{BS}) to society from development *after* mitigation[2]. All benefits and costs are assumed to be discounted and in constant dollars.

Hence, a more complete picture of the consequences of the social profitability of port development emerges when estimates of environmental and mitigation costs are included. As compared with narrow, purely financial analyses, this more inclusive picture can better guide whether scarce coastal land, labor, capital and other resources are being used in a way which, overall, expands net benefits to the public, taking into account both financial and environmental benefits and costs.

Quantifying environmental costs can contribute to port development is several important ways. First, estimates of project benefits and costs expand the assessment of net benefits and can influence whether a project will proceed, as noted immediately above. Also, estimates of environmental costs can aid in decision-making concerning actions to reduce environmental harm. These include adoption of avoidance practices, for example, the efficacy of dredging windows -- periods when dredging is banned in order to protect species during vulnerable migration or spawning periods (National Research Council, 2001; Grigalunas, Opaluch and Luo, 2003). Or, quantification of environmental costs can help assess mitigation measures, such as construction of noise barriers to protect residents near roads heavily traveled by trucks, as we illustrate in Chapter IV.

Quantifying environmental costs in common units, dollars, also may help set research or protection priorities. Not all environmental issues are equally important -- some issues require more study and perhaps more mitigation than others. Thus, quantifying environmental costs in a common metric helps put the relative magnitude of external costs in perspective.

In summary, quantifying environmental costs may help:

- separate the more important from the less significant environmental issues,
- contribute to benefit-cost analysis of the whole project, and
- evaluate the benefits and costs of avoidance or mitigation options, as we describe in more detail in succeeding chapters.

We recognize that many difficulties arise in estimating environmental costs, and the challenges faced should not be understated. For one thing, external costs typically fall outside of the market place and require the use of non-market valuation methods (e.g., Braden and Koldstad, 1991; Freeman, 2003). Other challenges occur because of the need to estimate the cause-and-effect links between stressors, such as air emissions and noise, to exposure of the

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[2] Offsetting environmental benefits may result with new container port facilities. For example, introduction of a container barge feeder system for the Northeast US could reduce road use by heavy-duty trucks and, by that, reduce *overall* road traffic congestion and air emissions in a region (Ricklefs and Ellis, 2001).

population, and ultimately, to the resulting external costs. Related challenges arise from the data requirements for implementing appropriate valuation methodologies to estimate external costs.

Notwithstanding these (and other) difficulties, non-market valuation methods can shed much light on many environmental issues in port planning. In the chapters which follow, the many challenges faced for the issues of concern in this report (air emissions and noise) are illustrated -- as are means to overcome some of the difficulties confronted. The logic of the approach used in this report is illustrated in Figure I.2 and explained below.

I.D. Overview of the Study and Methodology

By way of a preview, noise -- unwanted sound – is a pervasive externality and a common concern in port projects. In this report, emphasis is on noise from port-related vehicular traffic, by which we mean heavy-duty trucks, because this is likely a major source of port-related noise to which the public near port routes will be exposed[3]. A key building block for estimating traffic comes from our year-two report (Grigalunas, Luo and Jung, 2002). Not surprisingly, these results suggest that successful new hub ports require substantial container throughput. Our year two container port and related multimodal transportation demand simulation model results are used herein to provide estimates of traffic through and at the port. The same model provides estimates the optimal (i.e., least-cost) multimodal rail and road split for projected container moves through the hypothetical port as well as the least-cost routing for trucks along roads near the port, information used in our assessment of potential externalities in this study.

Given estimates of heavy truck traffic, routing, and other information described later, exposure of residential housing to noise levels along the main port connector road is estimated. Noise propagation from heavy-duty trucks and its diffusion over space are simulated using results from a traffic noise simulation model developed by the Federal Highway Administration (1998). The estimates of exposure of residential housing to this noise allow us to illustrate use of a property value model (a hedonic price model) to estimate the potential external costs of noise. Efficient mitigation of noise through the use of potential use of noise barriers also is addressed.

Turning to air emissions, exposure to air pollution above threshold levels threatens human health, materials and property, trees, plants, and water quality (e.g., Cropper, 2000; Rowe, et al., 1998: Burtaw, et al., 2003; Hall, et al., 2003). Air quality remains a concern in Rhode Island (Table I.1) due to violations of ozone health standards. Therefore, the potential additional emissions from dredges, trucks, trains, terminal vehicles, and vessels is important to assess.

[3] For residences in close proximity to berths, noise from offloading containers onto chaises can be an issue, as has been the case at the Port of Charleston, South Carolina, Wando Welch Terminal where homeowners in an upscale neighborhood just beyond a buffer area have complained of noise.

TABLE I.D.1. Number of Days Ozone Standard Exceeded in Rhode Island, 2001-2002 [a,b]

Ozone concentrations	2001	2002
Unhealthy for sensitive groups, AQI (101 – 105)[c]	12	15
Unhealthy for all population, AQI (151-200)[c]	6	3
Total	**18**	**18**

[a]Note: Ozone can reach unhealthy concentrations when the weather is hot and sunny with little or no wind. In New England, these conditions usually occur between 1:00 and 7:00 pm from May through September.
[b]Source: US Environmental Protection Agency, 2002 (www.epa.gov)
[c] AQI is the Air Quality Index used by EPA to classify the risk of harm to different exposed groups of people.

Air emissions are estimated for three EPA-designated criteria pollutants (HC, CO and NO_X) from port-related road and off-road mobile sources -- trucks, trains, terminal yard vehicles -- and for vessels[4]. For vehicles, air emission coefficients in grams/mile for each pollutant for each source are used to estimate incremental air emissions for each pollutant[5]. Emission coefficients are adjusted, over time, anticipating the gradual and eventual full implementation of Phase I and II EPA air regulations for heavy trucks[6]. For dredges, we focus on NOx emissions. Using data from a recent review (Federal Register, 2003), environmental costs per ton of NOx emitted (the most environmentally threatening emission) are used to put air pollution cost in some perspective. Details on the methodology used are given in Chapter IV.

Again, estimates of container moves from our year-two container port and multimodal transportation demand simulation model and projections of demand are used to estimate the train and truck activity levels. Estimates of truck trips per container move, and traffic estimates for yard vehicles and vessels, are based on industry practices and area-specific information (see Table II.D.1 for details).

We emphasize that this report considers a hypothetical hub port, *not* a feeder port. Feeder ports using barges and/or small ships to carry containers on short hauls between it and a hub port require less (perhaps no) dredging, and would generate much less traffic as compared with the hub port considered in this study. Hence, fewer and less environmentally intrusive issues are likely to arise with a feeder port. Still, a large feeder port (tens of thousands of container box moves per year) could generate considerable localized truck traffic and might raise local public concerns with the issues addressed in this report -- noise and air emissions. Hence, the information provided here could be employed to help assess a feeder port (for example, as proposed by the Port of New York and New Jersey (Riklefs and Ellis, 2001), with appropriate adjustments for the different nature, scale, and truck/train split to move containers for a feeder versus a hub port.

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[4] A detailed analysis of potential emissions from dredging is omitted because little information is available about the exact extent, nature and timing of this activity for the proposed port used as our case study. Extensive dredging, however, could temporarily exacerbate air quality problems, particularly during the summer months, when the threat of ozone is important. However, information from the PNYNJ (US Army Corps of Engineers, 2003) and other sources are drawn upon to provide insight into air emissions and external costs from dredging in our illustrative case study.
[5] Trucks by far are the major air emission concern; coefficients for this source were estimated using results from an application of EPA's Mobile 5b (US EPA, Office of Air Resources, 2002).
[6] Regulations also have been proposed for locomotives and vessels but their implementation is less clear than for heavy duty trucks. Hence, we use current emission factors for sources considered other than trucks, which will tend to overstate these emissions as regulations phased in over the 20-year operating period in our model.

I.E. Organization

The underlying concepts, an overview of available methods, and selected issues specific to our application of the methods used herein are presented in Chapter II. Then, methodology and data used to apply these concepts, as well as the results, are given in Chapters III for air emissions and in Chapter IV for noise.

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II. CONCEPTS, METHODS, AND COMMON PORT DEVELOPMENT ASSUMPTIONS USED

II.A. Market Failure: Externalities and Public Bads

Port-related environmental effects are a classic case of market failure: externalities or public goods. Externalities are the unpaid side effects activities have on third parties, such as the harm caused by air and noise pollution, traffic congestion, or degradation of area amenities. Since the issues of interest in this report, air quality and noise, simultaneously affect many members of the public, the market failures involve what are referred to as public goods – or more accurately, given their undesirable nature, public "bads". The scope of public bads can range from relatively localized adverse effects, such as noise, to regional, national or even international harmful effects, for example, air emissions contributing to regional ozone problems or global warming.

To promote the sustainable and efficient use of resources, the prices of goods and services should reflect the full social costs incurred to produce them. These full social costs include private costs and external costs. Operators failing to face the external costs they impose on others respond to the wrong market signals. This results in undesirable outcomes in that:

- the true costs to society of the activity are understated,
- too much of the good in question is supplied, and
- those harmed by pollution end up subsidizing the polluting operator and/or the users of its product.

For example, take a company responsible for oil and grease releases into coastal waters, which harm shell fishermen and recreational users. Since the polluting operator does not pay for the external costs it imposes on these users, the true costs of its activity to society are understated, and production is higher than it would be if the firm faced the full costs of its actions. Also, the operator or users of the company's products in effect are subsidized by the harmed fishermen and recreational users.

When companies are confronted with the full costs of their activities, they will as a matter of course adjust their production, methods of operation, and the price they charge, if they can. This internalization of external costs helps to "get the price right"— an important condition for sustainable resource use.

As emphasized at the outset, potential externalities are a major concern in port planning. Unless avoided or mitigated, external costs would fall on the public at large. Quantifying environmental costs assigns "shadow" prices to non-market environmental and natural resource services, by that expanding the information available to improve benefit-cost analyses and mitigation decisions. For example, in prior work estimates of shadow prices have been used to capture:

- the cost to recreational and commercial fisheries of port dredging and marine dredge disposal (Grigalunas, Oplauch and Luo, 2000, 2001);
- the amenity costs or tradeoffs from loss of upland open space (Mazzotta, 1995; Opaluch et al., 1999; Johnston, et al., 2001, 2002) and
- the cost of lost natural resource services from filling in of intertidal and subtidal wetlands habitat and nursery grounds (Opaluch et al., 1999).

Later chapters of this report expand upon the port-related, non-marketed environmental services addressed in our research by (1) taking into account port-related noise, and (2) putting air emission and their associated external costs in perspective.

II.B. Noise and Air Pollution as Externalities from Port Development

By definition, container ports are transportation intensive. Port-related dredging and the later, substantial anticipated activity by heavy trucks, trains, on-dock vehicles, and vessels often raise concerns about air pollution and about noise along heavily traveled roads near the port. Up to a point, air emissions and noise can be assimilated, but beyond a threshold, both noise and air pollution impose external costs on exposed individuals.

Consider first air pollution. Air pollution above acceptable thresholds can cause throat and eye irritations, asthma attacks, other physical discomforts, or restricted activity days. While pollution above thresholds is of particular concern to sensitive groups (elderly, children, and infirmed), even healthy people are at risk during high pollution levels. In Rhode Island, for example, in 2001 and 2002 summer ozone limits were exceeded 18 times each year (Table I.C.1). During ozone alerts, the public is advised to avoid strenuous outside activity and encouraged to take public transportation, which in Rhode Island is provided free on bad ozone days.

Chronic or extreme air pollution can cause or contribute to premature mortality, especially to those vulnerable as a result of respiratory ailments or other debilitating physical conditions. Poor air quality also can degrade exterior home, building and car surfaces, paints, and materials, and reduce property values (e.g., Jones and Delucchi, 1997). Trees and plant life can also be harmed, reducing amenities or, in some cases, habitats (Natural New England, 2002). Air pollution, largely from major discharges by Mid-West power plants, also may contribute to estuarine water quality problems through atmospheric deposition (TETRA TECH).

In agricultural areas, air pollution reduces crop production or requires additional use of fertilizer or water to maintain productivity. This has been found to cause lost farmer profits and higher prices to consumers due to reduced yields or increased costs of agricultural production (Kopp and Krupnick, 1987; Cropper, 2000).

Turning to noise, above threshold levels noise interferes with hearing normal discussions or broadcasts, causes lack of sleep, annoyance, discomfort, and headaches. Extended exposure to loud noise (e.g. rock musicians, unprotected factory or construction workers) can cause or contribute to eventual deafness.

Individuals worried about the mere *risk* of harm experience a loss. For example, people often attempt to reduce perceived risks to health by installing air or water filters to avoid pollution. Car buyers install air bags for safety. Most people buy home fire insurance, many insure themselves against disability, and some buy insurance to avoid the unforeseen cancellation of an expensive vacation trip. The adverse health effect, fire, disability, or trip cancellation in the examples used may not occur, but the extra precautionary outlays reflects the value (willingness to pay) people have to reduce or eliminate the risk involved.

In sum, air pollution or noise from port development can cause losses in several ways:

- Direct effects on an individual's health and on amenities, such as for air, atmospheric smog, gritty or deteriorated paint surfaces, and loss of trees and plants; and loss of sleep and annoyance for noise

- Direct effects from increased risks due to perceptions that air emissions and noise pose threats to well being, including health.
- Indirect effects through higher consumer prices or lower profits to affected farmers for agricultural products, or through losses in property value to residential property owners.
- Indirect effects through lower productivity ecosystems via effects on estuary water quality and acid rain.

Estimating the potential exposure of people to air emissions and noise is crucial in any study of potential externalities in port development. The fundamental challenge is to link estimated port activity to air emissions and noise, then to exposure for affected populations, and, ultimately, to connect exposure to adverse effects and their value: damages. Several of the links, such as estimating emissions and noise, are based on engineering and science principles, as we explain below, and constitute the important "non-economic foundations" of many economic studies of environmental issues (see, for example, Freeman, 2003; Adams and Crocker, 1991). The many challenges posed in estimating the critical links between port-related activity and external costs are described next.

II.C. Linking Air Pollution and Noise to External Costs from Port Development: The Importance of *Incremental* Effects

Any analyses of proposed projects or programs must focus on incremental effects – that is, the effects on the item(s) of interest *with* the project as compared to the items *without* the project (the "baseline"). Hence, a first step for the issues of interest in this study – air pollution and noise – is to estimate air pollution and noise generated due to port development over and above air emissions and noise from other activity which would occur at the site without a port. In this manner, the incremental effects of the port can be isolated.

II.D. Quantifying Incremental Air Pollution and Noise from Container Port Development

Scale, temporal, and spatial elements all must be addressed in estimating air pollution and noise emissions due to anticipated container port activity. *Scale* refers to the port facility size and the planned activity per period. In particular, moves of containers through the port is a major determinant of noise and emissions.

Temporal elements arise because of the need to anticipate port growth and the resultant increases in emissions and noise over time. Further, regulations on air pollution are being phased in over time, so that implementation of regulations or mitigation measures reducing potential externalities also raises temporal issues.

Spatial issues are significant because noise and air emissions also depend importantly, as we show later, on (1) the multimodal split (truck-train) of container movements to and from the port, and (2) the main route(s) used by trucks and trains. Also, noise and air pollutants do not mix equally over the affected area, but instead are transported by winds and diminished by distance or weather. Further, our key concern is exposure of people to noise or air pollution, and this depends upon the geographic distribution of potentially affected populations and residential structures relative to the path of air pollution and noise.

In sum, assessments of environmental issues ideally should take all of these (and other) factors, described later, into account. Given the scale, timing, and geographic distribution of port-related activity, estimates can be made of the generation of air emissions and propagation of noise.

The logic of the study is presented in Figure II.D.1. We begin with estimates of initial port activity adopted from our container port and multimodal simulation model and also adopt forecasts of growth through the port (Table II.D.1). Initial activity in the year 2007 (the hypothetical start up time for operations at a port planned in 2003), is 316 thousand TEUs (or 211 thousand moves)[7]. Container moves through the port grow at 5.4% per year, the mean value of estimates in the literature, reaching a maximum of 857.5 TEUs (571.7 thousand moves) in the 20th year of operation (see, Grigalunas, Luo and Jung 2002).

Success as a hub port requires access to a Class I (national) rail connection with double stacking capability between Quonset Point and Mid-west markets. Given this rail access, the model simulation results show that the least-cost modal mix is 70 percent of container moves by train and the remaining 30 percent is sent by truck[8]. The model results also show the least-cost routing of trucks from the port toward markets, information critical for our later assessment of air emissions (Chapter III) and noise (Chapter IV).

[7] Moves are less than TEU since some moves involve 40 foot containers, in which 1 move = 2 TEU. In our calculations we assume 1 move = 1.5 TEU, based on experience at the Port of New York and New Jersey (see table in text).

[8] These results are similar to the conclusions by RK Johns & Assoc. (2000) ("RKJ"), although RKJ's analysis did not involve a formal and instead was based on expert judgment. Quonset Point Partners (1999) also estimated about 70% of containers would move by train (and 10 % would be shipped by barge).

FIGURE II.D.1. Simplified Depiction of Logic of Study.

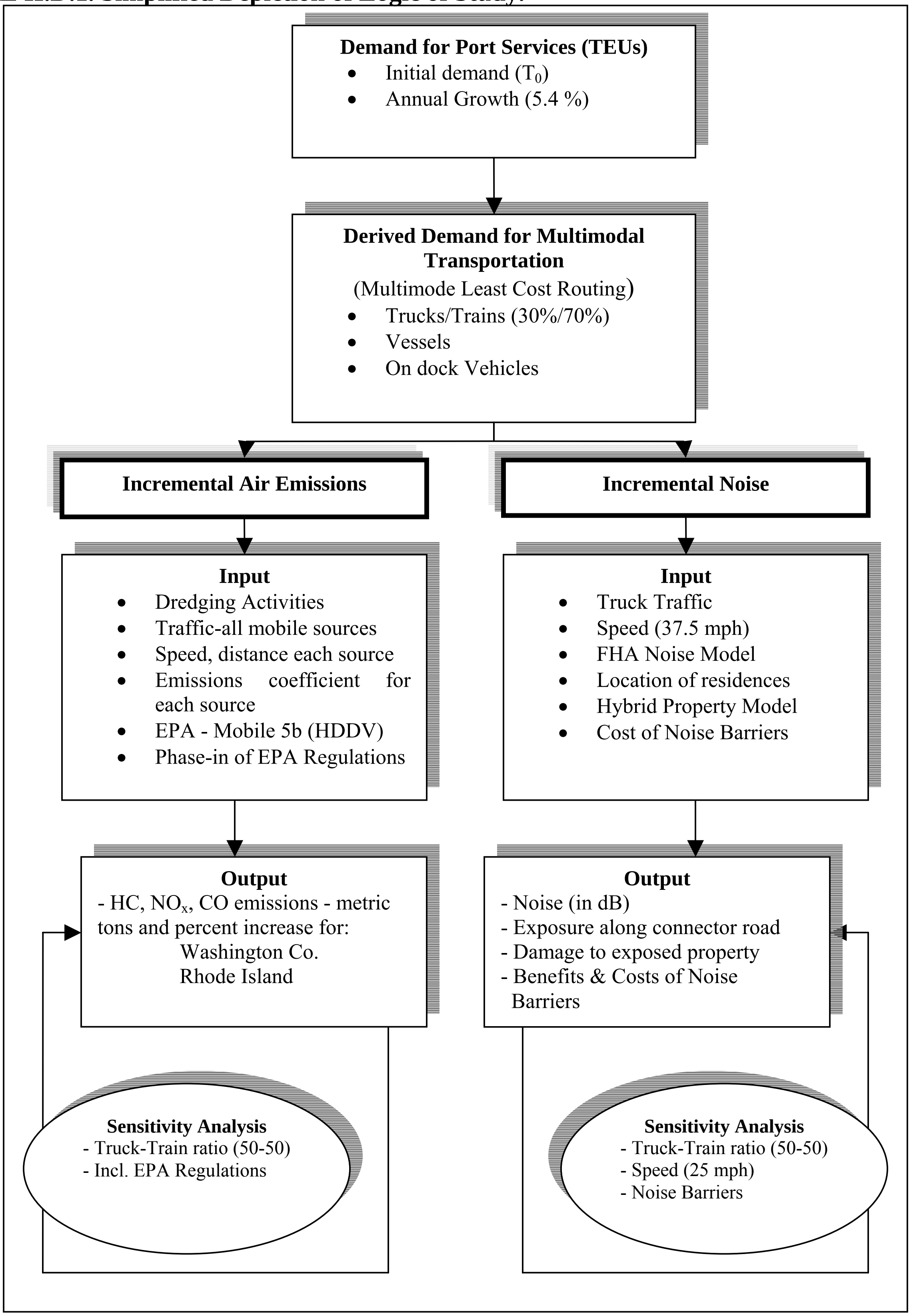

TABLE II.D.1. Base- Case Assumptions and Estimated Annual Activity Levels for Hypothetical Multimodal Container Port at Quonset Point, Selected Years

	****		Year	****	
	1	**5**	**10**	**15**	**20**
TEUs (000)[a,b]	316	390	507	659	858
TEU/Move[c]	1.5	1.5	1.5	1.5	1.5
Moves (000)	211	260	338	440	572
Annual Growth Rate[d]	5.4%	5.4%	5.4%	5.4%	5.4%
Modal Split					
Percent Rail	70	70	70	70	70
Percent Truck	30	30	30	30	30
Truck Trips/Move[e]	1.7	1.7	1.7	1.7	1.7
Truck Trips (000)	107	132	172	224	292
Truck Idle Time @ Port	0.5 hr	0.5 hr	0.5 hr	0.5 hr	0.5 hr
TEUs/Train	400	400	400	400	400
Train Trips	368	455	591	769	1000
Vessels					
Container Ships Visits	105	130	169	220	286
Tugs (2/Ship) Visit	210	260	338	439	572

[a] Luo (2002)
[b] Grigalunas and Luo (2002)
[c] Ratio assumed to be the same as at the Port of New York and New Jersey (PNYNJ)
[d] Jung (2001) and literature summarized in Grigalunas, Luo, and Jung (2001)
[e] Ratio assumed to be same as at the PNYNJ
[f] Not included in analysis
http://www.nytimes.com/2002/10/28/opinion/28SAFI.html?todaysheadlines

For air emissions from dredges, we adopt estimates of emissions per million cubic yards, based on experience in the Port of New York and New Jersey (USACE, 2003). For mobile sources, area-specific estimated emission coefficients for heavy-duty trucks (the major potential pollution source) are adopted from an application of the Environmental Protection Agency's air pollution model (Mobile 5b).

Air emission coefficients are used for each source and major pollutant. Emissions of air pollutants per mile traveled for heavy trucks are a non-linear function of speed, particularly for CO and NOx, based on the efficiency with which engines process diesel fuel and other factors. The rate of emission of a pollutant j (say, NOx) per mile traveled by a heavy truck, e_j, can be expressed as a function of speed:

$$e_j = \alpha_o + \alpha_1(\text{mph}) - \alpha_2(\text{mph})^2 \qquad (1)$$

where the α's are the technical links between speed and emissions of NOx per mile and are illustrated in the nearby Figure. Thus, e_j at first decreases with speed, reaches a minimum, and then begins to increase (Figure II.1). Emissions by truck per hour while idling (that is, $e_j = \alpha_o$ at mph = 0) also are important, especially if extensive waiting occurs at ports or on congested roads[9].

[9] In this report we allow for ½ hour idling time as a waiting period by trucks into and of the port. (Emissions due to road congestion could also occur but raise complicated issues outside the scope of this report.)

To estimate truck emissions of pollutant j, we account for emissions while moving and while idling. The estimated number of truck trips per period t is T_t, and the miles traveled on least-cost routes at speed s in time t is M_{st}. The emission coefficient for pollutant j for each vehicle type is a function of speed and other vehicle characteristics, c, e_{jsc}, and the emission coefficient for idling in grams per hour h is e_{jhc} for a given period per trip, I (in hours). Hence, the total estimated emissions of pollutant j at time t, E_{jt}, other things being equal (for example, congestion and weather) are:

$$E_{jt} = \left[\sum_{s} \left(e_{jsc} \times M_{st} \right) + e_{jhc} \times I \right] \times T_t \qquad (2)$$

assuming for simplicity here that each trip involves the same speed and number of road miles. Actual estimates of total emissions in the report use road-specific distances and speeds for major Rhode Island road segments along the least-cost road routes estimated in the container port and related intermodal demand simulation model. As noted, emissions occurring outside of Rhode Island are ignored in the quantifications of external costs made in this paper.

Exposure of residents to a particular air pollutant depends upon not only the type and amount of emissions but also where one lives in relation to the source. Wind speed and direction, temperature, and other considerations also influence the transport and fate of air emissions, and their variability adds a complicated, probabilistic dimension to the problem.

For noise, estimates from the Federal Highway Administration Agency's noise propagation and dispersion model are adopted (Federal Highway Administration (1999). Briefly, the noise generated depends upon the vehicular traffic per period (hour), the type of vehicle (heavy trucks are louder than light trucks, which in turn are noisier than automobiles), road steepness, and the hardness of the road's surface (resitivity).

II. E. Linking Emissions to Exposure

Given estimates of the scale, temporal, and spatial dimensions of port-related activities, the connection between emissions of air pollution and the generation of noise, on the one hand, and exposure of individuals to these stresses, on the other, must be established. Both air pollution and noise raise similar conceptual issues, although each also has unique features.

First, we take up air pollution. Air pollution exposure (say, in parts per million) depends on the level of port-related activities, the location of the emission source relative to the receptor site, and the population and their attributes at the receptor site. A simple model would show (1) total emissions of a pollutant j, E_j, as a function of the level of activity at a port – here containers moves -- and (2) loss in well being (utility) of people exposed as a function of net emissions at receptor site i. The model also would show emissions and exposure varying over space and should encompass pollution from many sources, including transboundary sources.

For a given level of activity through a port, a simple model of exposure of individuals to air pollutant j, at receptor site i, in time t, can be stated as follows:

$$C_{ijt} = \sum_{k=1}^{K} E_{jkt} a_{jik} + TR_{ijt} \quad i = 1, 2, 3, \ldots, I; \quad j = 1, 2, 3, \ldots, J \qquad (3)$$

where

C_{ij} = the concentration of pollutant j at receptor site i (a household, neighborhood, block or other location) at a point in time t as results of emissions from all k sources in the study area (of which port-related sources may be only a small part) and transboundary pollution.
E_{jk} = the total emissions of pollutant j from source k at time t given the level of port-related activities
a_{ijk} is the *transfer coefficient*, which converts a unit of emission j by source k into a concentration at receptor site i.
TR_{ijt} = the contribution of transboundary sources of pollutant j to concentration of the pollutant at site i due to all sources outside of the study area at time t

Hence, people at site i are exposed to emissions from all k sources within the study area (unless a site is upwind, in which case $a_{ij} = 0$), plus the transboundary pollution affecting site i. Thus, spatial features of the problem — the sources of the emission of a pollutant and the location of the receptor sites—are important. To account for the path of air emissions and pollution concentrations over time and space, transport models are used in the literature (see, Burtraw, et al, 2003 for a survey of selected major models). As we show below, for the pollutants studied, the increment to annual emissions from development of the hypothetical port is relatively modest, even for the "worst case" -- and the worst case rests on strong and most unlikely assumptions (see Chapter III). Given these results, the extra effort to apply a transport model seemed unnecessary and hence is not part of the research results reported below.

Air emissions by trucks waiting to enter or leave a port potentially are an important factor to consider since idle vehicles emit population. In our estimates in Chapter III, emissions from idle trucks at the port are included by assuming a half-hour of waiting time for trucks dropping off or picking up containers at the port.

Missing from the above, simple model is exposure at receptor sites to pollutants, which result from mixing of other pollutants. For example, ozone is not emitted but instead results from interaction between precursor emissions, NOx and volatile organic hydrocarbons (VOC), from vehicles and sunlight during warm, summer months.

Turning to potential noise externalities, exposure to noise also depends upon the scale and location of activity relative to the receptor site. Exposure (typically in given decibels (dB)) to noise at location i in time t, N_{it}, depends on the distance (D_{ik}) receptor site i is from propagation site k (in this case, midpoint of a roadway), the type of vehicle(s) using the road, the number of vehicle trips per period (T), road surface type (R) (hard surfaces generate more noise than soft surfaces), speed (S), and other factors (O), such as road steepness. Assuming all traffic involves trucks (or "truck equivalents"), N_{it} can be stated as:

$$N_{it} = F(D_{ik}, T_t, R, S, O) \qquad (4)$$

where F(•) is a function that captures the relation between the variables within the parentheses and N_{it}.

N_{it} is based on purely acoustical and related scientific principles and, again, makes up the noneconomic foundations of the noise externality problem. Noise decreases with distance from the source, but increases with the number of trucks per period, speed, and road hardnesss:

$$\partial N_{it}/\partial T < 0; \quad \partial N_{it}/\partial T > 0; \quad \partial N_{it}/\partial S > 0; \text{ and } \quad \partial N_{it}/\partial R > 0 \qquad (5)$$

Later, we show that noise is non-linear in distance, the number of vehicles per hour, speed, and with the size of roadside barriers to mitigate noise. These factors have implications for assessing not only the potential external costs from noise but also the net benefits from mitigation through use of sound barriers (see Chapter IV).

Avoidance and mitigation can reduce the magnitude of these externalities -- but come at a cost. Understanding the non-economic foundations of air pollution as noise will help us to weigh the efficacy of various potential mitigation measures, as our examples in subsequent chapters illustrate.

II. F. From Exposure to External Costs

Suppose that port development increases noise or air emissions or imposes other externalities, by that lowering environmental quality from an initial level "Q_o" to a lower level, "Q_1". The measure of external cost (damages) is the most that someone would pay to avoid environmental outcome Q_1 and keep the current level of the environment, Q_o. This can be stated as:

$$V(\text{Income-WTP}, Q_o) = V(\text{Income}, Q_1) \qquad (6)$$

where V(●) is the (indirect) utility function, and WTP is the most an individual is *willing to pay*, such as for a house in a cleaner or quieter neighborhood, in order to avoid the decrease in air or noise quality from the level Q_o to the lower level, Q_1.

If individuals have the right to a clean and quiet environment, then the correct way to pose the issue is: What amount of compensation is required in order for residents to accept the additional noise or dirtier air? For example, individuals in communities harmed by development may be willing to accept a power plant, prison, or noxious facilities, provided they are compensated, for instance, with lower taxes and/or higher public services from taxes paid by the facility. The amount of compensation required for an individual to accept the change from Q_o to the lower quality Q_1 is the willingness to accept compensation (WTAC):

$$V(\text{Income}, Q_o) = V(\text{Income} + \text{WTAC}, Q_1) \qquad (7)$$

In this case, the public is no worse off with the development than they were without the development because they have been compensated for the degradation from Q_o to Q_1. We note that WTAC generally results in higher estimates than WTP but is more difficult to measure validly and reliably in surveys (Knetch and Sinden, 1984; Freeman, 2003; Hanley, Shogren and White, 1997; Horowitz and McConnell, 2002)[10]. As a result, WTP rather than WTAC is usually employed and provides a conservative (lower bound) estimate of WTAC (Carson, Flores, and Hanneman, 1998).

Estimates of WTP (or WTAC) are aggregated over the affected population to get total costs or benefits. Typically, federal projects show estimates of benefits and costs for the nation as a whole (for example, as "National Economic Development Benefits" used by the US Army Corps of Engineers). However, who gains and who pays -- the distribution of benefits and costs over the affected population -- often are central to public decisions in practice (e.g., Zeckhauser, 1985). Our prior research recognizes the importance of, and addresses net benefits from, two perspectives (1) the nation and (2) the port host state or region, defined as the *current residents* of the area (Grigalunas, Luo and Chang, 2001). The rationale for this host-state perspective is that it is the current residents (and their representatives) who must decide, as part of the public

[10] Differences between WTAC and WTP depends upon the availability of substitutes for affected resources and the income effect (Hanemann, 1991; Hanley, Shogren, and White, 1997).

process, whether to assume the financial and environmental risks of port development in return for a share of the benefits, which port development, creates[11]. Details of the concepts used to define, and the accounting system used to sort out, costs and benefits are given in Grigalunas, Luo and Chang (2001). Here we note that the resulting assessment of benefits and costs is based on standard economic concepts of incremental effects and bears little resemblance to gross "economic impacts" using naïve "multipliers", for example.

Given the nature of air and noise externalities outlined above, several economic valuation methods can be used to estimate the resultant external costs from additional air pollution or noise due to port-related activity. These valuation methods fall into three broad categories:

- *Revealed preference* methods use information on peoples' actions in markets to estimate the implicit value individuals have for clean air or quiet surroundings. An important example, and one employed later, is the property value (hedonic) method. Here, information on housing transactions in a market is used to isolate the contribution site, neighborhood, and environmental attributes make to the value of a home. In such studies, air quality and noise have been found to affect property values, after allowing for the influence of all other factors, for example, the size of the home and lot, number of bathrooms, location, proximity to open space (see, e.g., Palmquist,1991; Freeman, 2003; Huang and Smith, 1995; Kwon, 2003). Another revealed preference approach, avoidance costs, uses data on individuals' outlays to prevent or reduce harm, such as purchases of air filters or of noise insulation, buffer fencing, or landscaping. Such actions in effect allow the household to use various inputs (buffer fences, landscaping, insulation, air filters, and labor) to "produce" cleaner air or a quieter environment. Hence, these outlays provide evidence of the value of clean air or quiet.
- The *productivity approach* uses information on the value of lost output and/or additional costs and higher prices to value air quality, noise, or other external effects. For example, air pollution effects can be measured as reduced work output and additional medical costs from illness; as reduced farm output and higher costs to consumers; and as reduced fish catch, if air pollution actually reduces water and aquatic habitat quality. Poor air quality, such as acid rain, also might harm forests, with losses measured as the reduced value of timber harvests or of recreational visits to a forested area.
- *Stated preference* methods use carefully developed surveys to create a "constructed market" (Carson, 1991) for non-marketed environmental goods and services. A random sample of individuals in the population of interest may be asked their willingness to pay additional taxes or fees for an effective program to avoid specific deteriorations in air quality or noise. Modern, well-done surveys are akin to public referenda, which often are used to assess the public's preferences, and willingness to pay additional taxes for specified environmental programs as indicated in votes for or against the proposed program. Stated preferences have the advantages of flexibility and provide the only way to estimate directly total economic value, but these methods can be very expensive to apply and raise their own challenges.

II. G. Selection of Valuation Methods: Issues

[11] We emphasize *share* of the benefits since cost some savings from a port will be spread over a broad geographic area, including the Midwest in our hypothetical port case (Luo, Grigalunas, Jung, 2002).

Attempts to estimate externalities from port-related activity raise several challenges, as we describe in detail in succeeding chapters. Of these, three are noted here: (1) the choice or "philosophy" in selecting an overall methodology, (2) the use of benefit transfer in the case of hedonic methods, and (3) complications added by "joint externalities" which often arise in practice.

II.G.1. Choice of Methods for Modeling External Costs

Our basic approach for studying port-related external costs involves assessing individual externalities using methods appropriate for each issue. One reason for our adoption of this issue-specific, additive approach is that public debate and related policy issues, for example, concerning dredging, dredge disposal, and possible mitigation measures for other issues, focuses on particular issues, and there are many of them, as noted in the introduction to this report. Use of a single valuation method – described below -- would likely not capture enough detail to contribute usefully to discussion of many issues.

However, an issue-by-issue assessment raises the risk of double counting. For example, noise and air emissions might both decrease the value of residential property value along roads near a port. If separate studies of each issue (for example, a property value study for noise and a contingent valuation study for air pollution) are carried out, with the results naively added together, the same loss could be counted twice. (Property values declines may reflect *both* noise and air pollution.)

An alternative approach could use the contingent valuation method (CVM) to consider all externalities together to estimate "total value" (e.g., Mitchell and Carson, 1989; Randall, 1991; Freeman, 2003). This approach avoids possible double counting, but comes at a price. For one thing, well done (that is, valid and reliable) CVM studies are very expensive—much beyond the resources available for our research. Another likely problem is that a study of total value for port development almost certainly would require a level of abstraction for resource issues that would not help resolve disputes over the numerous, resource- and area-specific, individual environmental concerns which are common to port development. As a result, a CVM study would not allow researchers to separate the more important from the less important issues. Hence, CVM studies likely would be of little help in identifying resource issue priorities and therefore their results could not contribute to consideration of benefits versus costs on individual issues. Finally, CVM studies of passive use values remain problematic (Hausman, 1993; Diamond, 1994), despite important advances in the state-of-the-art.

Another stated preference method, Contingent Choice (CC), avoids some of the problems of CVM and might be used to assess multiple port-related externalities. CC involves using carefully developed surveys to elicit respondents' willingness to tradeoff resources or amenities in well-specified alternative resource program (Mitchell and Carson, 1989; Opaluch et al, 1999; Mazzotta, Opaluch and Grigalunas, 2000; Mansfied, Van Houten, Huber, 2002). If one of the attributes of each program is its cost, then the total value of the program can be estimated, in principle. However, it is again the case that such surveys are expensive to do well. Moreover, the large number and complexity of the issues involved with port-related activities likely would overwhelm the cognitive ability of the general public to respond meaningful to survey questions with many choice alternatives[12] Other problems with stated preference methods, such as

[12] For a discussion of cognitive issues in surveys, see Mazzotta and Opaluch (1995)

responses symbolic of broad environmental concerns rather than the specific issue at hand, also may arise (Opaluch, Mazzotta and Grigalunas, 2000).

II.G.2. Use of Benefit Transfer of Hedonic Results in Ex Ante Analyses

A second issue concerns the appropriate way to use benefit transfer of hedonic analysis results for *ex ante* valuation of potential damages, when the environmental stress to be valued is increasing over time. Stated briefly, benefit transfer involves adopting or adapting the results of a study carried out for one area for use in another similar area for a comparable issue (DesVouges, Naughton and Parson, 1992). For our later assessment of noise externalities, for example, the overall goal is to estimate the change in the *asset* value of housing near the main connector route due to additional, port-related noise from additional truck traffic. Specifically, in Chapter IV a two-step approach is used in which we (1) simulate exposure of property along a major port connector road to noise from additional traffic because of the port, and then (2) estimate how the additional noise reduces the market value of exposed properties. To carry out the second step, we estimate the effect of noise on property values using the results of a hedonic study of noise from aircraft using TF Greene Airport, in Warwick, RI (details of the benefit transfer are given Chapter IV and in an Appendix).

Our approach thus involves a "hybrid" model coupling original results from a hedonic analysis of aircraft noise on property values in a nearby, RI community transferred to vehicular traffic noise in the "policy area" near the hypothetical port. As we explain in detail in Chapter IV, the implicit values on environmental attributes in hedonic studies typically are assumed to reflect foresight by households in the affected housing market – that is, individuals anticipate future adverse or positive environmental effects, and these expectations are built into the price of homes today. Our port estimates have truck traffic and hence noise increasing with time. In this setting, the estimation of external costs from noise must be adjusted so that the affected housing market fully reflects growth in port traffic and the associated noise increases over time (see Appendix to Chapter IV).

II.G.3. Joint Externalities

Another issue concerns joint externalities. For example, heavy trucks generate both noise and air emissions. Noise increases with speed, but CO and NOx emissions *decrease* with speed up to a point (Figure II.1). Hence, a single avoidance or mitigation measure, such as enforcing lower speed limits on trucks, would decrease noise but could increase emissions. Our later calculations illustrate this point.

The joint externality problem somewhat complicates avoidance or mitigation measures, and calls for use of two policy instruments to correct these externalities, one for each problem. For example, speed reductions, installation of noise-reducing barriers or landscaping, or sound-dampening pavement materials can be used to reduce noise, while air emission standards can be employed to lower these emissions. Choice of a policy instrument from among several available to deal with a particular issue would depend upon the benefits and costs (or cost-effectiveness) of each option, taking into consideration the ease with which each might be implemented and their social acceptability and therefore political feasibility (Sterner, 2003).

In reality, heavy trucks are associated with multiple potential external costs, contributing to accelerated outlays to repair road wear and tear, congestion, and accidents as well noise and air emissions (e.g., Ozbay, et al, 2001). Hence, a range of instruments *may* be needed to avoid or mitigate potential these external costs, such as additional state fees on fuel use for road repair, and improved traffic management, for example, use of road signage, lights, lane restrictions, or better enforcement of traffic laws on all vehicles to reduce accidents and resulting damages, injuries and mortality.

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III. PERSPECTIVE ON CONTAINER PORT-RELATED AIR QUALITY ISSUES

III.A Introduction

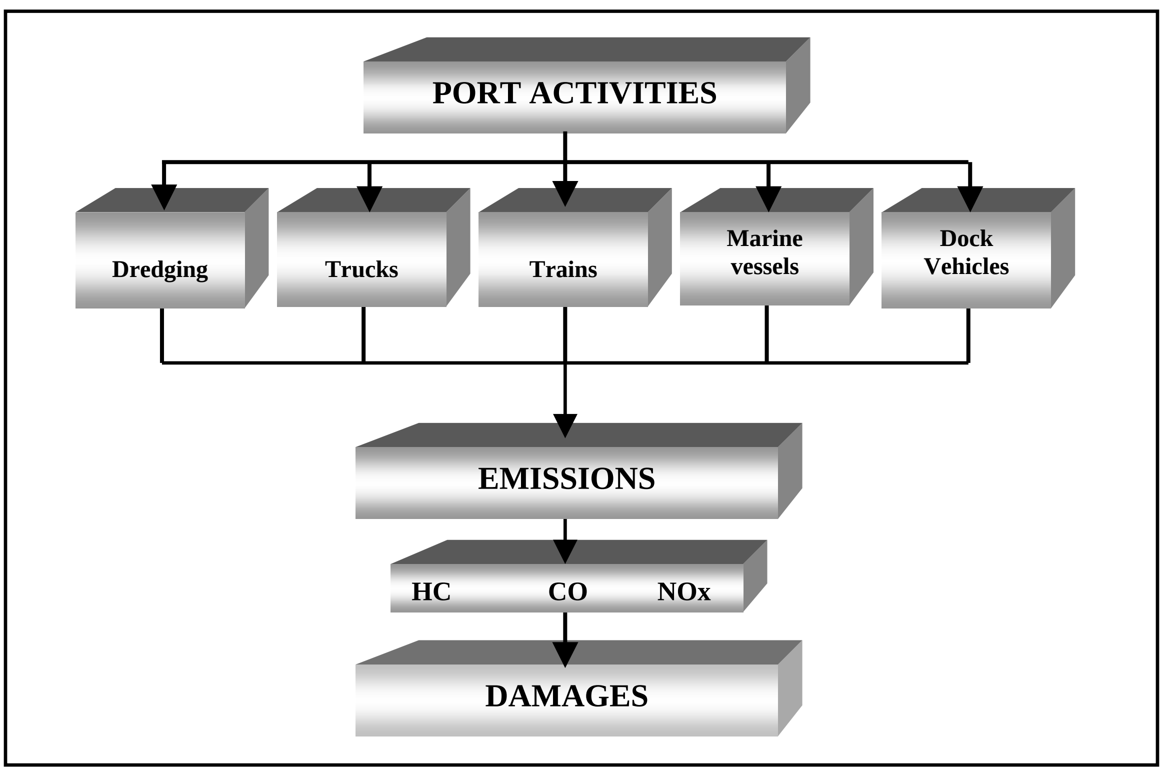
Air pollution is an important environmental concern not only in Rhode Island but also throughout much of the Northeast United States. In 2001 and 2002, for example, Rhode Island experienced a total of 36 days when ozone health limits were exceeded (Table I.D.1).

Large-scale port development generates substantial onsite and offsite vehicular traffic, as well as train and vessel movements (Table II.D.1), all of which are sources of air emissions and potential external costs. Hence, an important question concerns whether port-related development would substantially exacerbate air quality problems, recognizing that potential problems might be avoided or reduced through regulations, design, or mitigation measures.

A considerable literature examines the consequences of air pollution in general (for example, see McCubbin and Delucchi, 1999; Rowe, *et al*.,1995; Adams and Crocker, 1991; and Cropper, 2000). A smaller literature addresses air pollution resulting from marine vessels and container port-related activity in particular (for example, Corbett and Fischbeck, (2002), Bomba, (2002), RK Johns and Associates, (2000), EIS (Containerization International, 2002).

However, studies of port-related air pollution issues typically are done in isolation without clearly tying emissions to a detailed port development model. This may simplify such studies but makes it difficult to assess how changes in (1) the scale of port development, (2) multimodal assumptions or estimates, or (3) implementation of regulations or mitigation measures will affect air pollution and damages. Further, most few studies of air pollution from port-related activities have an economics perspective, which we provide in this report.

FIGURE III.A.1. Simplified Depiction of Emissions by Source.



This Chapter integrates container port-related air pollution issues into our comprehensive port development framework presented in Grigalunas, Luo and Chang, 2001; Grigalunas, Luo and Jung, 2002). As we show above, emissions from port stem from several sources (Fig. III.A.1) and depend upon many factors, including:

- the scale of operations,
- the relative use of trains and trucks,
- road speed, and
- implementation of, and compliance with, proposed new air pollution regulations.

III.A.1 Purpose and Scope

This chapter estimates potential air pollution from container port development. Annual air emissions are estimated for selected key pollutants for a hypothetical new container port. Our example application draws upon the results of our prior work, and we continue to use a *hypothetical* container hub port at Quonset Point, Rhode Island as the example.

For the hypothetical port, air emissions are based on estimates of the (1) annual demand for transportation services (container moves) and (2) related multimodel (vessel-train-truck) transportation services over time. For each transportation source, annual emissions estimates are given for key pollutants generated annually for a twenty-year planning period.

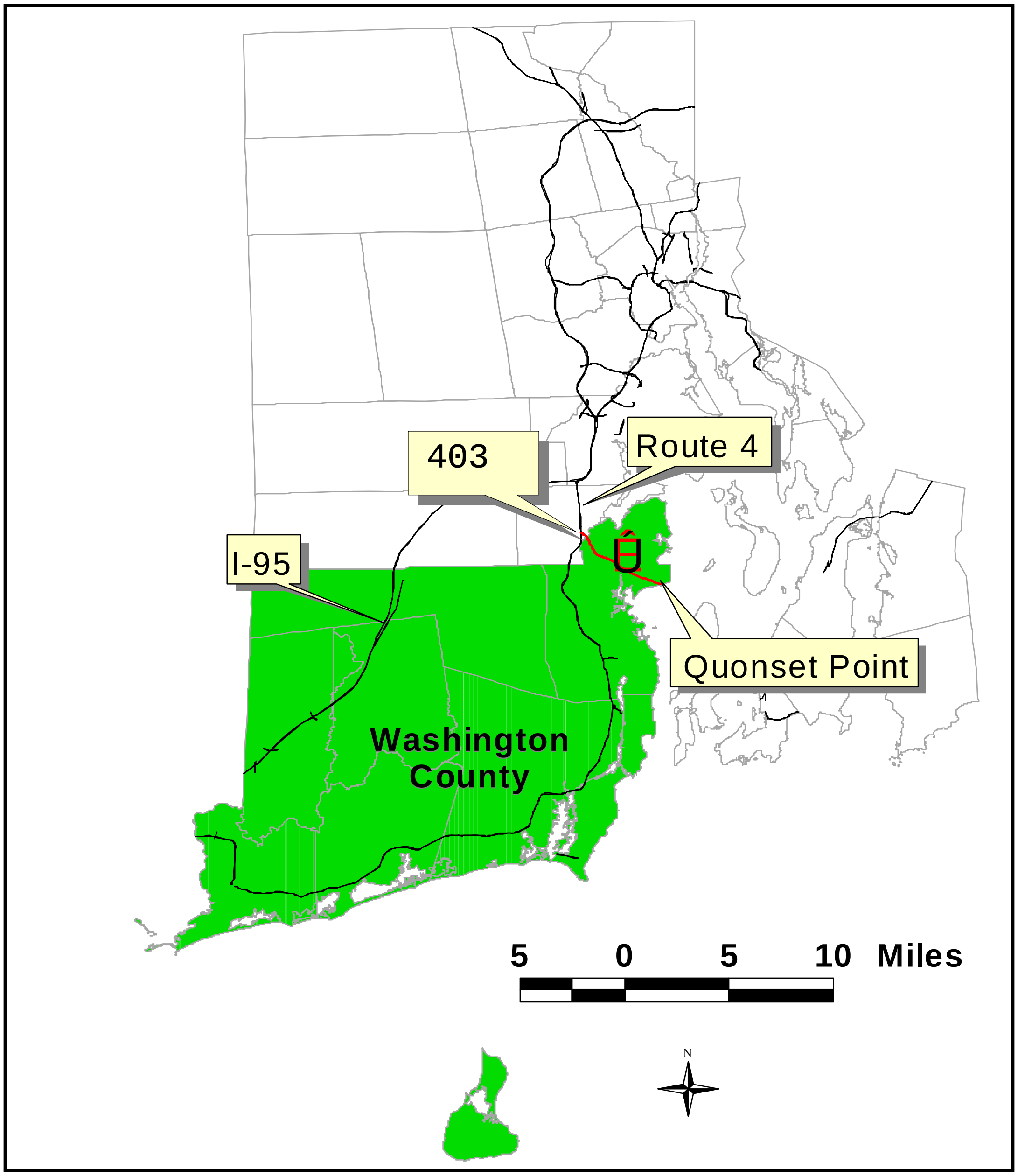
Two opposing factors are at work for air emissions over time. Projected growth in port traffic will generate additional air emissions, while the implementation of EPA's air emission regulations on heavy-duty diesel trucks (the major potential source of air emissions) will substantially reduce emissions per mile. Hence, it is the interaction of these two opposing effects, which determines net emissions from port development. As described below, we include both growth in traffic and the phasing in of national air pollution regulations for container port-related heavy-duty truck sources under the Clean Air Act. This allows us to sort out the net effect of these two important, vying trends[13].

Estimated annual emissions are compared with a baseline level of air emissions. This "with-versus-without" comparison provides insight into the potential contribution of port-related development on air pollution in Rhode Island. Simply stated, a projected increase in emissions of 0.1 percent (that is, 0.001) over baseline levels is of less concern than an increase of, say, 10 percent, all else being equal[14]. For this purpose, two baseline areas are used, Washington County, Rhode Island, because it contains the site of the hypothetical port, and the State of Rhode Island as a whole, recognizing that trucks will move throughout much of the state and air emissions around the port, driven by prevailing westerly winds, will be transported over and potentially affect a broad area (see map below).

[13] However, not considered are the net effects on area emissions if a port at Quonset or Providence substitutes for road transportation by truck from another port in the without-port case

[14] It is recognized that even a relatively small percentage increase in aggregate emissions might cause harmful localized effects due to elevated exposure in selected situations (e.g., in areas with a high population concentration of elderly).

Figure III.A.2. Rhode Island Map.



No original estimates of damages from air pollution are attempted in this report. We do, however, use benefit transfer to provide estimates of potential damages for illustrative purposes. We also draw upon economic arguments to describe types of potential damages and methods which could be used later to develop original estimates the pollution damages and the benefits from mitigation, should such a future effort be pursued.

III.A.2. Organization

First, for background, information is summarized on (1) air pollution management, (2) the general effects of air pollution, and (3) air quality violations in the case study area. Next, key economic concepts are introduced. Then, the methodology and data are presented. Key results, qualifications and limitations are discussed in the final section.

III.B. Background

Under the Clean Air Act, air quality is managed by the EPA in cooperation with environmental agencies in each state. Management typically involves National short-term (1 hour) and longer-term (for example 8 hour or 24 hours) ambient exposure thresholds to be met for specific pollutants. Also, emission limits (for example, discharge of NO_x in grams per mile) must be met for stationary (for example, refineries or factories) and mobile (for example, truck and train) emission sources.

Six principal air pollutants, referred to as Criteria Air Pollutants, are the focus of EPA regulations:

- carbon monoxide (CO),
- lead (Pb),
- nitrogen dioxide(NO_2),
- ozone (O_3),
- particulate matter (PM),
- sulfur dioxide (SO_2).

These six pollutants have been singled out by the EPA because of their potential to cause harm to people, property, and the environment. Of these six, four (CO, Pb, NO_2 and SO_2) result solely from direct emissions from a variety of mobile (for example, trucks, cars, trains, construction equipment) and stationary sources (for example, power plants, factories, refineries, wood burning). Of the remaining two, PM also can result from direct emissions, but is commonly formed when emissions of nitrogen oxides (NO_x), sulfur dioxides (SO_2), ammonia, and other gases react in the atmosphere.

Ozone (O_3) is not directly emitted, but it is formed when NO_x and volatile organic compounds (VOCs) (largely from motor vehicles) react in the presence of sunlight. Ozone is of particular concern during the summer months, because the photochemical reactions leading to the formation of this pollutant occur mostly during this period. Exposure to the air pollutants above certain thresholds (Table III.B.2) can cause a variety of damages to human health, property and materials, and trees and plant life (Table III.B.3).

Generally, motor vehicles are responsible for (1) up to half of the smog-forming VOCs and nitrogen oxides (NO_x), (2) more than 50 percent of the hazardous air pollutants, and (3) up to 90 percent of the carbon monoxide found in urban air (US EPA, 2002). Carbon monoxide (CO) and VOCs are the product of incomplete combustion of motor fuels and, in the case of VOCs, of fuel vapors emitted from the engine and fuel system. Oxides of nitrogen (NO_x) emissions are the products of high-temperature chemical processes, which occur during the combustion itself.

EPA calls the six pollutants listed above *criteria air pollutants* because it has regulated them by developing health-based *criteria* (science-based guidelines) for setting permissible exposure levels. National air quality standards for each criteria air pollutant are set by the EPA and implemented by each State through adoption of a State Implementation Plan (SIP).

The SIP is the federally enforceable plan for each State, which identifies how that State will attain and/or maintain the primary and secondary National Ambient Air Quality Standards

(NAAQS) set forth in Section 109 of the Clean Air Act (CAA). Developed through a public process, the SIP plan sets out the control measures and strategies formally adopted by the State to attain and maintain the NAAQS. The Governor's designee to EPA submits the plan to EPA for action. States can revise their SIP, as necessary, to address the unique air pollution problems they face. Therefore, EPA from time to time must revise SIPs (US EPA, 2002). However, state thresholds must be at least as strict as the national thresholds.

For each criteria pollutant, EPA gives two sets of limits. One is the *primary standard*, which is designed to protect health, the other is the *secondary standard, which* is intended to prevent environmental and property damage (Table III.B.1). Criteria air pollutants and examples of their effects on humans and environment are described in Table III.B.3

TABLE III.B.1. National Ambient Air Quality Standards

POLLUTANT	STANDARD VALUE *		STANDARD TYPE
Carbon Monoxide (CO)			
8-hour Average	9 ppm	(10 mg/m^3)	Primary
1-hour Average	35 ppm	(40 mg/m^3)	Primary
Nitrogen Dioxide (NO_2)			
Annual Arithmetic Mean	0.053 ppm	(100 µg/m^3)	Primary & Secondary
Ozone (O_3)			
8-hour Average	0.08 ppm	115 (µg/m^3)	Primary & Secondary
1-hour Average	0.12 ppm	(235 µg/m^3)	Primary & Secondary
Lead (Pb)			
Quarterly Average	1.5 µg/m^3		Primary & Secondary
Particulate (PM 10) *Particles with diameters of 10 micrometers or less*			
Annual Arithmetic Mean	50 µg/m^3		Primary & Secondary
24-hour Average	150 µg/m^3		Primary & Secondary
Sulfur Dioxide (SO_2)			
Annual Arithmetic Mean	0.03 ppm	(80 µg/m^3)	Primary
24-hour Average	0.14 ppm	(365 µg/m^3)	Primary
3-hour Average	0.50 ppm	(1300 µg/m^3)	Secondary

* Parenthetical value is an approximately equivalent concentration.
Source US Environmental Protection Agency, 2002

TABLE III.B.2. Ozone Concentration, Air Quality Index Values, and Air Quality Descriptor

Ozone Concentration (ppm) (8-hour average, unless noted)	Air Quality Index Values	Air Quality Descriptor
0.0 to 0.064	0 to 50	Good
0.065 to 0.084	51 to 100	Moderate
0.085 to 0.104	101 to 150	Unhealthy for Sensitive Groups
0.105 to 0.124	151 to 200	Unhealthy
0.125 (8-hr.) to 0.404 (1-hr.)	201 to 300	Very Unhealthy

Source: US Environmental Protection Agency, 2002 (www.epa.gov)

III.C. Concepts

Air emissions are an important class of potential external effects, both because of their pervasiveness and the seriousness of their effects on people. Above some ambient pollution concentration, exposure to particular pollutants can limit visibility, harm human health, deteriorate materials, and cause mortality to plant life and trees (Table III.B.1 – Table III.B.3). Human health effects include premature mortality as well as morbidity (illness) effects. Morbidity encompasses restricted activity days (no strenuous outside activities) or symptom days (cough, headaches, or irritated throat) (Cropper and Freeman, 1991). Losses to agriculture, silverculture, and to natural forests because of air pollution also can occur.

The basic task in assessing the environmental risks from air pollution is to estimate potential exposure of individuals, property, or natural resources and the resultant damages because of the activity of interest -- here container port-related activity. Given estimates of exposure, various non-market valuation methods might be used to estimate the marginal damages from increased emissions or, viewed the opposite way, the marginal benefits from reducing air pollution (see, for example, Cropper and Freeman, 1991; Adams and Crocker, 1991; Freeman, 1993).

Clearly, linking port-related air emissions to damages is extremely complicated. As noted earlier, the annual level of the activity of interest (here, major port-related activities) and resultant emissions must be estimated for each pollutant from each key source, such as truck and train trips. This means estimates are needed of not only future activity through a port but also the multimodal transportation (train-truck) split. A related complication stems from the mobility of important sources – especially trucks – so that speed and miles traveled in the study area must be considered. Air quality in an area often is affected by (and in the case of small areas, like Rhode Island, largely determined by) emissions from distant areas, such as exposure of people in the Northeast states to air pollution from power plants in the Midwest or elsewhere in the Northeast (e.g., Burtaw and Palmer).

TABLE III.B.3. Summary of Air Pollution Sources and Potential Health, Environmental, and Property Damage Effects

	POLLUTION SOURCE	HEALTH EFFECTS	ENVIRONMENTAL EFFECTS	PROPERTY DAMAGE
Ozone	Chemical reaction of VOCs and NO_x in the atmosphere	Breathing problems, reduced lung function, asthma, irritates eyes, stuffy nose, reduced resistance to colds and other infections, may speed lung tissue aging.	Ozone can damage plants and trees. Smog can cause reduced visibility	Damages rubber, fabrics, etc.
Nitrogen Dioxide	Burning of gasoline, natural gas, coal, oil etc. Cars are an important source of NO_2	Lung damage, illnesses of breathing passages and lungs (respiratory system)	NO_2 is an ingredient of acid rain (acid aerosols), which can damage trees and lakes. Acid aerosols can reduce visibility	Acid aerosols can eat away stone used on buildings, statues, monuments, etc.
Carbon Monoxide	Burning of gasoline, natural gas, coal, oil etc.	Reduces ability of blood to bring oxygen to body cells and tissues; cells and tissues need oxygen to work. Carbon monoxide may be particularly hazardous to people who have heart or circulatory (blood vessel) problems and people who have damaged lungs or breathing passages		
Particulate Matter	Burning of wood, diesel and other fuels; industrial plants; agriculture (plowing, burning off fields); unpaved roads	Nose and throat irritation, lung damage, bronchitis, early death	Particulates are the main source of haze that reduces visibility	Ashes, soot, smokes and dusts can dirty and discolor structures and other property, such as clothes and furniture
Sulfur Dioxide	Burning of coal and oil, especially high-sulfur coal from the Eastern United States; industrial processes (paper, metals)	Breathing problems, may cause permanent damage to lungs	SO_2 is an ingredient in acid rain (acid aerosols), which can damage trees and lakes. Acid aerosols can also reduce visibility	Acid aerosols can eat away stone used in buildings, statues, monuments, etc.
Lead	Leaded gasoline (being phased out), paint (houses, cars), smelters (metal refineries); manufacture of lead storage batteries	Brain and other nervous system damage; children are at special risk. Some lead-containing chemicals cause cancer in animals. Lead causes digestive and other health problems	Lead can harm wildlife	
VOCs	Burning of gasoline, oil, wood coal, natural gas, etc.), and from use of solvents, paints glues and other products at work or at home. Cars are an important source of VOCs. VOCs include chemicals such as benzene, toluene, methylene chloride and methyl chloroform	In addition to ozone (smog) effects, many VOCs can cause serious health problems such as cancer and other effects	In addition to ozone (smog) effects, some VOCs such as formaldehyde and ethylene may harm plants	

Source US Environmental Protection Agency, 2002

The regulatory framework also is important, and therefore implementation of, and compliance with, air pollution control regulations must be considered. Last but not least, the proper focus of any analysis is on the incremental emission of any activity -- in this case, air emissions over-and-above those which would occur from alternative uses of the coastal site in the absence of a port.

III.C.1. Damages

Individuals exposed to air pollution above threshold levels may experience (1) ill effects on health, (2) physical discomfort, for example, from throat or eye irritation, asthma attacks, or other physical discomfort and illness, and (3) premature mortality to the elderly or sick in extreme cases. Individuals also are made worse off if air pollution harms residential or personal amenities, such as housing or car exteriors, plants, or trees. Atmospheric deposition also can cause losses by affecting water quality and ecosystem productivity, for example, through acid rain or nitrogen inputs to estuaries (EPA, 2002; TETRA TECH, 2001; Grigalunas, et al., 2003).

Valuation of air pollution damages can proceed along several lines. If the harmful effects of air pollution trigger avoidance behavior, such as opting to buy homes in areas with low air pollution or installing air filters, then the individuals' actions in markets (buying housing and air filters) provides a "paper trail". Market transactions can be used to reveal that individuals value clean air at least as much as the cost incurred. Given sufficient data, it is possible to infer from market purchases and the value of time used the implicit value individuals attach to air quality (Freeman, 2003). The reduced value of homes would pick up many adverse effects of pollution such as on health, visibility, and harm to material surfaces, plants and trees, allowing for the influence of other factors affecting the property. This presumes that occupants of homes are aware of the pollution and its consequences.

Alternately, contingent valuation or contingent choice might be used. These stated preference methods have the advantage of flexibility and of assessing total value. However, such studies can be costly to do and validity and reliability issues arise, putting severe demands on researchers -- and budgets. Or, separate studies using different methods (revealed preference, stated preference, or a combination of the two) might be done in order to value individual effects on health (morbidity and mortality) and their resulting costs, on the exteriors of structures or cars, or on visibility, etc. The individual costs then could be added, with due care taken to avoid double counting. Here, we use a simple approach: benefit transfer for illustrative purpose concerning air pollution damages, as described below.

III.C.2. Methods and Data Used

The general logic of our method is given in Figure II.D.1 and the steps involved are explained below.

- *Initial container moves* through the hypothetical port are based on the results of the container port and multi-modal simulation demand model developed in Luo (2002) and Grigalunas and Luo (2002). These results suggest an initial demand for 211 thousand moves (316 thousand TEUs) in year one operation, under the assumptions used, including a productive port with Class I rail access to major markets in the mid- West.
- *Projections of container moves* are based on a literature review of national forecasts of container moves and a preliminary econometric estimate of national demand for TEUs by Jung

(2001) (see, Grigalunas and Luo, 2002). Use of the midpoint of these estimates is an annual national growth rate of 5.4%. This aggregate national growth rate was assumed to apply to our hypothetical port, allowing us to project moves through the port over time.

- *Multi-modal use and road selection* is based on the container port and related multimodal transportation demand simulation model, which estimates the least-cost, intermodal split and route(s) from sources and markets through the port. The results suggest that about 70% of moves will be by train and 30% by truck[15]. While trucks would move along several routes, most trucks would use a new connector road between the port and Interstate 95 (Figure III.C.2.2). As a simplification, all truck trips are assumed to use the connector road.
- Emission factors (in grams per mile) for each source -- trucks, on-dock vehicles ("yardhorses"), trains and vessels (ships and barges) -- for each pollutant are used to estimate total emissions, as follows. For trucks (the major potential source of air pollution), results from an application the EPA's Mobile 5b model was used[16]. The resulting truck emission factors are a non-linear function of speed, decreasing with speed to 50 mph, and then increasing (Figure III.C.1). Emission rates also are included for idling vehicles (assuming the average trucks have a ½ hour idle time at the port). For the least-cost route, estimates were made of emissions based on the speed at the port facility (15 mph), on the Quonset property (25 mph), on the connector road (37.5 mph) and Interstate highway (55 mph) to the RI border[17].
- Potential port-related air emissions are compared against baseline emissions, which have two elements. One is the total emissions of the key pollutants for Washington County (which contains the planned port site) and for Rhode Island as a whole. We use the most recent year for which data could be obtained (see Table III.C.3). These account for virtually the entire baseline. The second part of baseline emissions is from the 200 acres used for alternative purposes without the port. These are estimated assuming that the traffic per acre for the area is the same as estimates of the per acre traffic for the entire facility site (see Table III.C.2). The baseline is assumed to remain the same over the 20-year study period.

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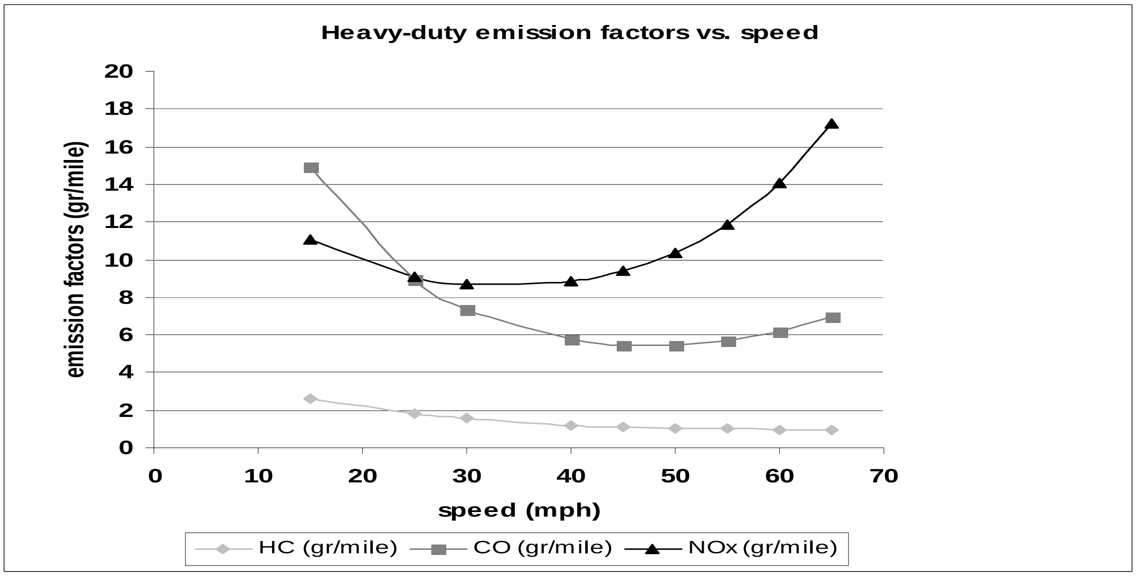
[15] The model estimate of 70% moves by train appears to be consistent with the judgment in RK Johns and Assoc. (2000).

[16] We acknowledge the help of Mr. Ron Marccacio of EPA who provided the Mobile 5b results used in this report.

[17] The legal speed for the connector road is 25 mph but the actual speed is anticipated to be between 35 – 40 mph, according to the North Kingstown Police Department. We use 37.5 mph. All other road speeds are set at the legal speed limits.

FIGURE III.C.1. Speed Influence on Emissions of HC, CO and NO_x from Trucks (Mobile 5b).



Source: Application of EPA Mobile 5b model (US EPA, Office of Air Resources, 2002)

TABLE III.C.1. 2002 Heavy-Duty Diesel Emission Factors vs. Speed (Mobile 5b)

SPEED (mph)	HC (gr/mile)	CO (gr/mile)	NO_x (gr/mile)
5	4.19	30.5	15.54
10	3.29	20.72	12.89
15	2.64	14.95	11.08
20	2.17	11.29	9.84
25	1.82	8.92	9.11
30	1.56	7.38	8.71
35	1.36	6.39	8.63
40	1.22	5.79	8.86
45	1.12	5.49	9.43
50	1.05	5.45	10.39
55	1.01	5.66	11.86
60	0.98	6.15	14.04
65	0.98	6.99	17.21
Idle	4.64 gr/hr	35.31 gr/hr	16.91 gr/hr

Source: US EPA, Office of Air Resources, 2002

TABLE III.C.2. Baseline-Daily and Hourly Traffic Volume on Davisville Rd. by Vehicle Types

Vehicle Type	Traffic per Day[a] (TPD)	Traffic per Hour[b] (TPH)
Automobile	15,180	1,265
Medium Truck	990	83
Heavy Truck	330	28
Total	***16,500***	***1,376***

Source: 2000 Traffic Flow Map (based on 1999) and 1998 Truck Flow Map (based on 1997), RIDOT.
a: Traffic volumes by vehicle types are calculated using given total number (16,500) and percentage of medium truck (6%) and heavy trucks (2%).
b: TPH = TPD/12

III.C.3. Air Pollution

As noted, the air quality analysis for this project is intended to determine the emissions of the proposed development for two areas:

- Washington County, Rhode Island, which contains the hypothetical port site of Quonset Point as well as the main connector road which would be used by trucks, and
- The State of Rhode Island as a whole.

Many natural, regulatory, and mechanical factors influence air pollution. The weather, compliance with regulations, vehicle characteristics - engine, speed, age, weight -- mechanical problems, geographical conditions, wind speed, temperature inversions, and the like, all will affect emissions per mile. An application of EPA's Mobile 5b model was used to provide estimates of emissions coefficients from trucks, the major source of pollution, under the conditions in the study area (see figure and table above for emission coefficients as a function of speed).

Also important in any *ex ante* air quality analysis is the prevailing and proposed regulations for the pollution sources under study. Next, we outline the EPA's regulations for primary mobile sources and how they are incorporated in our analysis.

III.C.4. Implementation of New Air Pollution Emissions Regulations

EPA regulations will substantially reduce air emissions from mobile sources, including heavy-duty vehicles, light-duty vehicles, and locomotives. Generally, this will be done in Phases. Here we focus discussion on heavy-duty, diesel-powered trucks, by far the major potential source of harmful emissions, as we show below.

EPA regulates emissions from, and has an emission certification process for, large or "heavy-duty" diesel engines used in trucks. Trucks have been regulated since the mid-1970s with progressively more stringent standards, but compliance rates may vary. Most of the engine manufacturers have continuously improved the emissions performance of their product trying to reach agreement with the EPA.

Historically, the prime target of diesel emission regulations in the U.S. has been *new* diesel engines. Through a series of progressively more stringent standards, new engine emissions have been reduced to such low levels that the black smoke traditionally associated with diesels has been either eliminated or substantially reduced. Still, final emission standards for 2004 and later model year highway heavy-duty vehicles and engines are expected to go much further by setting near-zero emission limits.

For existing trucks, old diesel engines emit substantial quantities of PM and NO_x. For these engines, EPA has the Voluntary Diesel Retrofit Program, aimed at reducing emissions from in-use heavy-duty diesel engines in both highway and nonroad applications. However, the current heavy-duty retrofit program is voluntary.

EPA hopes to work with other federal agencies, state governments, environmental groups and industries to encourage the retrofits. Under the program, states will receive emission credits in their State Implementation Plans (SIP) for retrofitting existing heavy-duty diesel engines with emission control devices.

The SIP credit structure has been designed to create incentives for states to establish a range of programs encouraging retrofits. State programs may include a number of voluntary, tax incentives, or market mechanisms such as "green" contracts, preferential parking, differential tolls, high occupancy lane use, etc. For example this type of incentive has been already implemented in Massachusetts (Majewski, 2000).

The voluntary retrofit program adopts a wide definition of the engine retrofit, which includes the following:

- retrofitting engines with a catalytic converter or a diesel particulate filter
- engine upgrade
- engine replacement
- use of clean fuels and/or fuel additives
- a combination of the above

However, given that this is a voluntary and not a mandatory program, truck owners might choose to comply with the new standards set by EPA by taking into consideration the company's management policy also. This means that they might not replace their truck fleet while it is still usable and profitable nor will they increase costs by investing in new engines, unless it is mandatory.

III.C.5. Assumptions Used to Estimate Potential Air Emissions

Two major alternatives and sensitivity analyses are analyzed below:

- No Port Development
    - Use of the 200 acres earmarked for a port is assumed to generate the same traffic per acre as currently is generated by developed parts of the site (Table III.C.2). Air emissions from this traffic are estimated using emission coefficients for each vehicle source.
- "Base Case" (see Table II.D.1):
    - containers moves are 30% by truck and 70% by train
    - startup moves in year 2007 are 315,700 containers with a 5.4% average annual growth rate
    - EPA air emission regulations on heavy trucks are implemented as described in text and Figure III.C.6.1 with 100% compliance by 2030.
- Sensitivity Analyses
    - Containers moves are 50 % truck and 50 % train
    - EPA air emission regulations on heavy trucks *not* implemented
    - Combined case: containers move 50% by truck, 50% by train and EPA air regulations are not implemented
    - Trucks travel at the legal speed (25 mph) versus practice (37.5 mph)

Note that 50% of moves by truck for a hub port are most unlikely because a successful hub port at Quonset would almost certainly require access to Midwest markets, which in turn requires the substantial use of double stacked trains. Also, implementation of EPA's Phase I and II reduction on truck emissions appears a foregone conclusion.

To quantify the potential port-related air emissions, four primary sources of transportation emissions are included:

- dredges
- trucks
- trains
- port utility vehicles, and

- vessels.

All vehicles are assumed to be equipped with heavy-duty diesel-powered engines. These are considered to be one of the most polluting engines, which also serves to overstate emissions.

For all mobile pollution sources, emissions are presented for benchmark years 1, 5, 10, 15, and 20. This provides a perspective on the net effect of growth of air emissions over time from increasing traffic versus the reduction in emissions per mile from compliance with tougher EPA regulation of emissions.

To acknowledge spatial and speed issues, quantities of air pollutants emitted annually are estimated for defined geographical locations. Emissions are estimated by multiplying a source activity unit, for example, the number of miles by truck at given speeds for the connector road, Route 4 and I 95 (Figure III A.2), by an associated unit activity emission factor, such as grams of pollutant emitted per mile traveled for a given speed (see Figure III.C.1) or per gallon of fuel burned.

For vessels, Kristensen's (2003) main results are adopted. His results show emissions are a function of vessel size and speed. For size, we adopt his intermediate case results and assume that container ships using the port carry 3000 TEUs. For speed, vessels are assumed to travel the limit in Narragansett Bay, 15 knots per hour. We use a 16-mile round trip distance from the mouth of the Bay to the hypothetical port site. Annual emissions are estimated by multiplying the emission factor for each vessel by the number of miles for each trip and by the annual number of estimated vessel trips. Following Rhode Island practice, container vessels generate no emissions when tied to the dock.

The number of tug boats used when container ships are approaching and within the Bay itself will vary with the size and characteristics of the vessel, among other factors. We also use two tug boats per vessel in the model, but recognize that more tugs might be used in some cases, depending upon the container vessel and port congestion, for example.

Yard vehicles are assumed to engage in two trips per container move at the terminal site, with each trip involving one mile. For estimating emissions, yard vehicles are assumed to generate the same emission per mile as heavy trucks. These conservative assumptions overstate emissions from this source.

For dredging, we use the ratio of emission per million cubic yards dredged given in an in-depth study for the Port of New York and new Jersey (USACE, 2003). These results show that 45 tons of NOx are emitted per million cubic yards dredged. We assume that some 376 metric tons are dredged based on RKJohns (2000). Dredging takes place over two years, with equal volumes dredged each year.

III.C.6. EPA Air Emission Regulations: Rate of Adoption and Compliance

Estimated air emissions from port-related operations will depend upon implementation of, and compliance with, EPA regulations on emissions. Given the importance of this issue, these regulations and the assumptions used in arriving at our estimates are spelled out in some detail.

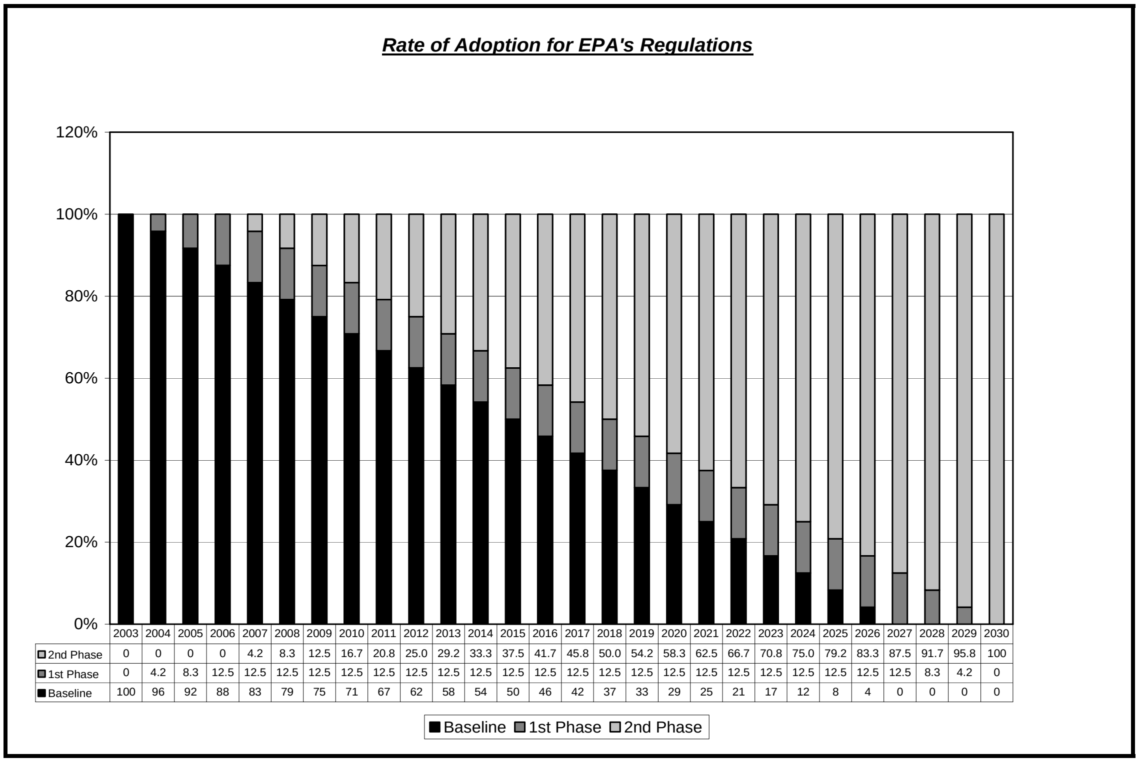
EPA regulations on emissions from heavy-duty diesel trucks will be implemented in two phases. According to the EPA, Phase I starts in 2004, and as a result emissions per mile are anticipated to decrease by 40 percent. Stricter, Phase II regulations are to take effect in 2006 - 2007, leading to another 90 percent reduction in per mile emissions. According to the EPA, the program (both phases) will be fully implemented by 2030 (USEPA, Office of Transportation and Air Quality, EPA420-F-00-026, July 2000).

Our simulation model assumes operation of a hypothetical port, which starts in 2007 (Grigalunas, Luo and Jung, 2002). Hence, the heavy-duty trucks serving the port will be a mix of today's "vintage", some meeting Phase I standards, and some meeting the more environmentally demanding Phase II standards. The proportion of vehicles meeting each standard will depend upon, in part, the age distribution of the fleet which would serve the port and trucking operators' replacement policy, which in turn depends upon several factors outside the scope of this study[18]. Further complications arise from EPA's offers of incentives, noted above, to encourage upgrading of trucks to reduce emissions (USEPA).

In the face of these many uncertainties, we adopt a pragmatic approach for the phasing in of more restrictive regulations on air emission from trucks. We presume that in any year the fleet has an age-mix of vehicles ranging from brand new to age 20, the maximum life of a heavy-duty truck. In 2003, all trucks are assumed to meet current standards. In each of following years, 4.7 percent of the vehicles leave the fleet and are replaced by an equal number of trucks meeting the air emission standard in effect at that time. This transition from the status quo to the ultimate, full implementation of Phase I and Phase II is illustrated in Figure III.C.2, which shows a steady conversion from today's relatively high polluting vehicles to a much cleaner fleet over time. By 2030, all trucks meet EPA's Phase I and II standards. Again, full compliance with appropriate EPA air emission regulations is assumed.

[18] Planned optimal replacement involves a comparison of the annualized cost of different vehicles with different capital and operating cost (a more expensive truck may last longer and have lower operating costs than a less costly vehicle). Once in operation (that is, "at the margin") an operator will compare the operating cost for running a truck for another period with the estimated annualized cost of a new vehicle for the same period.

FIGURE III.C.2. Rate of Adoption for EPA's Air Emission Regulations on Heavy-Duty Trucks.



III.C.7. Results

Key results for the Without Port case are given in Tables III.C.3 – Tables III.C.7 The baseline emissions for Washington County and, for the State as a whole, show that emissions of CO are the largest category for the pollutants considered, followed by NOx (Table III.C.3). Baseline emissions are for the latest year available, 1999. For comparative purposes, vehicles responsible for baseline emissions are assumed to adopt the EPA regulations explained above.

TABLE III.C.3. Total Yearly ("Baseline") Emissions in Metric Tons from On-road and Off-road Mobile Sources for Washington County and Rhode Island as of 1999

			****	**Year**	****	
	Pollutant	*1*	*5*	*10*	*15*	*20*
Washington County	*HC*	3,110	3,093	3,075	3,058	3,041
	CO	17,704	17,564	17,423	17,283	17,142
	NOx	4,122	3,849	3,577	3,304	3,031
Rhode Island	*HC*	24,226	24,092	23,957	23,823	23,689
	CO	235,877	234,727	233,577	232,428	231,278
	NOx	33,539	31,867	30,194	28,521	26,848

Source: USEPA, Office of Air and Radiation
[a] For comparability with port emission cases, 1999 emissions were adjusted downward to reflect implementation of EPA regulations

Next, the Base Case port development results are provided for the three pollutants studied. Results are given for Washington County and for the State of Rhode Island as a whole.

Note that the Base Case results capture the emissions from all port-related sources, less the emissions for alternative use of the 200 acres of Quonset land "earmarked" for port development -- that is, we show incremental emissions. Recall, the port development case assumes the use of 30 percent truck and 70 percent train for deliveries of containers to and from the port, a 5.4 % growth rate, and other assumptions given above (Table II.D.1).

TABLE III.C.4. Emission of Key Pollutants in Metric Tons from Use of 200 Acres of Port Land for Non-Port Use(s), Selected Years for Washington County and Rhode Island ("Without-Port Case")

			****	**Year**	****	
	Pollutant	*1*	*5*	*10*	*15*	*20*
Washington County	*HC*	0.37	0.30	0.22	0.14	0.07
	CO	1.96	1.56	1.16	0.75	0.35
	NOx	1.99	1.58	1.17	0.76	0.35
Rhode Island	*HC*	0.86	0.68	0.51	0.33	0.15
	CO	4.69	3.73	2.76	1.80	0.84
	NOx	7.72	6.13	4.55	2.96	1.37

TABLE III.C.5. *Incremental* Emissions of Key Pollutants in Metric Tons for Hypothetical Port, Selected Years, Assuming Implementation of EPA Regulations on Heavy Trucks and Use of 30 % Truck - 70 % Rail to Move Containers[a]

			****	**Year**	****	
	Pollutant	*1*	*5*	*10*	*15*	*20*
Washington County	*HC*	4.54	4.74	4.99	4.90	4.22
	CO	22.34	22.93	23.52	22.01	17.10
	NOx	45.61	51.73	61.09	71.01	81.02
Rhode Island	*HC*	9.37	9.66	9.98	9.44	7.52
	CO	48.31	49.15	49.70	45.21	32.68
	NOx	107.91	116.40	128.60	136.10	135.10

[a]Estimates reflect "with-port" emissions minus emissions for "without port" use of land.

TABLE III.C.6. Percentage Increase from Washington County and Rhode Island Baseline Emissions of Key Pollutants for Hypothetical Port, Selected Years, Assuming Implementation of EPA Regulations on Heavy Trucks and Use of 30 % Truck - 70 % Rail to Move Containers[a]

			****	**Year**	****	
	Pollutant	*1*	*5*	*10*	*15*	*20*
Washington County	*HC*	0.15	0.15	0.16	0.16	0.14
	CO	0.13	0.13	0.14	0.13	0.10
	NOx	1.11	1.34	1.71	2.15	2.67
Rhode Island	*HC*	0.04	0.04	0.04	0.04	0.03
	CO	0.02	0.02	0.02	0.02	0.01
	NOx	0.32	0.37	0.43	0.48	0.50

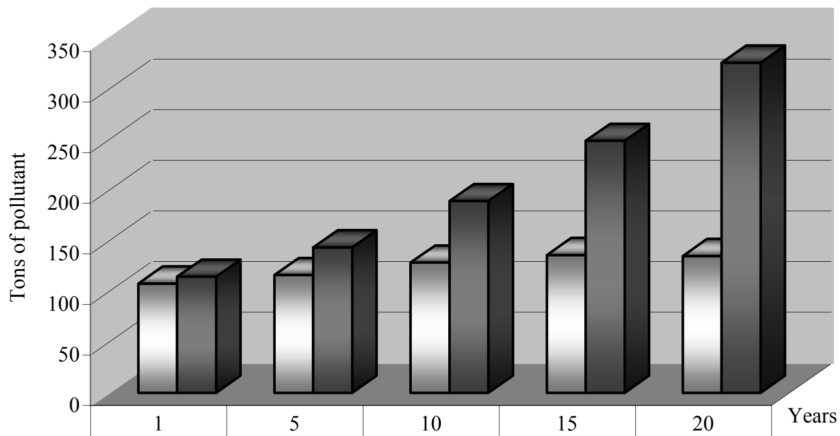
TABLE III.C.7. Incremental Emissions from Each Source in Metric Tons for Base Case Hypothetical Port Development for Selected Years in Rhode Island

		****		Year		****
		1	**5**	**10**	**15**	**20**
Truck	*HC*	9.86	12.17	15.83	20.59	26.78
	CO	54.20	66.89	87.01	113.18	147.22
	NOx	87.16	107.57	139.92	182.01	236.75
Train	*HC*	0.53	0.65	0.85	1.11	1.44
	CO	1.41	1.74	2.26	2.95	3.83
	NOx	14.32	17.67	22.99	29.90	38.90
Dock vehicles	*HC*	0.04	0.05	0.06	0.07	0.08
	CO	0.08	0.11	0.14	0.16	0.19
	NOx	0.06	0.08	0.10	0.11	0.13
Marine vessels	*HC*	0.66	0.82	1.07	1.39	1.80
	CO	2.05	2.53	3.29	4.28	5.57
	NOx	21.71	26.80	34.86	45.34	58.98
Total	*HC*	10.15	12.75	16.86	22.21	29.17
	CO	52.60	66.13	87.56	115.43	151.68
	NOx	114.79	143.65	189.40	248.91	326.30

The key results for the port development Base Case can be summarized as follows:

- With port development, the largest single pollutant is $NO_{x.}$ The port increases NOx emissions from 114.79 metric tons in year 1 to 326.30 metric tons in year 20. CO is the second largest emission (Table III.C.7).
- For the *state as a whole*, emissions of NOx from the hypothetical port development are a very small addition to total Without Port emissions: less than a 0.4 *percent* (that is, 0.004) increase for the initial year and less than 0.6 percent for year 20 (Table III.C.6).
- For *Washington County*, emissions of NOx represent a 2.6 % increase for year 20. Emissions of other pollutants are less (Table III.C.5).
- As for sources, trucks by far generate the most emissions, contributing about two thirds of all emissions (Table III.C.7).

FIGURE III.C.3. Changes in Emissions of NOx influenced by EPA Regulation for Heavy Duty Vehicles for Rhode Island.

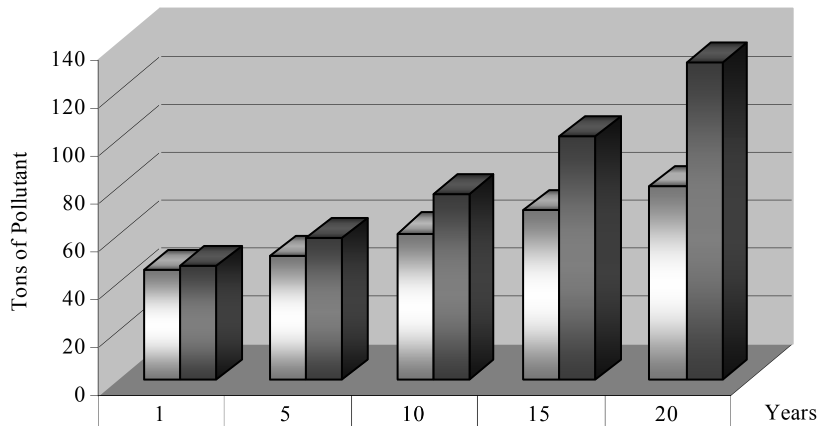


	1	5	10	15	20
NOx with implementation	107.91	116.40	128.60	136.10	135.10
NOx without implementation	114.79	143.65	189.40	248.91	326.30

III.C.8. Perspective on the External Costs from Air Emissions

Information in the recent literature provides some insight into the magnitude of potential damages from air emissions considered in this paper. A survey by Burtaw, et al. (2003) of several studies of NO_X and CO emissions from electrical utility plants suggests marginal damages to health of NO_X of around \$800 per ton. However, the Burtaw, et al. survey applies to stationary sources, is for health effects only, and overall is not well suited to reflect the mobile, ground-level sources examined in the research reported on in this paper.

FIGURE III.C.4. Changes in Emissions of NOx influenced by EPA Regulation for Heavy Duty Vehicles for Washington County.



	1	5	10	15	20
NOx with implementation	45.61	51.73	61.09	71.01	81.02
NOx without implementation	47.48	59.11	77.54	101.50	132.67

A recent summary of the air pollution damages literature by the Office of Management and Budget (Federal Reg., 2003) is more appropriate for our purposes. It contains results for mobile sources, which are close to the ground and do not disperse and dilute as readily as stationary sources, such as used by the utilities considered in Burtaw et al., which tend to use tall smokestacks. Further, the OMB review specifically included the benefits and costs of federal regulations on emissions from trucks under the phased implementation of EPA regulations discussed above. In keeping with the goal of overstating costs when possible, the OMB's inclusive[19], high estimate of damages per metric ton of emission is $5,618 (in year 2002 dollars) is employed to provide perspective on potential damages from port-related air emissions[20].

Now, potential air pollution damages from the case study container hub port can be put into perspective. First, we describe air pollution damages from dredging activity alone, which are common to all of the port development cases assessed. Then, we show the total damages from dredging plus damages from port operations for the base case and the sensitivity analyses for a 20-year port operating period. For discounting annual damages, a rate of 5.875% is used, the rate applicable for port projects while this research was being done.

Damages from air pollution from dredging alone amount to $1.73 million (Table III.C.8). Base case air pollution damages for dredging *and* port operations combined amount to $7.98 million for Rhode Island as a whole (Table III.C.9). Of these damages, Washington County

[19] The OMB results for damages include the effects of PM for which NO_x is a precursor.
[20] The major environmental costs in the EPA analysis were for premature mortality. Use of a constant damage implies a linear dose-response function for pollution and harmful effects.

residents bear over half of the damages ($3.81 million), assuming the same damages per ton as for the state as a whole.

TABLE III.C.8. Present Value of Damages for NOx from Dredging Activities (in 2002 dollars)

Damages/ Ton of Poll.		NO_x Emissions [c, d] (tons)	PV of Damages [b]	Total PV
$5,618[a]	Year 1	188.33	$891,476	$1,733,483
	Year 2	188.33	$842,008	

a. Source: Federal Register, Vol.68, No.22, Feb.3, 2003
b. Discount Rate = 5 7/8% (Source: USACE)
c. Total Quantity Dredged = 8.37 MCY (Source: RKJ & Associates Report, 2000)
d. 45Tons of Pollutant/MCY (Source: Deepening Project, April 2003, US Army Corps of Engineers – New York District, http://www.nan.usace.army.mil/harbor/pdf/industry.pdf

TABLE III.C.9. Present Value of Damages for NO_x Emissions from Dredging and Operations: Base Case (30%Truck-70%Train) EPA Regulation Implemented (in 2002 dollars)

Damages/ Ton of Poll.	Area	Dredging	Operations – Base Case	Total PV
$5,618[a]	Rhode Island	$1,733,483	$6,244,896	**$7,978,379**
	Washington County	$866,742	$2,942,334	**$3,809,076**

a. Source: Federal Register, Vol.68, No.22, Feb.3, 2003

III.C.9 Sensitivity Analyses

Here incremental port-related air pollution and the resulting damages are estimated for several cases using assumption, which differ from those in the Base Case results. For emissions we show the worst case, which assumes:

- Trucks move 50% rather than the 30% of containers estimated in the Base Case,
- EPA Phase I and Phase II air pollution regulations on heavy-duty trucks are *not* implemented, and
- A combined case Trucks move 50% of containers *and* EPA regulations on trucks are not implemented (the "Worst Case")

The sensitivity analyses show that:

- increasing the use of trucks from 30% to 50% of all container moves has a small percent increase in the air emissions studied.
- failure to implement the Phase I and II EPA regulations of emissions from heavy duty trucks has a more serious effect on the growth of emissions.
- the worst case considered -- where Phase I and II EPA regulations on emissions are not implemented *and* trucks are used to move 50% of containers – has the most serious consequences for air pollution. In this case, year 20 Washington County emissions exceed baseline levels by 3.26% and RI emissions increase by 1.27%. As mentioned earlier, this case is considered most unlikely.

TABLE III.C.10. Sensitivity Analysis: Percentage Increase of Key Pollutants over Washington County and Rhode Island Baseline Emissions for Hypothetical Port, Selected Years, Assuming EPA Regulations on Heavy Trucks are *Not* Implemented and 50 % Truck - 50 % Rail Used to Move Containers

		****		Year		****
	Pollutant	*1*	*5*	*10*	*15*	*20*
Washington County	*HC*	0.25	0.31	0.40	0.52	0.67
	CO	0.23	0.28	0.36	0.47	0.61
	NOx	1.55	1.79	2.16	2.64	3.26
Rhode Island	*HC*	0.07	0.08	0.11	0.14	0.19
	CO	0.04	0.05	0.06	0.08	0.10
	NOx	0.49	0.60	0.77	0.99	1.27

Sensitivity analyses for air pollution damages are given in Table III.C.11. Damages range from the Base Case results described above, \$3.8 million for Washington County to \$7.9 million for Rhode Island, to the "worst case" damages, for which damages are \$14.8 million at the state level and \$5.9 million for the County. The biggest change in damages occurs if the EPA's does not implement phased air emission control on heavy duty trucks. Clearly, full implementation of, and compliance with the regulations is important for controlling emissions from the proposed port development.

TABLE III.C.11. Present Value of Damages (in 2002 dollars) for NO_x from Dredging and Mobile Source Activities for Base Case and All Sensitivity Analyses [b,c]

		*** Cases Considered ***			
Damage/ Ton of Poll.		**30-70 EPA's Reg. Implemented (Base Case)**	**30-70 EPA's Reg. Not Implemented**	**50-50 EPA's Reg. Implemented**	**50-50 EPA's Reg. Not Implemented**
5,618 [a]	Rhode Island	7,978,379	10,743,531	10,161,904	14,873,724
	Washington County	3,809,076	4,556,790	4,696,900	5,969,692

a. Source: Federal Register, Vol.68, No.22, Feb.3, 2003
b. Discount Rate = 5 7/8% (Source: USACE)
c. Dredging takes place over 2-year period; operations over a 20-year period beginning in year 7.
d. Air pollution costs are allocated 50% Washington County, 50% rest of RI

In addition to damages from total incremental emissions, the marginal damages per mile are of interest for some purposes, such as assessments of the full social costs of transport modes. The above results allow us to estimate, for example, the shadow price of truck road use per mile for air pollution. This value is given by:

$$\frac{\partial D}{\partial M} = \frac{\partial D}{\partial E} \times \frac{\partial E}{\partial M}$$

where D is damages, M miles, and E emissions per mile. Assuming trucks travel 50 miles per hour, and using the emission factors in Table 4, the cost per mile ranges from \$ 0.0023 in the base case considered to \$0.0584 per mile for the (unlikely) case where air pollution control regulations considered in this report are not implemented.

III.D. Summary and Conclusions

Air pollution, especially ozone, remains a concern in RI and the Northeast. Port container development generates considerable vessel and off road port traffic for the specific proposed location (Quonset Point) as well as truck traffic for other nearby major routes. Port-related transportation, especially trucks, generates NOx (a precursor of ozone) as well as CO and HC. An important issue is whether the increase in traffic would substantially degrade air quality, and by that imposed substantial external costs through potentially restricting outdoor activities, harming human health, and causing environmental damages to property and materials.

Given the large scale of the multimodal container port development case considered, we had expected a reasonably large percent increase for Washington County and for the State of Rhode Island as a whole in annual emissions for NO_x, CO and HC. These pollutants are considered by the USEPA, Region 01 (New England) as being the most important for mobile sources powered by heavy-duty diesel engines. The results, however, suggest that Base Case container port development would cause only a small percent increase in the total annual emissions for these three pollutants over baseline levels.

These results are especially noteworthy in light of the fact that EPA recently has proposed new restrictions on emissions from *off road* vehicles (New York Times, 2003). Implementation of these regulations would apply to yard-horses and, hence, further decrease air emission problems at a port. Also, our research did not consider the fact that containers moving through a port at Quonset would substitute for container moves by truck into and through the state from the Port of New York and New Jersey and perhaps other ports[21]. Therefore our results overstate the net emissions (Net emissions taking into account regional port developments are being addressed in planned future research).

Notwithstanding the findings of modest air pollution increases given above, local problems could conceivably occur, particularly if vulnerable populations are exposed to concentrated emissions. Also, particulate matter has not been included because it was not part of the EPA Mobile5b model results relied upon in this study. This could be an important omission, and particulates should be addressed in further research.

For potential externalities from air pollution, annual incremental emissions for key pollutants were estimated for trucks, trains, yard vehicles and vessels. To do this, emission coefficients were used for NO_x, CO, and HC. Emissions from heavy duty trucks, the largest pollution source by far, were estimated using the (1) least-cost truck-train split of 30% truck and 70% train, (2) least-cost road and train routes, (3) speeds traveled, and (4) annual number of trips. A 5.4% annual growth in port demand was included, and phasing in of EPA regulations on air emissions for heavy duty trucks was assumed. Benefit-transfer was used to translate metric tons of emissions into damages for Washington County and for the State of Rhode Island as a whole.

Despite the use of assumptions that overstate costs, we must acknowledge that several constraints on the analysis unavoidably understate the cost estimates. For example, our illustration of external costs of air emissions from the port uses a 20-year operating period, because assessments of externalities beyond 2028 seemed problematic, given available data. Hence, air pollution costs incurred after 20 years of operations were not considered. Also, air pollution damages from truck emissions beyond Rhode Island borders were not considered, which also understates total emission and the associated external costs to society.

[21] We address this and other regional issues in ongoing research, with special attention to the regional container distribution system being initiated by the Port of New York and New Jersey.

Finally, we should note that our results would likely not apply to ports in other countries which do not have strict environmental controls. For example, US regulations of air emissions have substantially curtailed air pollution from heavy trucks, and regulations being phased in will essentially drive these emissions to near-zero levels. Also, lead is no longer emitted from mobile sources. Other countries may not have such restrictive regulations. Hence, the total emissions and their composition per TEU may be substantially greater in such cases.

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IV. PERSPECTIVE ON EXTERNAL COSTS FROM NOISE

IV.A. Introduction

This chapter examines potential noise externalities associated with port development. Specifically, we estimate potential damages to residents exposed to incremental noise along the main port connector road (also referred to as Route 403 or Davisville Rd.). To do this, we estimate, in sequence: (1) the incremental noise due to added traffic from port-related development and (2) damages from the incremental noise by using benefit transfer of the results from a hedonic price equation by Kwon (2003) (see Appendix for details).

Two potential public noise mitigation measures also are analyzed: construction of roadside noise barriers, and reduction in truck speed. Construction of road barriers diminishes exposure to noise along roads and, hence, reduces damages. The effectiveness and cost of this action will depend upon the configuration (height, length and location) of the barrier, and the type of material used, among other factors. As for speed, truck noise decreases with speed, and hence noise damages and their mitigation through improved enforcement of speed limits is an option for consideration. Other aspects of speed (time saved or lost, or effects of speed on accidents) in principle are relevant, but are not addressed in this report.

IV.B. Propagation of Noise Externalities

Here we explain the methods, data and assumptions used to estimate baseline noise and noise due to port-related traffic. These represent the first step for estimating potential external costs and constitute the important "non-economic foundations' of our economic assessment of the external costs attributable to additional traffic by heavy-duty trucks (Freeman, 2003).

IV.B.1 Baseline Traffic (The "Without-Port" Case)

The "baseline" or the without-port noise has two parts: (1) traffic from the port complex having nothing to do with the container port and which will occur whether or not there is a port, plus (2) traffic from alternative uses of the 200 acres of land "earmarked" for a container port. Traffic in (1) and (2) must be considered because noise is a non-linear function of traffic, as we show later in this chapter.

Traffic into and out of the Quonset Point facility amounts to some 16,500 vehicles per day (RI Economic Development Corporation (RIEDC)- Master Plan). Some 92 % of this traffic is automobiles; only 2% is comprised of heavy trucks. The 16,500 vehicles per day is equivalent to 1,375 vehicles per hour for a 12-hour day for the facility (Table IV.B.1.1).

With no container port, the 200 acres "earmarked" by the RIDEC for port use will be used for other activities. Lacking specific information, we assume that the alternative use(s) of the 200 acres generates the *same* level and composition of traffic *per acre* of land as occurs at Quonset Point-Davisville. The hourly traffic of 1,375 vehicles given above implies 1.72 trips per acre per hour[22] for the 800 acres used at Quonset – Davisville as reported in the Master Plan.

[22] We recognize that use of the average understates the peak-period, hourly traffic and overstates off-peak hourly traffic.

Thus, the 200 acres would generate 344 [=(1375/800)*200)/12] vehicle trips per hour. This level of traffic is assumed to occur each year over the entire 20-year study period. The assumption of constant-per-hour traffic, as opposed to allowing for likely traffic increases, overstates the estimates of noise attributable to incremental road traffic used in our calculations below.

To sum up, the without port traffic case is 1,719 (= 1,375 + 344) vehicles per hour. This is the number we compare with traffic from a hypothetical container port.

TABLE IV.B.1. Baseline Traffic on Davisville Road by Vehicle Type

Vehicle Type	Traffic Volume per Day[a] (TVPD)	Traffic Volume per Hour[b] (TVPH)	Percent
Automobiles	15180	1265.0	98
Medium Truck	990	82.5	6
Heavy Truck	330	27.5	2
Total	***16500***	***1375.0***	

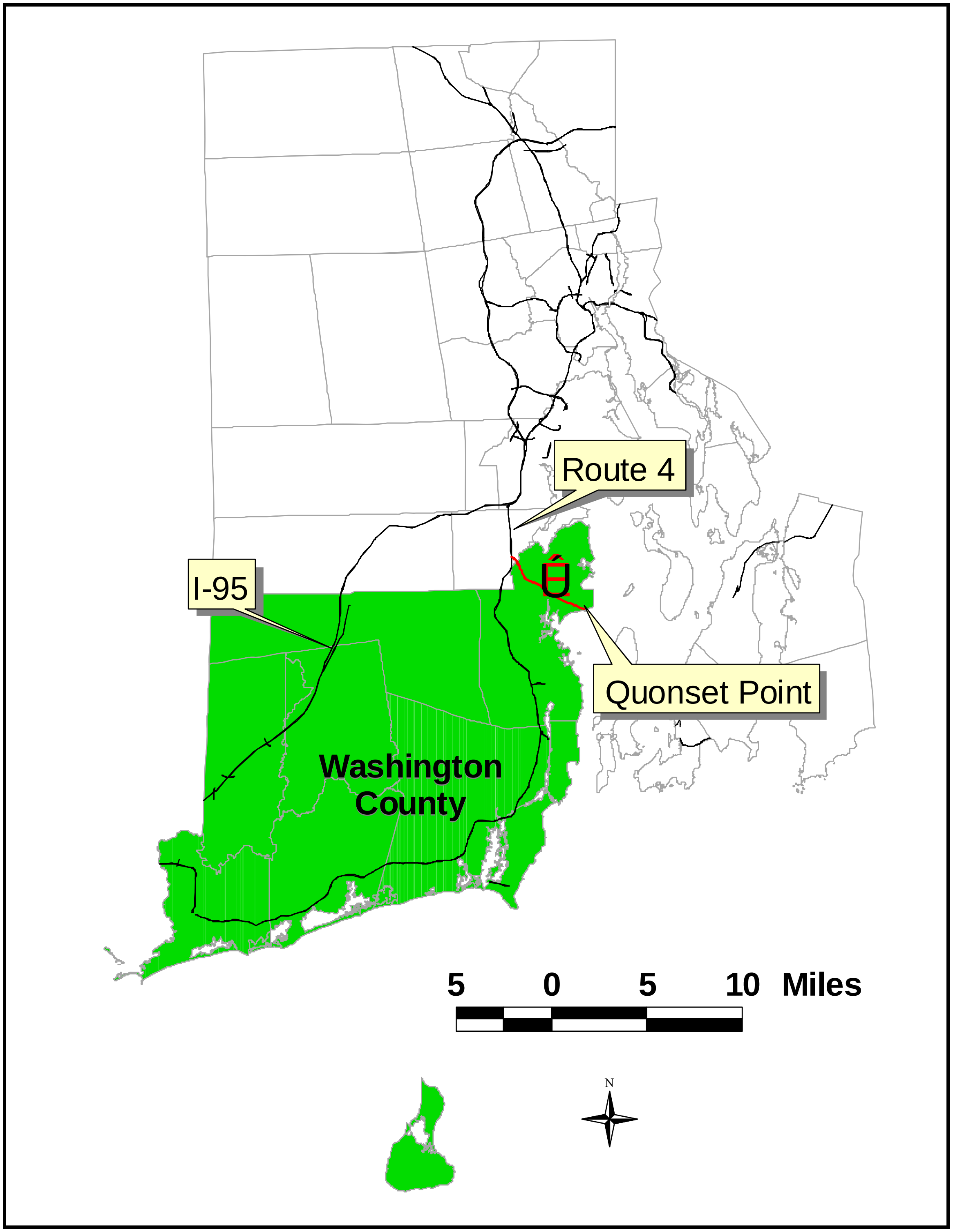
Source: 2000 Traffic Flow Map (based on 1999) and 1998 Truck Flow Map (based on 1997), RIDOT.
a: Traffic volumes by vehicle types are calculated by using given total number (16,500) and percentage of medium truck (6%) and heavy trucks (2%).
b: TVPH = TVPD/12

IV.B.2. Traffic Due to the Hypothetical Port

Least-cost routing of port traffic modeled in Luo (2002) and presented in Luo, Grigalunas and Jung (2003) shows that (1) 30% of containers will move by road and 70 % by train and (2) most truck traffic will use the connector road. In order to highlight the potential for noise effects, *all* road traffic to and from the port is presumed to use the connector road (see Figure IV.B.21).

We do not estimate external costs from noise occurring along roads (Rt. 4 and Interstate 95) served by the connector road. This is somewhat counterfactual, as noted, but justified on the basis that the port will constitute an important part of traffic on the connector road, but only a small share of overall traffic on Route 4 and a tiny fraction of all traffic on Interstate Route 95. Further, residential housing (which is most a risk to noise) generally is not as exposed to traffic along Routes 4 and 95 as compared with the Route 403 connector, so that the potential for noise externalities on residential unit seems much less significant for routes other Route 403.

FIGURE III.A.2. Rhode Island Map.



In sum, we focus our efforts on residential housing along the connector road and assume that all trucks use this road. Our approach clearly works to overstate incremental noise on the connector road, but reflects overall off-port road use.

Using the estimates for hourly vehicular traffic without and with the port, hourly noise exposure can be estimated. This is taken up next.

IV.B.3. Estimating Noise for Baseline and Port Traffic

Noise is estimated using the Federal Highway Administration (1999) road noise model. Given the estimated hourly traffic, and other determinants of noise, such as speed, slope, and road hardness, estimates of noise at different distances from the road are made for the main port connector road (Kwon, 2003).

For this analysis, three aspects of traffic are considered: current traffic, traffic due to alternative use(s) of the port land, and traffic resulting from port development. In applying the road noise model for this case, speed was set at the average speed limit on Route 403 connector of 25 mph, but actual speeds range from 30 mph to 45 mph (North Kingstown Police). To reflect the actual (versus posted speed limit) 37.5 miles per hour is used in our calculations. We also assume a hard surface and no slope (see Kwon (2003) for details).

TABLE IV.B.2. Average Hourly Traffic on Davisville Connector Road by Vehicle Types – Baseline (or Without-Port) Case

Vehicle Type	(A) Current Traffic*	(B) Alternative Use of Planned Port Land **	(A + B) Baseline (or Without Port) Case***
Automobile	1265.0	316.3	1581.3
Medium Truck	82.5	20.6	103.1
Heavy Truck	27.5	6.9	34.4
Total	*1375.0*	*343.8*	*1718.8*

*2001 Master Plan, RIDEC and QDMC. Traffic is as of 1999.
** Traffic volume due to alternative use(s) of 200 acres earmarked for port. See text for assumptions used.

Using the information described immediately above, estimates were made of potential noise along the connector road. Table IV.B.3 and Figure IV.B.2 illustrate some key aspects of the noise results.

Two results are noteworthy. First, noise diminishes only slightly with distance from the road, over the range of distances considered. Noise ranges from 70 dB at 20m from the road center to 64 dB at 120m (Table IV.B.3.2 and Figure IV.B.3.1). Hence, noise diminishes somewhat with distance, but not proportionately. For the same level of traffic, a 100% increase in distance from 30m to 60m leads to a decline in noise of only 4%. These results do not include the mitigating effects of construction of any noise barrier. Second, incremental noise from additional trucking is small – less than a 5 % increase over the without-port conditions. These results will become important when we discuss the benefits and costs of noise mitigation later in this chapter.

TABLE IV.B.3. Baseline (Without-Port) Estimated Traffic Noise on Davisville Road

Vehicle Type (Volume/hour)	Noise Levels[a] (dB) by Distance from Road[b]			
	30m	60m	90m	120m
Automobile (1,898) Medium Truck (124) Heavy Truck (41)	70.4	67.5	65.5	64.0

[a] Existing traffic noise levels was calculated by using FHWA TNM (1999) using baseline (without port) traffic reported above in Table IV.B.3.1.
[b] Distance is measure between center of the road and a receiver point at the indicated distance.

Earlier, it was assumed that traffic through the port would increase at an average rate of 5.4% over time, based on a survey of national container growth potential (see Table II.D.1). Higher noise levels are expected as traffic increases, all else being the same. Using the estimated annual growth in truck trips, estimates are made of noise propagation in selected years at a reference distance from the road, 30 meters (Table IV.B.3.3). These results show that noise increases noticeably in year one of port operation and, thereafter grows slowly as truck traffic grows at 5.4%.

FIGURE IV.B.1. Estimated Noise Level on Davisville RD by Distance (Year 1 of Port Operation)

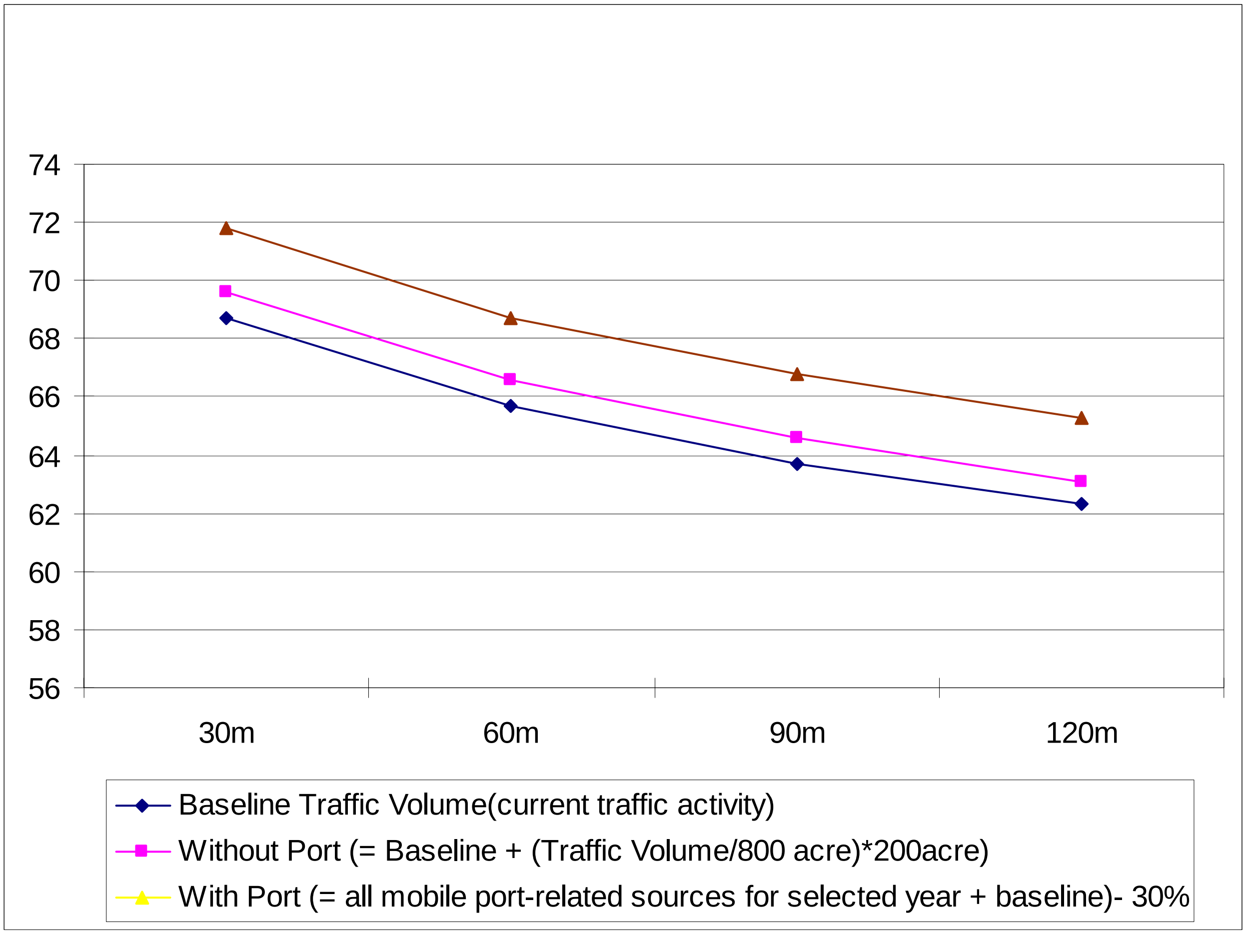


TABLE IV.B.4. Incremental Hourly Heavy Truck Volume on Davisville Road Due to Container Port Development for 30% and 50% Cases, Selected Years

Year	1	5	10	15	20
Hourly Heavy Truck Volume - 30 % of Containers Moved	554	684	889	1,157	1,505
Hourly Heavy Truck Volume - 50% of Containers Moved	923	1,139	1,482	1,928	2,508

Source: [a] Grigalunas, Luo and Jung (2003)
[b] The port is assumed to operate 8 hours per day.

IV.C. Exposure of Residential Property to Noise

Given the estimates of noise propagation and dispersion made above, next we estimate exposure of residential units along the connector road. Figure IV.B.2 and Table IV.B.5 shows the location of single-family homes along the connector road.[23] As indicated, homes tended to be dispersed along sections of the road in clusters and homes vary considerably in their distance from the road. These factors are important for assessing exposure, damages and the efficacy of noise mitigation, as we explain below.

The data show that 101 residential structures with an estimated value (in year 2000) of $13.2 million could be affected by noise in varying degrees, depending upon the level of noise generated and how far the structures are from the road (i.e., what "tier" they are in). Two-thirds of the residential structures are located along the North side of the road (Table IV.C.1). Of the 101 structures along the road, 31 structures worth $2.86 million are situated in tier 1 (Table IV.D.1).

IV.D. Damages

A "hybrid" model is used to estimate damages along the connector road. The methods used to estimate noise propagation and its diffusion over space are described above. Estimates have been made of incremental noise from additional traffic under a variety of assumptions, as explained below. Given these estimates of noise, estimates of the potential loss of property values were based on the use of a hedonic property model applied to TF Green Airport in Warwick RI (see Appendix for details). The estimated coefficient on noise from this study was used as a form of benefit transfer in order to estimate the potential external costs of noise from incremental port-related truck traffic along the Route 403 connector road. In sum, we estimate noise exposure over space and then convert this to damages, as explained below.

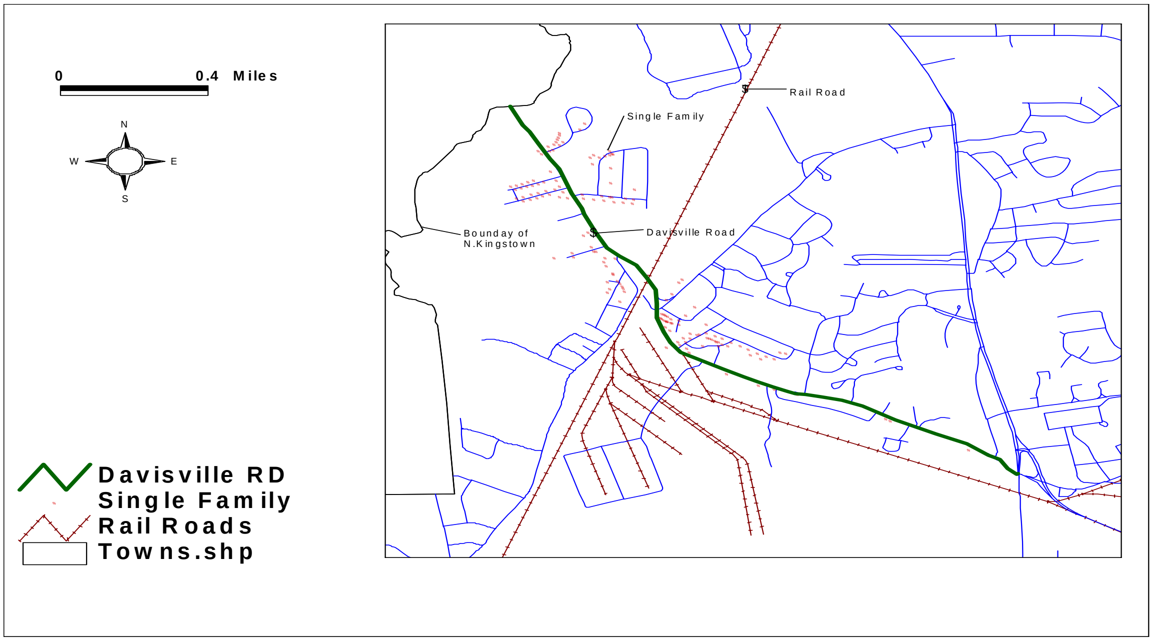
[23] Multiple family units are not considered because such units were not included in the hedonic data set used to estimate the effects of noise on property values. This means damages are understated a point we return to later in this chapter.

TABLE IV.C.1. Residential Housing along the Connector Road by Section and Tier

Section [a)]	Tiers	Houses [b)]	Assessed Property Values [c)] (Year 2000)	Note
N1	Tier 1 (30m)	5	$ 535,700	Low-density residential area.
	Tier 2 (60m)	0	0	
	Tier 3 (90m)	0	0	
	Tier 4 (120m)	0	0	
	Total	*5*	*$ 535,700*	
N2	Tier 1 (30m)	10	$ 1,189,200	High-density residential area.
	Tier 2 (60m)	5	597,000	
	Tier 3 (90m)	8	1,031,000	
	Tier 4 (120m)	17	2,271,700	
	Total	*40*	*$ 5,088,900*	
N3	Tier 1 (30m)	1	132,000	Low-density residential area.
	Tier 2 (60m)	1	208,700	
	Tier 3(90m)	0	0	
	Tier 4(120m)	0	0	
	Total	*2*	*$ 340,700*	
N4	Tier 1 (30m)	6	1,000,100	High-density residential area.
	Tier 2 (60m)	3	480,300	
	Tier 3(90m)	4	728,900	
	Tier 4(120m)	8	1,599,700	
	Total	*21*	*$ 3,809,000*	
N5	Tiers	0	0	Undeveloped area.
S1	Tiers	0	0	Undeveloped area.
S2	Tier 1 (30m)	12	1,161,500	Low-density residential area.
	Tier 2 (60m)	7	742,400	
	Tier 3(90m)	9	936,800	
	Tier 4(120m)	5	600,200	
	Total	*33*	*$ 3,440,900*	
S3	Tiers	0	0	Undeveloped area.
Grand Total		**101**	**$ 13,215,200**	

To estimates damages, data on residential property along the connector road was assembled (Figure IV.D.1). Then, the connector road was divided into sections along the North (N) and South (S) parts of the road (Figure IV.D.2 and Table IV.D.1), based on a review of the pattern of development along the road (Figure IV.D.1). Then, for each N-S section, residential units were placed into four, equidistant tiers (N1 to N4; S1 to S4). Tiers are distinguished by their distance in meters from the road, with Tier 1 nearest to the road (30-60 m) and Tier 4 farthest away (120 m). As displayed in Figure IV.B.1, noise decreases continuously with distance. Within each tier, property is presumed to be exposed to the estimated average noise level for that tier[24].

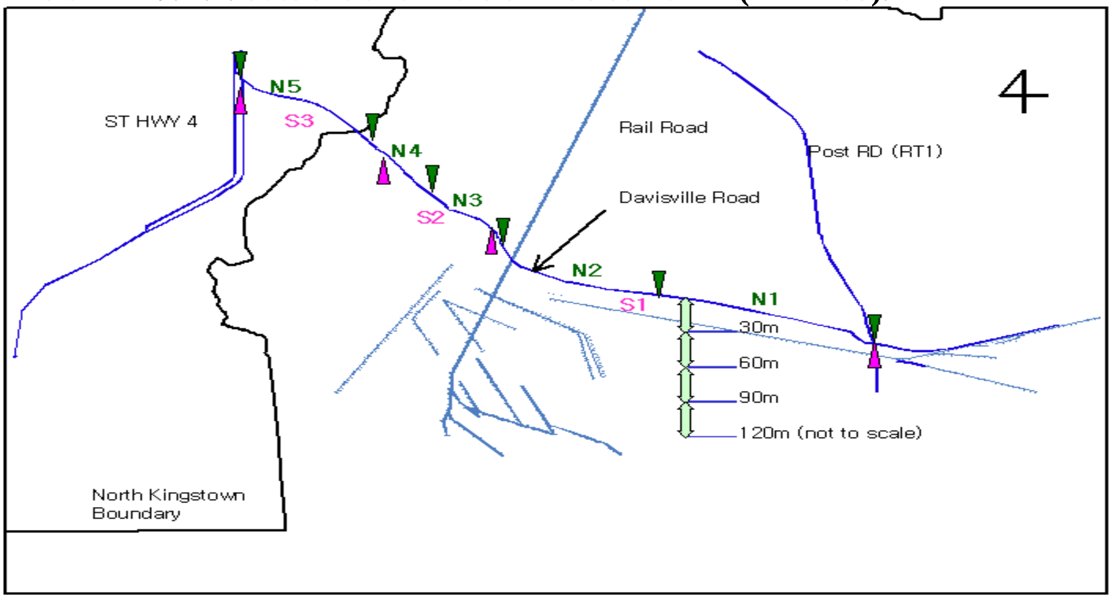
FIGURE IV.D.1. Single Family Homes Adjacent to Davisville RD (RTE 403).



Source: Town Hall of North Kingstown

[24] For example, residential properties in tier 2 are assumed to be exposed to the noise level estimated for a distance of 75 meters from the road, which is the average distance of the boundaries for tier 1 and tier 2.

FIGURE IV.D.2. Sections and Tiers on Davisville RD (RTE 403).



Here we focus on noise damages along segments and across tiers of the connector road due to the additional estimated hourly port-related traffic. Thus, for all section s and tiers t we first need to estimate how incremental increase in traffic, TR due to the port affects noise for each tier, and then how noise effects the value of property. For section s and tier t we have:

$$\frac{\partial D_{st}}{\partial TR} = \left(\frac{\partial D_{st}}{\partial N_{st}}\right) * \left(\frac{\partial N_{st}}{\partial TR}\right) \qquad (1)$$

Then, for total damages due to noise from incremental truck traffic due to port activity, TR, we must sum (1) across all s = 1,2, ..S sections and t =1,2,..T tiers for total damages, which gives the monetary value of the "public bad" created by the added noise:

$$\sum_{t}^{Teir} \sum_{s}^{S} \frac{\partial D_{st}}{\partial TR} \qquad (2)$$

Using a hedonic property value model developed as part of this research, Kwon (2003) finds that the value of a property changes by the expression \$5000 (ln(dB)) where dB is aircraft noise at Green Airport in Warwick, RI, all else equal (see Appendix). For this illustration, we use benefit transfer and take Kwon's results from Green Airport and apply them to noise along the connector road serving the hypothetical port, as noted.

Hedonic analysis is typically applied for environmental issues, which differs over space or over time and space, that is, localized public goods. Examples of the former are examining the value of open space or noxious odors at a point in time using sales in a single, given period. Examples of use of the hedonic approach over time and space include estimates of before and after property values from discovery of a toxic site, a nuclear reactor accident, or an earthquake (Freeman, 1987; Brookshire *et al*, 1985; Palmquist, 1991).

In hedonic property studies, buyers of homes are assumed to be aware of the existing environmental problem (e.g., air pollution or groundwater contamination) and anticipate the associated future loss in household well being because of this problem. This future loss in monetary terms implicitly is discounted in the market and, as a result, is reflected in the price of homes today. Differences in the price of homes before and after an accident, or differences due to variations in an environmental stressor (e.g., noise, air pollution, odor) over space, allows for a measure of the change in the property's asset value due to anticipated changes in the environmental factor of interest.

In the present case, however, a conceptual issue arises regarding the use of hedonic results for benefit transfer. Here, benefit transfer is being applied using the hedonic results for Green Airport in order to estimate the effects on residential property along the main container port connector road. In this case, we simulate residents' future exposure to noise from trucks hauling containers, and this traffic and resulting noise will increase over time. Hence, the issue arises as to how to properly include, in a simulation, changes in the asset value of homes as noise increases with greater truck traffic using the simulation approach applied in this study?

Below the damages because of future noise are estimated by summing the *annual increment* to damages because traffic and the resultant noise increases over the 20-year study period. We distinguish between the section (S) along the road and tiers (T) away from the road, where each tier is a uniform distance from the road. For road section s and tier t, damages in the time 0, the start of port operation is:

$$D_{st1} = \frac{\partial P}{\partial(dB)} \times [\ln(dB_{WPst1}) - \ln(dB_{WOPst1})] \times Nst_1 \qquad (3)$$

where dB_{WP1} and dB_{WOP1} are the noise in *decibels* in period 1 with the port and without the port (i.e., the baseline), respectively, and N_1 is the number of homes. In year 1, damages in area 1 are:

$$D_{12} = \left[\frac{\partial P}{\partial(dB)} \times \ln(dB_{WP11} - dB_{WOP11}) \times N_1 - D_{11}\right] \times (1+r)^{-1} \qquad (4)$$

and for the final year, T:

$$D_{ST} = \left[\frac{\partial P}{\partial(dB)} \times \ln(dB_{WPST} - dB_{WOPST}) \times N_{ST} - D_{ST}\right] \times (1+r)^{-(T-1)} \qquad (5)$$

Assuming the marginal implicit value of noise remains approximately the same as in Eq. 1 above, (\$5000 * ln(dB)), total damages (in present value terms) is the sum in the following expression over the life of the port project, here 20 years:

$$D_{ij} = \sum_{i=1}^{T} \sum_{j=1}^{S} \left[\frac{\partial P}{\partial(dB)} \times [\ln(dB_{WPij} - dB_{WOPij})] \times N_{ij} - D_{ij}\right] \times (1+r)^{-(i-1)} \qquad (6)$$

Given the earlier estimates of incremental noise from the port (Tables IV.B.4), and using a discount rate of 5 7/8 %, the administratively-set rate used by the US Army Corps of Engineers current federal port projects (O'Leary, 2003) to represent the social rate of discount, damages using (6) are estimated (Table IV.D.1). Alternative results for a 3% discount rate (the rate used in Natural Resource Damage Assessments under the Oil Pollution Act) also are presented.

TABLE IV.D.1. Summary of Present Value of House Damage along Connector Road by Section (N and S) and Tier (1,2,3,4)

Section and Tier	Present Value (2000 US$)	
	3%	5.87%
N1	1,462	1,308
N2	12,365	11,071
N3	591	528
N4	6,463	5,785
N5	0	0
Sub Total	*20,881*	*18,692*
S1	0	0
S2	9,985	8,933
S3	0	0
Sub Total	*9,985*	*8,933*
Grand Total	**30,866**	**27,625**

Estimated damages, which are constituted by the change in the asset value of the residences due to incremental noise, range from $27,625 to $30,866 (in year 2000 dollars), depending upon the used discount rate. About two-thirds of the damages are experienced by residences on the north side of the connector road. Damages are highest in N2, S2, and N4, in that order. We note that considerable undeveloped property along the connector road would be affected, but the ownership and status of these properties is unknown and they are not included in this analysis. Hence, the estimate of damages is understated for this reason.[25]

Following the same methodology, sensitivity analyses were used (Table IV.D.2) to show how damages to property values varies with (1) increases in truck traffic if 50% of moves are by truck (as opposed to 30% in the base case), (2) a higher growth rate of 7.1% (the high-end growth estimate in Grigalunas, Luo and Jung, 2003) in annual container moves 5.4% in the base case, and (3) enforcement of the speed limit of 25 mph rather than 37.5 used in the base case. Using the 5.875% discount rate, across cases damages range from a low of $15,588 for Case 1, the Base Case with a 25 mph speed enforced for trucks, to a high of $43,961 for the Case 5, the "worst case". Again, multi-unit housing and undeveloped properties are not included so that overall potential damages to property are understated.

[25] Roughly one third of the property which might be devoted to residential use is developed. Therefore, if all the property is developable for residential uses, and assuming future development is similar to current property patterns, damages might be three times as high as presented in the text.

TABLE IV.D.2. Present Value of House Damage along Connector Road for Alternative Port-Related Truck Traffic Cases

Alternative Cases	Present Value (2000 US$)	
	3%	*5.87%*
Base Case (Case1): 30% Truck 70% Train, 5.4% Growth, and 37.5 mph	$30,866	$27,625
Case 2: ***50% Truck 50% Train*** 5.4% Growth, and 37.5 mph	42,452	38,717
Case 3: 30% Truck 70% Train, 5.4% Growth, and ***25.0 mph***	19,375	15,588
Case 4: 30% Truck 70% Train, ***7.4% Growth***, and 37.5 mph	37,020	32,358
Case 5: ***50% Truck 50% Train,*** ***7.4 % Growth***, and 37.5 mph	49,237	43,961

IV.E. Optimal Public Mitigation

Public actions to reduce noise may involve constructing fences or berms, installing vegetation, or using noise-reducing pavements, or some combination of measures. Reducing speed also will lower noise. Private actions also may be adopted, such as installing special windows or installation, fencing, or noise buffering trees and bushes.

We note that some noise mitigation approaches necessarily are ‘lumpy” investments. For example, noise dampening pavements must use a large scale, while others actions (berms, vegetative buffers) can involve small (“continuous”) actions. The selection of the most efficient or cost-effective combination of mitigation actions raises important and interesting issues, but resolution of such issues is beyond the scope of this report.

Here, we restrict ourselves to examining the benefits and costs of public mitigation -- construction of noise barriers. Although not used to date in Rhode Island, a common public measure is to use barrier fences along roads to absorb or deflect noise so that for a given level noise propagation, exposure of residents along a section of road is reduced. Several types of barriers can be used (concrete, cement block, wood and other materials), but nationally most fencing is concrete (40%) or cement block (25%) (Table IV.E.1).

Costs are a factor in selection of noise fencing and costs vary with the type of material used and of course the height and length of the barrier. Representative annualized costs of barrier fencing per meter square, adopted from (Kay, 2000) are summarized in Table IV.E.2.

The question becomes: What is the optimal design of mitigation measures for fencing, given the anticipated benefits and costs? The optimal scale occurs where the sum of the benefits is equal to marginal cost, the standard public good solution. Hence, given the level of traffic, speed and all other factors determining the propagation of noise, optimal mitigation for all tiers in a given section s occurs at point N*, where

$$\sum_{t}^{T} \partial Dt/\partial Nt\, \partial Nt/\partial Mt = \partial C/\partial Mt$$

and the use of mitigation can be expected to vary by section of road due to differences in exposure and damages between section.

TABLE IV.E.1. Total Noise Barrier Area by Material Type Used in United States (2000)

Material	Square Meters (Thousands)	Percent of Total Area Used in US
Concrete/Precast	4,292	39.73
Block	2,731	25.28
Wood/Post & Plank	508	4.70
Concrete/Unspecified	456	4.22
Berm Only	344	3.18
Wood/Glue Laminated	294	2.72
Metal/Unspecified	240	2.22
Wood/Unspecified	239	2.21
Absorptive	154	1.43
Brick	94	0.87
Combination*	1,311	12.14
Other	139	1.29
Total	10,802	100.00

Source: Highway Traffic Noise in the United States: Problem and Response, 2000
*Combination Barriers: Berm/Wood, Concrete/Block, Wood/Concrete, Berm/Concrete, Berm/Metal, Metal/Concrete, etc.

Table.IV.E.3 shows how noise changes for different barrier heights, again drawing upon the Federal Highway Administration Traffic Noise Model (FHWA TNM 1.0). The results show that a barrier has diminishing marginal benefits with height and with distance. For example, for the year one results, a 3-meter barrier reduces noise to homes 30 meters from the road by 10.3 dB -- but only by 5.9 dB when the barrier is increased to 6 meters.

TABLE IV .E.2. The Life Cycle Costs of Noise Barriers by Material Type

Barrier	Estimated Service Life	Estimated Initial Construction Cost (Year2000) ($/m², $/ft²)	Discounted Future Costs ($/m², $/ft²)[1]	Estimated Life Cycle Cost ($/m², $/ft²)
Earth Berm	50+	111(10.33)	39(3.60)	150(13.93)
Precast / Prestressed Concrete Stacked Panals, Steel Posts[2]	50	212(19.67)	43(4.03)	255(23.70)
Precast / Prestressed Concrete Stacked Panals, Steel Posts[2]	50	262(24.33)	28(2.62)	290(26.95)
Timber Post-And Panel (Hardwood or Softwood)	25	180(16.70)	122(11.35)	302(28.05)
Precast / Restressed Cantilever	50	291(27.00)	30(2.80)	321(29.80)
Carsonite ®	50	273(25.33)	50(4.65)	323(29.98)
Precast Concrete, Full-height Panels, Monolithic Posts	50	305(28.33)	28(2.62)	333(30.95)
Glue-laminated wood	25	197(18.33)	145(13.48)	342(31.81)
Durisol ®	25	212(19.67)	152(14.14)	364(33.81)
Noishield ® Steel	25[3]	298(27.67)	131(12.19)	429(39.86)
Noishield ® Aluiminum	25	377(35.00)	163(15.15)	540(50.15)

1. $PW = ICC + \sum_{k=1}^{n} FC\left(1/(1+i)^n\right)$, where PW=present worth of all costs, ICC=initial construction cost, FC=future costs of maintenance and replacement, I=interest rate, and n=number of years.. Discount rate is 5.875 %.
2. Type of barrier approved for use but not constructed to date in Illinois, included for cost comparison.
3. Based on barrier redesigned to correct corrosion problems.

Source: Dianne Kay, 2001, ASC Proceedings of the 37th Annual Conference (http://asceditor.unl.edu/archives/2001/kay01b.htm)

TABLE IV.E.3. Estimated Noise levels on Davisville Road with Port Development[a] Without and With Noise Barrier of Different Heights

Year	Vehicle Type (Volume/Hour)	Noise Barrier	Noise Levels[b] (dB) by Distance[c]			
			30m	60m	90m	120m
1	**Automobile (1,898)** Medium Truck (124) Heavy Truck (595)	No Barrier	75.8	72.7	70.8	69.3
		Barrier (3m)	65.5	64.0	63.0	62.1
		Barrier (6m)	59.6	57.6	56.3	55.3
5	**Automobile (1,898)** Medium Truck (124) Heavy Truck (725)	No Barrier	76.5	73.3	71.4	70.0
		Barrier (3m)	66.3	64.8	63.8	62.8
		Barrier (6m)	60.3	58.3	57.0	56.0
10	**Automobile (1,898)** Medium Truck (124) Heavy Truck (930)	No Barrier	77.4	74.2	72.3	70.9
		Barrier (3m)	67.2	65.8	64.7	63.8
		Barrier (6m)	61.2	59.3	58.0	57.0
15	**Automobile (1,898)** Medium Truck (124) Heavy Truck (1,198)	No Barrier	78.3	75.1	73.2	71.8
		Barrier (3m)	68.3	66.8	65.8	64.9
		Barrier (6m)	62.2	60.3	59.0	58.0
20	**Automobile (1,898)** Medium Truck (124) Heavy Truck (1,546)	No Barrier	79.3	76.1	74.2	72.8
		Barrier (3m)	69.3	67.8	66.8	65.9
		Barrier (6m)	63.2	61.3	60.0	59.0

a: 30 percent of container moves estimated to be carried by Heavy Trucks; average speed is 37.5mph.
b: Noise levels calculated by using FHWA TNM(1998)). Noise Levels = fixed existing noise level + modal noise level generated by port development.
c: Distance indicates a length between center of road and receiver.

The least-cost option for constructing a 3m and 6m barrier is given in Table IV.E.4 These results provide some insight into the net benefits of barriers in the cases studied. The lengths used for assessing costs are those needed to protect the areas identified as *most vulnerable to noise*, that are for areas with the most exposed homes and highest damages.

It is evident from the table that the costs are considerably larger than the benefits – damages avoided -- under the assumptions used. For example, area N2 has the highest estimate damages ($11,077), but the least-cost barrier of even three meters is $483,360. This suggests that a barrier cannot be justified for the cases considered.

TABLE IV.E.4. Initial Construction Costs of Noise Barrier on Davisville RD (RTE 403)

Section and Tier a)	House b)	Length (m)	Area (m^2)	Costs ($) c)	Area (m^2)	Costs ($)
			3m barrier		6m barrier	
N2	40	760	2,280	483,360	4,560	966,720
N4	21	360	1,080	228,960	2,160	457,920
S2	33	550	1,650	349,800	3,300	699,600

a) Sections are categorized by level of development and north and south based on Davisville Road. Barrier construction costs for N1, N3, N5, S1, and S3 are omitted because their sections and tiers are undeveloped or low density area.
b) Number of residential units is counted by using Orthphoto (http://ortho.edc.uri.edu) and Plot Map given by Town Hall of North Kingstown .
c) Concrete material (Precast / Prestressed Concrete Stacked Panels, Steel Posts) for noise barrier was mainly used (39.73% of total area in the United States), and its initial construction cost per square meter is $212.00 (Dianne Kay, 2001 and FHWA, 2000).

However, an important qualification should be made. Our analysis focuses only on incremental traffic from the port. As noted earlier this is only a small share of all traffic. Also, we include only single-family homes; multiunit residences and undeveloped but developable land are not considered. Finally, the area exposed to noise is larger than included in our estimates of damages above. Including these factors would increase damages and may justify investment in noise prevention barriers.

IV. F. Summary and Conclusions

This chapter estimated the potential external costs from incremental noise along the main port connector road because of added truck traffic from a hypothetical port at Quonset Point, Rhode Island. Truck traffic was estimated using simulation results for port demand and for least-cost multimodal movement of containers between the port and markets. Given the estimated incremental traffic, the additional noise (noise over the without-port case) from the incremental traffic was estimated using the Federal Highway Administration noise model. This model also shows the attenuation of noise over distance, allowing us to estimate exposure of single-family homes along the road to the additional noise.

Damages were estimated using the results of a hedonic property model applied using data from the nearby city of Warwick, RI. The results suggest that property value decreases according to the relation 5000(ln(dB). Several sensitivity analyses were done to examine the effect of additional traffic on noise and damages. Also, mitigation measures were considered. These included enforcement of the 25 mile per hour speed limit (trucks going slower generate less noise) and the installation of least-cost road barriers.

Estimated damages from the incremental noise because of the port are modest for all cases considered. One reason for this is that port traffic represents only a small increase in traffic in the without-port case. Future refinements of this work should include the many multi-unit residences along the road and vacant land, which is zoned for residential use. These were excluded because of uncertainty about the status of undeveloped lands and because the hedonic analysis used for benefit transfer focused only on single-family homes.

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APPENDIX A

Effects of Noise on Property Values:
A Case Study of Theodore Francis Green Airport in Warwick, RI

By Suk-Jae Kwon and Thomas A. Grigalunas

A.1. Introduction

Our concern is with the potential external costs of noise from additional vehicular traffic because of port development. Noise can affect people in many ways, for example, by causing annoyance, aggravation, headaches, and the like (FICON, 1992). A useful "endpoint" for capturing many if not most of the external costs of noise is through its effects on property values. All else equal, homes exposed to more noise would be expected to be worth less than homes in a quieter setting. If two homes were identical, except that the one exposed to more noise sold for, say, \$4,000 less than the quieter property, then the damage to the owners of that home from the noise is \$4,000, as revealed in the housing market. Because the decline in value reflects the market's assessment current and *future* noise, the \$4,000 is the change in the *asset value* of the home due to the difference in the level of noise between the two homes (Kopp and Smith, 1993; Freeman, 2003).

However, rarely is "all else equal". Many factors influence the price of homes, and in order to isolate the effect of noise, these "other factors" must be identified and their influence on property values taken into account. This is where the hedonic (property) model, used later in this Appendix, becomes relevant.

Hedonic analysis gets its name from "hedonism" – the personal pleasure one gets from the use of different things. Based on the seminal work by Rosen (1974), the hedonic method has subsequently been extended and applied by a great many authors in the field of economics in general and environmental economics in particular (e.g., Nelson, 1982; Brookshire *et al*, 1985; 1991; Palmquist, 1991; Forrest *et al*., 1992; Garrod and Willis, 1992; Leggett and Bockstael, 2000; Freeman, 2003).

Hedonic analysis recognizes that individuals purchasing a good, such as a home, car, an apple, or seafood really are purchasing a bundle of attributes associated with the commodity concerned. For cars, the make, model type, mileage, fuel efficiency, and options are of interest; crunchiness and sweetness are important for apples; and color, flavor and packaging are key attributes for seafood, such as salmon. In the case of housing, important attributes can be grouped into *site* (for example, lot and home size, garage), *neighborhood* (such as zoning, distance from work), and *environmental* (for instance, noise, proximity to the ocean) characteristics.

Housing markets reflect behavior by buyers, on the one hand, and by suppliers on the other, with prices in the equilibrium price in the overall market determined by the interactions between many buyers and sellers. Individual buyers, however, cannot influence the market price of homes and thus take the price as given. Prospective buyers of a home know their preferences for the attributes of home (number of bedrooms and bathrooms, location, lot size, garage, basement, etc.) and how much they can afford. Given this information, potential buyers weigh tradeoffs between the given price of homes and the attributes important to them. They then purchase the home which is in their best interest -- that is, they maximize their well being as they see it, given their likes, dislikes, and financial resources.

In practice, of course, buyers weigh a great many factors when choosing between homes, and the challenge is to explain housing market behavior using an appropriate model and data to apply the model. If enough data can be obtained on housing sales, and on each of the important attributes for the homes sold, it may be possible to estimate statistically the implicit (or virtual) price of each of the attributes. This implicit price represents the *marginal willingness to pay* for each attribute as reflected by behavior in the housing market. If one of these attributes is noise, then we can estimate the marginal value of noise of homes in Warwick.

A.1.2. Purpose, Scope, Methodology and Organization

This section provides estimates of (1) how noise from a hypothetical port affects property values on the main connector road to and from port and (2) how mitigating measures might reduce noise and hence damages from this environmental stress.

The overall approach we follow involves development of a "hybrid" model. First, a hedonic property model is used to estimate how noise affects the value of residences, using as a case study home sales around Theodore Francis Green Airport ("Green Airport" or "T.F. Green") in Warwick, RI. This case study was selected because adequate noise data for highways does not exist near the port or elsewhere in Rhode Island, but substantial data on noise is available for T.F. Green Airport. Then, we estimate (1) the additional truck traffic serving the hypothetical port, (2) the incremental noise that traffic will generate and the resulting exposure of homes to noise along the major port connector road. Next, we estimate (3) how property values along the major route from the port would be affected by the noise. In this manner, we estimate the potential external cost of noise because of container port development.

Several sensitivity analyses also are carried out. The number of trucks and their speed are varied in order to see how changes in these variables would affect noise and, hence, property value. Also considered are the costs and benefits of mitigation measures, such as construction of fencing which reduces noise.

A.2. Background

The application involves estimation of the effect of noise by aircraft using Green Airport in Warwick RI[26] on home property values in the city of Warwick, RI in 2000. Some 155,545 thousand plane takeoffs and landings occurred in 2000, and commercial jet and cargo operations made up 38 percent of these flights (www.landrum-brown.com/env/pvd/eis/pdf/4-00_1.41.pdf). Although newer vintage jets are far less noisy than their earlier counterparts, and many sound-reduction measures have been adopted by the Rhode Island Airport Corporation, jets nevertheless create considerable noise, particularly on takeoff, landing, and while taxiing. The resultant noise is an important issue, particularly to residential neighborhoods near most commercial airports, and Green Airport is no exception (Providence Journal, 12/14/2000; 8/6/2002). Commercial facilities are viewed as less vulnerable to noise because their

[26] We recognize that airport noise is not exactly the same as truck traffic and that using road noise might have been.

background noise masks airport noise, and commercial facility operations occur primarily during daytime hours, so that interference with sleep, a major irritant, is not an issue.

Noise from Green Airport has been a contentious issue for nearby residents for many years. For example, the 1993 Warwick Comprehensive Plan specifically sought to discourage expansion of runways (Warwick Comprehensive Plan, 1993). Nevertheless, ongoing plans by the RI Airport Corporation to expand further the length of airport runways to accommodate newer, longer-range aircraft have raised this issue anew (Providence Journal, 07/16/2001).

Using the results of an in-depth acoustical engineering study carried out as part of Federal requirements for assessing airport noise (Landrum and Brown, 2002), noise contours[27] around T.F. Green Airport have been estimated (Figure A.2.1). In their original work, Landrum and Brown (2002) estimated noise contours of 75 dB, 70 dB, and 65 dB for areas adjoining T.F. Green Airport. At the request of the authors, they subsequently estimated additional contours of 60 dB and 80 dB. Hence, the work reported on herein incorporates results for five noise contours versus the three in Landrum and Brown's original report.

Along each contour, noise is the same; noise decreases for contours more distant from the airport. The mapped contours range from 60 decibels (dB) to 80 dB[28], as noted. For perspective, 45 dB of noise inside a residence interferes with conversation and causes annoyance; sustained noise exposure[29] above 70 dB can cause hearing impairment (EPA, 2002). As we describe later, the average estimated dB for homes contained in our data base of housing sales in 2000 was 39.9 dB.

Noise diminishes with vertical or horizontal distance from the source. In fact, steep ascents and use of flight paths over the Bay or open space to avoid passing over homes are among the means of reducing noise exposure for those residing near airports. Note the irregular shape of the noise contours, which reflects the landing and takeoffs patterns using the main and secondary runways at Green.

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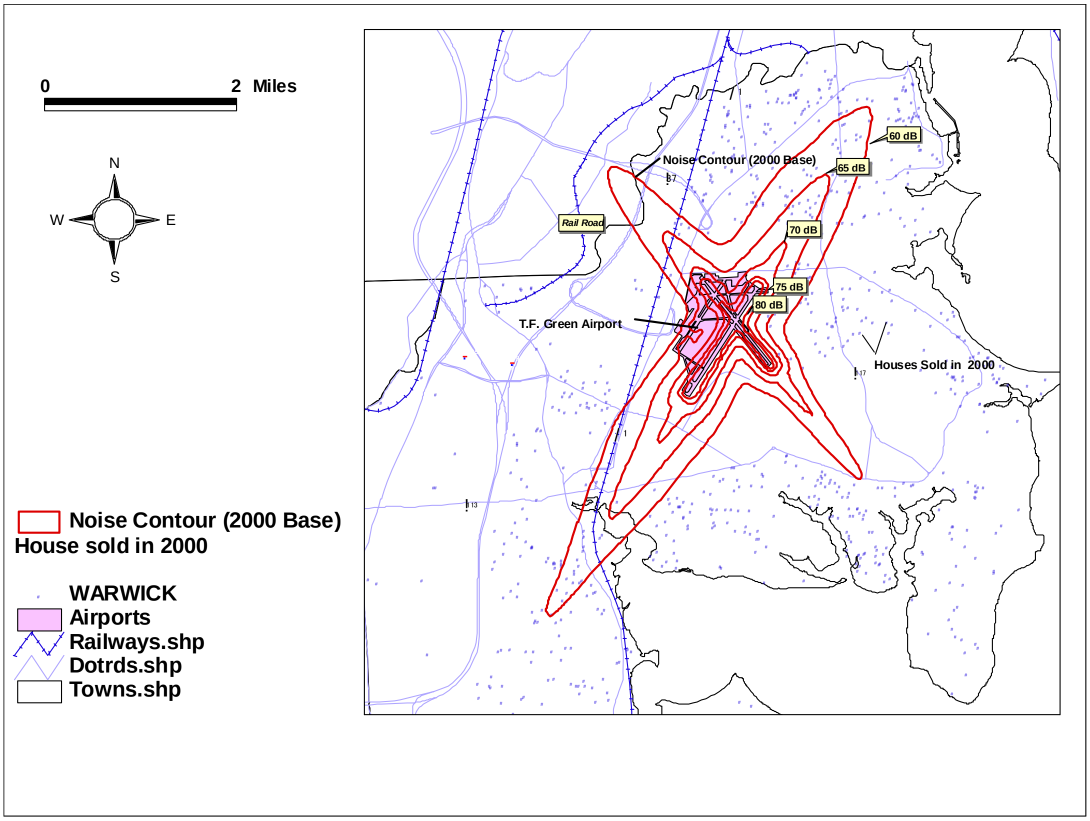
[27] Noise contours are estimate of the total noise exposure for a particular airport resulting from aircraft movements over specific period of time, usually a planning peak day. Noise is measured in decibels and for airports, the measure metrics are the Day-Night Average Sound Level(DNL), the Equivalent Sound Level(L_{eq}), the Sound Exposure Level (SEL), A-Weighted Maximum Sound Level(L_{max}), the Third Octave Band Sound Pressure Levels(SPL), and the Time Above(TA). The preferred measure for airports is the DNL[27] (FAA,), which involves an adjustment to dB to reflect annoyance from evening flights. Noise contours are produced by airport noise models approved by the FAA. Estimated noise contours are airport specific and depend upon the aircraft movements, fleet composition, runway utilization, flight paths in and out of runways, air speed, and engine power during approach and landing procedures. Other factors include atmospheric pressure and temperature distributions and wind directions and velocities during the planning day. Important elements that may attenuate the exposure of individuals to aircraft noise around airports, such as topography of the area (buildings, vegetation, etc.), also are included. (Pereira Filho, *et al*, 1995)

[28] The measure used in this report is the Day-Night Average Sound level (DNL). This is the official metric for airport noise used by the Federal Aviation Administration and is measured as the average 24-hour sound level in dB from the accumulation of all noise-causing events with the addition of 10 dB to sound levels from 10 P.M. to 7 A.M. The higher weighting for nighttime reflects the greater interference with sleep caused by noise during these hours (www.aee.faa.gov/noise/DNL.htm).

[29] Noise exposure is characterized by LA_{eq} over 8 hours. Where LA_{eq} indicates

FIGURE A.2.1. Estimated Noise Contours for T.F. Green Airport.



Source: Landrum & Brown, 2002

A.3. Data, Model Specification, and Results

A.3.1. Data

To estimate the effect of airplane noise on property values in Warwick, data were obtained from TF Green Airport and its consultant (Landrum & Brown, 2002), from the Warwick Tax Assessor's Office, and from numerous resource maps provided online for RI by the DEM and other sources. These data are described in the paragraphs which follow.

Records for all residential property sales in Warwick in the year 2000 were obtained from the city's Tax Assessor's Office. This data involved individual, hand-entry property records. Considerable information also were obtained from various sources in an electronic format. Important data from the Tax Assessor's office included the sales price as well as detailed information on the attributes of the house and property. The attributes included the number of bedrooms and bathrooms, the lot size, condition of the home, and whether there was a basement or garage. Property characteristics, such as lot size or special features, such as pool or tennis court, also were noted.

Relevant data for neighborhood and environmental attributes also were obtained from city and state sources. Neighborhood data included zoning, village boundaries[30], and location on a state highway or heavily traveled road. Environmental variables included location in the coastal fringe, on a flood plain, or near open space. This information was obtained from state sources (http://www.edc.uri.edu/rigis). Detailed definitions for the variables used are given in Table A.3.1.1. Noise exposure at the property site is a key variable, and below we explain the methodology used to capture noise externalities in the hedonic pricing model.

Because of the noise and other potential externalities and attributes have important spatial dimensions, each of the properties sold was put into a Geographical Information System format using ArcViewGIS 3.2® (Figure A.2.1). As illustrated by the small blue dots in the figure, 100 transactions were for homes situated within the five noise contours from 65dB to 80dB used in this study (see Table 3.1.2). Dummy variables for particular neighborhoods within Warwick were used to remove the influence of any variation in housing prices due to village-specific socioeconomic or demographic factors (income, crime, etc.) not captured by the variables used in the model. The omitted community was NBRD400 (neighborhoods are coded for assessing property by tax assessor office).

As is often the case in hedonic studies, measures of the environmental variables employed often are not available for each observation. Therefore, in developing a hedonic (or any other model requiring site-specific environmental attributes) an important issue is how to impute the site-specific measure of environmental quality for particular sites (homes) in the face of incomplete data (see, e.g., Opaluch, et al., 1999; Diamantides, 2002; Leggett and Bockstael, 2001). Here, estimates of noise were based on the use of available data, as follows.

For home sales *within* the area for which the independently estimated noise contours (60-80 dB) were available, the noise levels for the adjoining contours were interpolated. Outside of the 60 dB contour, estimates of noise at property sites had to be extrapolated from the five contour dB value estimates provided to the authors by Landrum and Brown (2002). In order to make these out-of-sample estimates, 32 equidistant transects were constructed from the airport center to the border of Warwick. The noise level at each independently-estimated contour was treated as an observation, providing in total five observations for each transect. Noise in dB was regressed on distance in feet for each transect. Linear, semi-log and log-log functions were estimated. The linear function fit best. Therefore, this function was used to interpolate noise for year 2000 housing transactions within the contours and to extrapolate noise for home sales outside of the noise contours.

In effect, the result of this process generates a “noise surface” which provides an estimate of noise for all year-2000 home sale throughout the city. Using this approach, aircraft noise at home sale sites in the data base range from 69 dB close to the airport, to zero (background) near the borders of Warwick. Of the 712 observations, a total of 100 homes fell within the contours, that is, had a noise level greater than 60dB. The average noise for all homes in the data base was 39.9 dB, as noted.

In total, data were obtained for 726 home sales during the year 2000, and of these, 712 were usable[31]. Socioeconomic and demographic statistics for Warwick are given in Table

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[30] Like many Rhode Island (and New England) cities and towns, Warwick is comprised of many communities called ‘villages”

[31] Two home sales were erroneously recorded twice; another seemingly anomalous transaction involved a home purchased at a very low price and then sold shortly thereafter for a very high price.

A.3.1.1. For comparative purposes, the table also show the same data for the entire state of Rhode Island (including Warwick) and for nearby North Kingstown, the town in which the hypothetical port and its main connector road is located. Summary descriptive statistics for the Warwick housing data used in our analysis are given in Table A.3.2.2.

Together, the statistics given in the two tables portray a city which is a well established with slow growth over the past decade, urban, very densely settled, and with a somewhat higher income as compared to the state as a whole. The population is somewhat older, and has proportionately few minorities compared to the state as a whole. The median housing price for Warwick in 2000 ($111,700) is substantially below that of the state ($133,000).

The average home sold in 2000 was 49.8 years old, had 0.28 acres, 2.88 bedrooms and 1.46 bathrooms. Just over half (52%) had a garage, and 57% had a porch. About 10% of the homes bought in 2000 were in the "coastal fringe" (defined as within 100 meters of the coastline). The average home sold for $139.2 thousand in 2000. As is often the case, averages can be deceiving. Like most cities, Warwick has considerable variability in its housing base, for example, several neighborhoods are situated along Narragansett Bay, and many of these are well off financially (Figure A.2.1).

TABLE A.3.1. Social Statistics for Warwick, Rhode Island, and North Kingstown (2000)

Statistics	**Warwick**	**Rhode Island (incl. Warwick)**	***North Kingstown***
Population (2000)	85,808	1,048,319	27,921
Area (sq miles)	35.50	1,045	43.59
Population/Sq. Mile	2,417	1,003	306.9
Population Growth (%) 1990 – 2000	0.4	4.5	10.7
Percent of Population in Single Family Homes	26.7	25.3	27.7
Percent Minorities	4.8	14.9	4.29
Percent > age 65	16.9	14.5	11.8
Median Household Income (1999)	46,483	42,090	60,027
Median Single Home Value	111,700	133,000	165,700

Source: U.S. Census Bureau, Census 2000.

TABLE A.3.2 Noise Level Range for Single Family Homes Adjacent to T.F. Green Airport

Noise Level (dB)	Number of Houses *
0-9	116
10-19	21
20-29	70
30-39	129
40-49	190
50-59	86
Sub Total	*612*
60-64	68

65-69	32
Sub Total	*100*
Grand Total	**712**

* The houses, which are great than 60 dB, are counted by the original contours (made by Landrum & Brown, 2002), and other houses, which are less than 60 dB, are counted by the simulated contours (made by Kwon).

Table A.3.1.2 shows the distribution of homes over the various estimated noise levels. One hundred homes are within 60 dB to 69 dB. Of thirty-two houses are exposed to 65dB-69dB, which are regarded as incompatible with residential use (the Aviation Safety and Noise Abatement Act, 1979). Two hundred seventy six houses are located on 40dB-59dB noise contours. In sum, 385 homes are estimated to have noise equal to or exceeding annoyance levels.

A.3.2. Model Specification and Results

Model specification is a major issue in demand analysis in general and hedonic analysis in particular. Specification involves two main elements: (1) deciding which variables best reflect household preferences for attributes and (2) the functional form to be used for the hedonic price model.

Selection of explanatory variables in the study areas was based on the literature and discussions at early stages of the study with realtors, the Warwick tax assessor's office, and appraisers. As is always the case, researcher judgment also plays an important role. Intuition (and common sense) suggests that, all else equal, the price of a home increases with the lot size, number of bathrooms, bedrooms or living area, and the presence of a garage, porch or other special features (e.g., a tennis court). All else being the same, homes near Narragansett Bay should be worth more than home not so favorably situated.

Additional issues in hedonic analysis concern possible multicollinearity among the explanatory variables and possible segmented markets. Multicollinearity often arises because several of the independent variables used (house size, number of rooms, number of bathrooms, garages) would be expected to be correlated. Serious multicollinearity increases estimated regression standard errors and, as a result, may inappropriately lead to failure to reject the hypothesis that an attribute has no affect on the value of a property. The partial correlation coefficients were not excessive, and as we show below, the results are statistically significant and robust for the specifications given. Hence, multicollinearity does not appear to be an issue in this case.

Segmented markets arise when (1) the study area includes different populations with different preferences (e.g., ethnic groups) or (2) the data being studied are from different time periods and important changes in the determinants of intra-area housing values have occurred in the market being studied over the time periods employed. In either case, if segmentation occurs, it is inappropriate to treat the data as a single market. For our case, data are for one period, and we know of no intra-period factors which would create the need to segment data by time of sale. However, differences in preferences could exist over different neighborhoods; to account for this, neighborhood dummy variables are used drawing upon the results of a recent study of neighborhoods by (Espey and Lopez, 2000).

The variables used in the Hedonic price model and their definitions are given in Table A.3.2.1, and descriptive statistics are presented in Table A.3.2.2. The variables included parallel those used throughout the State of Rhode Island by appraisers, as given in the Uniform Residential Appraisal Report[32], the standard used by appraisers in the State.

TABLE A.3.3. Dependent and Independent Variables in the Hedonic Property Model

Variable	**Definition**	**Mean Value**
HPRICE*	Continuous variable indicating the 2000 house sales price in dollars. Based on Warwick Tax Assessor Office Data for Residential Houses sold during 2000.	139151
ACRELND	Continuous variable indicating the size of lot (unit is acre).	0.2813
LnACRELND	The natural logarithm of ACRELND.	-1.5908
ZONING*	Dummy variable assigned a value of 1 if the houses are located in district zoned A15 or A40 (15,000 or 40,000 square feet), and a value of 0 if the houses are located in all other zoning classification.	0.0927
YEAR*	Continuous variable indicating age of house (base year is 2000).	49.8478
lnYEAR*	The natural logarithm of YEAR.	3.5973
SFLA	Continuous variable indicating square feet of living area.	1438
BETHRMS*	Continuous variable indicating number of bathrooms including half bathroom.	1.4585
lnBETHRMS*	The natural logarithm of BETHRMS.	0.3044
BASEMENT*	Dummy variable assigned a value of 1 if house has a full basement, and a value of 0 if others (none, craw/earth floor, or part).	0.8637
PORCH*	Dummy variable assigned a value of 1 if house has a porch, and a value of 0 if none.	0.5772
COASTALFRINGE **	Dummy variable assigned a value of 1 if the house is within 100 meter from bay, and a value of 0 if the house is further than 100 linear meters.	0.0969
BAYCOVEFRONT*	Dummy variable assigned a value of 1 if the house is ocean view, and a value of 0 if the house is not ocean view.	0.0674
CMMTDST	Continuous variable indicating the distance from each observation to Providence (Fleet Bank Center).	10.8087
CMMTIME	Continuous variable indicating the driving time from each observation to Providence (Fleet Bank Center).	16.4073
CMMTIMEsq	The square of CMMTIME.	286.6544
NOISE_LNR***	Continuous variable indicating noise level of each house against aircraft. Noise levels are calculated by using the 2000 Year Noise Contours*** of T.F. Green Airport.	36.4598
lnNOISE_LNR	The natural logarithm of NOISE_LNR.	2.8183
NBRD	Dummy variable assigned a value of 1 if the house belongs a specific code (among 20) for the neighborhood (which sets the land value), and a value of 0 if others.	

* Based on Warwick Tax Assessor Residential Document.
** Based on GIS coverage.
*** Landrum & Brown, 2002.

[32] The URAR is from Freddie Mac (Form 70) and Fannie Mae (Form 1004). It includes site variables (size of lot and home, zoning classification, size of basement, presence of "amenities" -- fireplace or deck, garage. "Sight appeal" and "view" also are considered although these obviously are subjective. The URAR also uses a comparison of the home being assessed with comparable, nearby recent sales.

TABLE A.3.4. Simple Statistics for Variables Used in Regression Analysis

Variable	N	Mean	Std Dev	Sum	Minimum	Maximum
HPRICE	712	139151	94448	99075800	22500	925000
lnACRELND	712	-1.591	0.669	-1133	-3.038	1.841
ACRELND	712	0.281	0.435	200.339	0.048	6.306
ZONING	712	0.093	0.290	66	0	1
lnYEAR	712	3.597	1.066	2561	-2.303	5.704
YEAR	712	49.848	29.933	35492	0.100	300
SFLA	712	1438	667.774	1023699	396	5158
lnBATHRMS	711	0.304	0.371	216.430	-0.693	1.504
BATHRMS	712	1.459	0.620	1039	0	4.500
BASEMENT	712	0.864	0.343	615	0	1
PORCH	712	0.577	0.494	411	0	1
COASTALFRINGE	712	0.097	0.296	69	0	1
BAYCOVEFRONT	712	0.067	0.251	48	0	1
CMMTDST	712	10.809	2.698	7696	6.100	18.290
CMMTIME	712	16.407	4.181	11682	10	28
CMMTIMEsq	712	286.654	146.843	204098	100	784
lnNOISE_LNR	712	2.818	2.125	2007	-2.303	4.234
NOISE_LNR	712	36.460	19.846	25959	0.100	69
NBRD100	712	0.062	0.241	44	0	1
NBRD105	712	0.059	0.236	42	0	1
NBRD110	712	0.004	0.065	3	0	1
NBRD120	712	0.020	0.139	14	0	1
NBRD130	712	0.066	0.248	47	0	1
NBRD140	712	0.027	0.161	19	0	1
NBRD145	712	0.010	0.099	7	0	1
NBRD150	712	0.024	0.153	17	0	1
NBRD160	712	0.066	0.248	47	0	1
NBRD170	712	0.003	0.053	2	0	1

Variable	N	Mean	Std Dev	Sum	Minimum	Maximum
NBRD180	712	0.081	0.274	58	0	1
NBRD190	712	0.028	0.165	20	0	1
NBRD200	712	0.129	0.336	92	0	1
NBRD205	712	0.017	0.129	12	0	1
NBRD210	712	0.046	0.210	33	0	1
NBRD220	712	0.062	0.241	44	0	1
NBRD230	712	0.044	0.204	31	0	1
NBRD240	712	0.017	0.129	12	0	1
NBRD250	712	0.018	0.134	13	0	1
NBRD255	712	0.028	0.165	20	0	1
NBRD260	712	0.021	0.144	15	0	1
NBRD300	712	0.066	0.248	47	0	1
NBRD302	712	0.029	0.169	21	0	1
NBRD303	712	0.007	0.084	5	0	1
NBRD304	712	0.020	0.139	14	0	1
NBRD305	712	0.001	0.037	1	0	1
NBRD310	712	0.007	0.084	5	0	1
NBRD320	712	0.021	0.144	15	0	1

The formal (null) hypothesis is that each of the variables included in the regression model has no effect on property value (i.e., the coefficient is zero); the alternative hypothesis is that they do affect property value[33]. The expected sign on all variables is obvious, with the exception of neighborhood dummies variables.

Many model specifications were tried, but simple specifications provided the best fit in terms of the standard criteria of overall explanatory power (R^2) and the sign, size, and statistical significance of the coefficients on variables used.

A.3.3 Results

Table A.3.3.1 shows the results for four functional forms. Equations 1 and 4 perform best in terms of the statistical criteria employed. For both models, over 80 percent of the variation in residential prices is explained by the variables used, all variables have the expected sign, all are statistically significant at least the 10% level, and the size of the coefficients are similar and appear to be reasonable in magnitude.

[33] Other variables were tested, such as commuting time from each village in Warwick to a central location in Providence, the state capital. This did not produce meaningful results, however, most likely because (1) there was little variation in commuting time and (2) in reality, multiple employment centers exist, including major shopping malls in Warwick. Hence, commuting likely has no systematic effect on property values.

The results are generally consistent across all four models with respect to site, neighborhood, and environmental attributes. Lot size, living area, number of bathrooms, presence of a basement and porch, and age all have the correct sign and appear reasonable in magnitude. Location in the coastal fringe or along the shoreline shows similar effects for all models.

Attempts to include commuting distance or time did not seem to "work" in this case. Data on household-specific commuting from individual residences is unavailable. Given this data limitation, commuting was measured as the distance between each home and a single destination, the center of commercial activity in Providence, the state capital. Specifically, the work center destination was designated to be a center point in the downtown -- Fleet National Bank—with distance between this site and each home measured using *MapQuest*. Commuting time is preferred to distance because time is a better proxy than distance for the opportunity cost of commuters time spent in travel. However, a simple linear specification for time yielded a high positive coefficient, and the use of a quadratic specification for time in Eq. 4 suggests that, beyond 15 minutes, additional commuting time is associated with *higher* home prices, which makes no sense. Including commuting distance, however, yields a positive, large, and statistically significant coefficient (Eq.3).

Recognizing several major employment centers exist within Warwick (shopping malls, the airport itself) and a number of retail, eating and drinking establishments occur in "strip malls" or along major roads, as well as in nearby Cranston, it is clear that commuting time is hard to capture without household data. Further, the average age in Warwick is somewhat high as compared to the state (Table A.3.1.1), suggesting a relatively more retired people for whom commuting to work is not a factor. Finally, commuting time was calculated simply as distance (D) over speed (s), given available data; yet, commuting involves peak traffic periods, and actual peak commuting time is not capture simply as D/s and may not be highly correlated with D/s. For all of these reasons, the relationship between home prices and commuting distance and/or time is problematic. In short, commuting time and distance may not be an important systematic factor explaining housing prices in Warwick and, as a result, commuting time and distance are not included in the final equations (1) and (4).

TABLE A.3.5 Regression Results for Hedonic Price Model for T.F. Green Aircraft Noise on Property Values in Warwick, RI

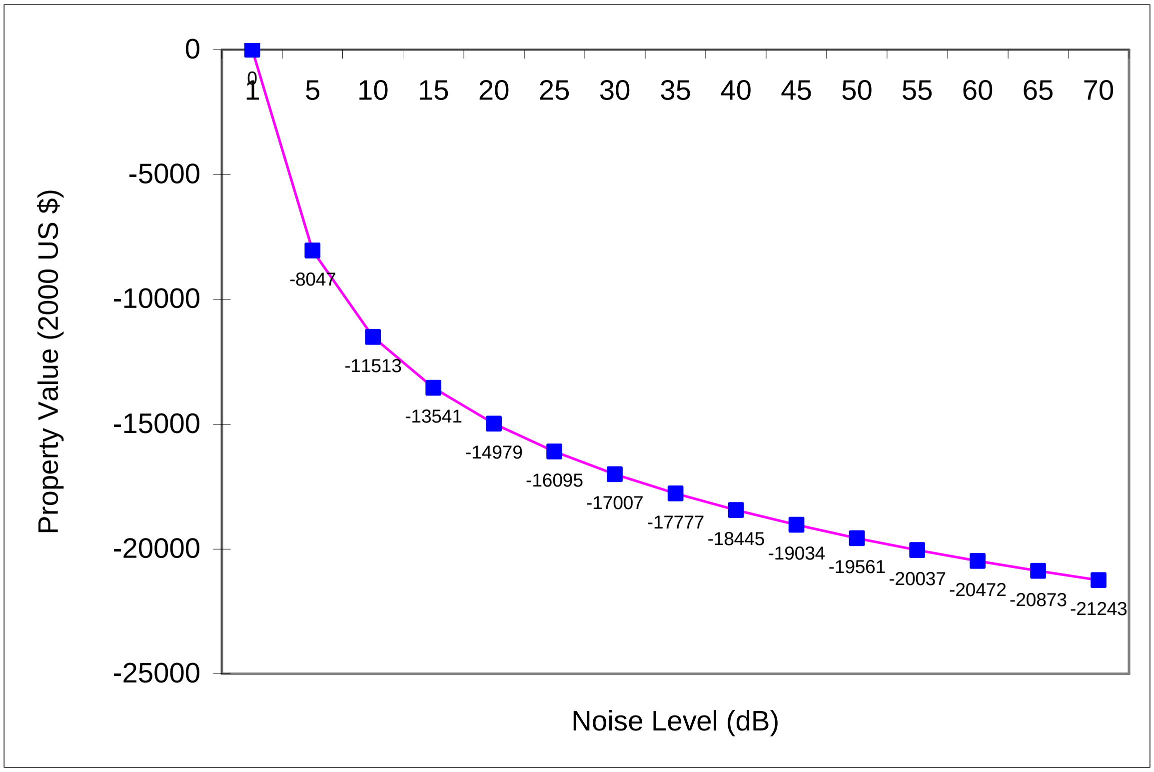
Variable	Model **1** Coefficient (t value)	Model **2** Coefficient (t value)	Model **3** Coefficient (t value)	Model **4** Coefficient (t value)
HPRICE	Dependent V.	Dependent V.	Dependent V.	Dependent V.
Intercept	209602*** (11.09)	200865*** (5.10)	199947*** (5.72)	338729*** (5.71)
lnACRELND	14807*** (3.93)	15807*** (4.08)	15888*** (4.14)	15957*** (4.18)
ZONING	13415* (1.69)			
YEAR	-412.766*** (-6.60)			
lnYEAR		-10472*** (-6.15)	-10293*** (-6.04)	-10061*** (-5.93)
SFLA	59.084*** (12.87)	65.537*** (14.38)	65.348*** (14.35)	64.736*** (14.27)
BATHRMS	17545*** (3.85)			
lnBATHRMS		13391* (1.87)	13771* (1.92)	14410** (2.02)
BASEMENT	9244.915* (1.91)	9909.404** (2.00)	10550** (2.11)	10074** (2.03)
PORCH	8441.132** (2.34)	7729.883** (2.13)	7706.505** (2.13)	7648.379** (2.12)
COALSTALFRINGE	27886*** (4.16)	30460*** (4.57)	30400*** (4.57)	28882*** (4.35)
BAYCOVEFRONT	31841*** (4.60)	30868*** (4.39)	29962*** (4.26)	28674*** (4.09)
CMMTDST		3740.362* (1.69)		
CMMTIME			2704.637** (2.01)	-15047** (-2.39)
CMMTIMEsq				532.564*** (2.89)
lnNOISE_LNR	-5000.163*** (-2.56)	-4787.391** (-2.35)	-4384.188** (-2.12)	-4064.871** (-1.97)
NBRD100	-141409*** (-8.59)	-131460*** (-6.14)	-139193*** (-7.73)	-140085*** (-7.82)
NBRD105	-125202*** (-7.59)	-116940*** (-5.44)	-126017*** (-7.09)	-124856*** (-7.07)
NBRD110	-177892*** (-6.40)	-156951*** (-5.16)	-165175*** (-5.75)	-156875*** (-5.46)
NBRD120	-168870*** (-9.30)	-165419*** (-8.34)	-174749*** (-9.67)	-166394*** (-9.14)
NBRD130	-185864*** (-9.78)	-189618*** (-9.21)	-199578*** (-10.59)	-194905*** (-10.36)
NBRD140	-186022*** (-9.57)	-196030*** (-9.90)	-210196*** (-10.84)	-223842*** (-11.27)
NBRD145	-153565*** (-7.21)	-168980*** (-8.00)	-184987*** (-8.53)	-201320*** (-9.03)
NBRD150	-33796** (-2.23)	-37838** (-2.33)	-56619*** (-3.12)	-92825*** (-4.23)

Variable	Model **1** Coefficient (t value)	Model **2** Coefficient (t value)	Model **3** Coefficient (t value)	Model **4** Coefficient (t value)
NBRD160	-154541*** (-9.02)	-166845*** (-9.77)	-175760*** (-10.21)	-179074*** (-10.44)
NBRD170	72703** (2.06)	53423 (1.50)	49533 (1.41)	57297* (1.63)
NBRD180	-141594*** (-8.90)	-145431*** (-8.91)	-149948*** (-9.57)	-142342*** (-9.01)
NBRD190	-156227*** (-8.74)	-174814*** (-9.69)	-175262*** (-9.83)	-168205*** (-9.40)
NBRD200	-148585*** (-9.43)	-138275*** (-6.55)	-142587*** (-7.76)	-150237*** (-8.13)
NBRD205	-151682*** (-8.08)	-141849*** (-6.57)	-144569*** (-7.15)	-143582*** (-7.14)
NBRD210	-137482*** (-8.11)	-125707*** (-5.92)	-130693*** (-6.96)	-133763*** (-7.15)
NBRD220	-144280*** (-8.79)	-142324*** (-7.77)	-150577*** (-9.15)	-143091*** (-8.64)
NBRD240	-174436*** (-8.56)	-177486*** (-7.81)	-176543*** (-7.96)	-172298*** (-7.80)
NBRD250	-145902*** (-7.72)	-141013*** (-6.74)	-139710*** (-6.80)	-138801*** -6.79
NBRD255	-146537*** (-8.42)	-143784*** (-7.64)	-141257*** (-7.51)	-144147*** (-7.69)
NBRD260	-142495*** (-8.04)	-147622*** (-7.88)	-144423*** (-7.63)	-141842*** (-7.53)
NBRD300	-109737*** (-7.75)	-112794*** (-7.84)	-110924*** (-7.67)	-102997*** (-7.04)
NBRD302	-141501*** (-8.36)	-145886*** (-8.57)	-143973*** (-8.43)	-136182*** (-7.91)
NBRD303	-151609*** (-6.53)	-160723*** (-6.81)	-158649*** (-6.70)	-150261*** (-6.34)
NBRD304	-134235*** (-7.34)	-135799*** (-7.19)	-131880*** (-6.86)	-127348*** (-6.64)
NBRD305	-139039*** (-3.18)	-124664*** (-2.80)	-121433*** (-2.72)	-114057*** (-2.57)
NBRD310	-155169*** (-5.97)	-175345*** (-6.71)	-169746*** (-6.54)	-171490*** (-6.65)
NBRD320	-160200*** (-7.60)	-186106*** (-8.53)	187096*** (-8.64)	-222199*** (-8.98)
F-value Adj R-Sq k^a n^b	78.36 0.8052 38 712	75.25 0.7990 38 712	75.41 0.7993 38 712	74.50 0.8015 39 712

* Significant at 0.10 level.
**: Significant at 0.05 level.
***: Significant at 0.01 level
a: number of variables (not included dependent variable and intercept).
b: number of observations.

The environmental variables in Equations 1 and 4 are of special interest. The key results show that noise matters. Aircraft noise decreases the price of homes, allowing for the influence of the many other factors affecting price. The "damage function" for noise illustrated in Figure A.3.3.1 shows diminishing marginal damages for noise.

FIGURE A.3.1. Change in the Property Value by Increase Noise Level.



Using the results from the best equation (Eq. 1), the effects of noise on property values (in year 2000 dollars) across the sample of 712 sales can be summarized as follows:

- A home located on the middle (70 dB) contour would be worth $21,251 less because of the noise, allowing for the influence of all other attributes.
- A home with the average value ($139,200) in 2000 exposed to the estimated average noise (39.9 dB) was worth $18,439 or 13.2% less because of the noise.

Zoning is expected to influence price (e.g., Edwards and Anderson, 1984; Johnston, et al., 2001), and (Eq.1) the results show large lot zoning has the anticipated sign and is significant. Further, homes located in the coastal fringe or along the shoreline are much more valuable, as expected. Another interesting result for an environmental variable is that being on the coastal adds almost $32 thousand to the value of a home, allowing for the influence of all other factors. Given these results, we now are in a position to turn to the task of simulating the potential costs of road noise.

A.4. Summary and Conclusions

This Appendix summarized estimates of the effect airport noise has on property values, using TF Green Airport in Warwick RI as a case study. Background on noise issues at the airport and the characteristics of the study area, Warwick, RI, were presented. Modeling challenges and data sources and limitations also were reviewed.

Using a hedonic property model, the results show that noise has a statistically significant and important effect of property values, allowing for the influence of other attributes. In

Chapter IV, the results generated in this Appendix are used as a form of benefit transfer to estimate the effect of noise on residential structure along the main connector road for the hypothetical port.

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