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THE POTENTIAL TRANSPORTATION BENEFITS OF IMPROVED ENVIRONMENTAL PREDICTION

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December 12, 1969

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SUMMARY

This project--the development of a technique to measure predictive performance--began with a review of the literature on the effects of environmental prediction, which led to the conclusion that the requirements of our study were truly unique. Existing studies were helpful in identifying operational areas in which environmental information is important, and suggested many of the kinds of benefits that should result from its proper use. In general, they noted that benefits were to be realized from improvements in the quality of predictions and from increasing their availability to users, but no serious attempt to quantify benefits at levels of predictive skill beyond today's could be found.

Environmental prediction is accomplished by the use of different techniques and the predictions take different forms, according to the uses for which they are intended. These techniques--deterministic, subjective, and statistical--are described along with the kinds of predictions normally associated with each. Specific emphasis is placed on the operational forecast directed at an operational decision. Implicit in such a prediction is a recommendation for or against a certain action. It is postulated that only the operational forecast can truly have an economic impact.

The technique for measuring predictive performance, both currently and at improved levels, is described as an accounting of hits and misses. The particular environmental phenomena must first be identified, along with its threshold of intensity and the warning time required. These characteristics are fixed by the nature of the operation to which the predictions will be addressed, by its sensitivity to the environmental condition, and by the complexity of the alternative actions that can be taken to diminish losses.

A hypothetical example assumes a cost for this impact when the condition occurs without warning. Another (lower) cost is assumed when timely warning is given and recommended alternative action is taken. A third cost is that of the alternative action, which becomes a penalty in the event of a false alarm. These costs are then aggregated over a year's experience (hypothetical) at a single location and at several levels of predictive performance to show the progressive improvement in cost savings. A method is then shown to extrapolate the results (from an actual case) to the national total.

In some operations preliminary analysis may show that the total of losses recoverable by the use of improved prediction is small: Either current predictive ability is high (because required warning time is very short) or because technological transportation improvements permit the operator to disregard environmental variation. In these instances, particularly when the level of operational activity is high, exercising the event-by-event technique described is not justified. Instead, a range of potential benefits, above that possible with current predictive skills but below that requiring complete foreknowledge of the environment, can be stated. Many transportation activities fall into this category.

The quantitative results of the analysis are presented in Tables S-1, S-2, and S-3 according to the three major transportation modes--air, ground, and marine--discussed in Chapters 6, 7, and 8. These tables show the recoverable costs or losses for levels representing predictive improvement of 25 percent, 50 percent, and prediction without error.

Table S-1

ANNUAL RECOVERABLE COSTS--AIR TRANSPORTATION
(1985)

Level	Savings In	General Aviation	Commercial Carriers	Military Transport	Total
1 25 Percent	Fatalities Aircraft Losses Operating Costs	4 $22,000 	 $4.0 million	 $0.4 million	4 $4.4 million
2 50 Percent	Fatalities Aircraft Losses Operating Costs	8 $44,000 	 $8.0 million	 $0.8 million	8 $8.8 million
3	Fatalities Aircraft Losses Operating Costs	15 $88,000 	 $15.5 million	 $1.5 million	15 $17.0 million

Table S-2

SUMMARY OF EXTRAPOLATED BENEFITS FOR THREE LEVELS OF IMPROVED PREDICTIVE ABILITY--ALL GROUND TRANSPORTATION (1985)

Level	Activity	Total Annual Benefit--Metropolitan Areas	Factor for Railroads	Benefit for Railroads	Factor for Highways	Benefit for Highways	Total Benefit--All Ground Activities
1	Snow Control	$ 36.3 million	0.12	$4.4 million			
	Accidents	6.4	0.12	0.8			
	Delays	62.0	0	0			
	Total	$104.7 million		$5.2 million	1.0	$104.7 million	$214.6 million
2	Snow Control	$ 69.4 million	0.12	$8.3 million			
	Accidents	12.7	0.12	1.5 million			
	Delays	124.2	0	0			
	Total	$206.3 million		$9.8 million	1.0	$206.3 million	$422.4 million
3	Snow Control	$158.5 million	0.12	$19.0 million			
	Accidents	25.6	0.12	3.1			
	Delays	247.9	0	0			
	Total	$432.0 million		$22.1 million	1.0	$432.0 million	$886.1 million

Table S-3

ANNUAL RECOVERABLE COSTS--MARINE TRANSPORTATION
(1985)

Level	Savings In		Total
1 25 Percent	Vessel Transit Time Vessel Damage/Loss Cargo Damage/Loss Fatalities	$0.7 million $7.5 million $2.3 million 15-18	$10.5 million 15-18
2 50 Percent	Vessel Transit Time Vessel Damage/Loss Cargo Damage/Loss Fatalities	$1.4 million $15.0 million $4.6 million 30-35	$20.6 million 30-35
3	Vessel Transit Time Vessel Damage/Loss Cargo Damage/Loss Fatalities	$2.7 million $29.3 million $9.3 million 60-70	$41.3 million 60-70

CONTENTS

1

INTRODUCTION

Central to any planning for an environmental observation and prediction system is the measurement of potential benefits that will be achieved from the improved environmental information. This measure of economic utility is required not only to define optimum data requirements and to make research and budgetary decisions, but also--in a larger sense--to determine the optimum mix of sensors and platforms that will evolve. The task, however, is difficult. For proper consideration, essentially three distinct tasks are necessary:

- determine the increased volume and quality of properly spaced data and relate it to improved levels of environmental predictions and climatology;
- relate the value of improved environmental predictions and data to benefits to the user; and
- determine the appropriate mix of sensors and platforms in the optimum environmental systems.

This study is concerned only with part of the second task and is further limited to a single user class--the transportation sector of the U.S. economy. The latter restriction eliminates a number of parameters that should be included in any general study of environmental information benefits--underwater currents and temperatures and salinity, to name a few. Instead, because of the nature of transportation operations, the emphasis falls upon the prediction of weather, including sea state and surface currents, and disregards some very interesting elements of the whole environment.

A 1966 report to the Committee on Atmospheric Sciences, the National Academy of Sciences described one of the problems in assessing costs and benefits:

> Such costs are not likely to be borne by any country or combination of countries until it becomes evident that they would be offset by the economic benefits to be derived from an extension of forecast range and accuracy. One is thus involved in a dilemma: until global or hemispheric data for scientific studies and numerical prediction experimentation become available, no significant gains can be made in our understanding of the global circulation and in extended-range forecasting, and until such gains are made we are not likely to be supplied with the additional observations.[1]

The costs referred to here were those that would have been involved in taking measurements before the advent of an earth satellite. The report goes on to suggest that the satellite-balloon-buoy-radiometric system of measurements will be far less costly. The principle in the quotation still stands, however. The new system will not be inexpensive and it will have to compete with many attractive programs in the national budgets.

With the limitations we have described, it was not anticipated that quantifiable potential benefits would be uncovered in amounts sufficient to justify, on a cost-benefit comparison, any significant portion of an extended global observation network. No consideration was given to the advantages of having more complete climatological data, or of the uses to which real-time environmental information may be put. Neither was it suggested that the transportation sector would provide the most fruitful area in which to look for economic benefits. Earlier studies have suggested that advantages to agriculture, construction, and the general public may after all be much greater.

Our study sought instead to develop and demonstrate a methodology that can be used to quantify economic benefits from improved prediction of varying environmental parameters in any sector of the economy sensitive to those variations,

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1. J. G. Charney et al., The Feasibility of a Global Observation and Analysis Experiment, National Academy of Sciences (Washington D.C., 1966).

and in such a way that the results will be credible to those who should use the predictions, as well as to those who make them.

Since such a goal would appear to be obvious, an explanation may be helpful. The fact is that, in general, the language and form of environmental predictions are not directly relatable to the options available to the user. Unless this gap is bridged, improvement in predictive skills will elicit no response from the user's decision-makers and there will be no economic impact from the predictions, one way or another. On the other hand, in specifying what the predictions must contain and how they will be presented, to give them practical value to the user, we must be aware of the effect these requirements will have on the meteorologists/oceanographers. This is particularly important if we are also to postulate levels of improved predictive performance. Those responsible for making the predictions must eventually say what level of improvement seems attainable; to do this they must know precisely what will be expected of them at that level, and what information will be provided to enable them to reach it.

Although the methodology presented has general application, the report will show that carrying it through its several steps may sometimes not be warranted. If preliminary analysis shows that the total of potential economic benefits moving from current predictive skills to perfect prediction of the environment is small, there is little purpose served in computing the partial values at intermediate levels. Such a situation can occur when current predictive performance is high, when technological development has largely succeeded in neutralizing the adverse effects of environmental phenomena, or when the environmental impact is overshadowed by other operating considerations. One or more of these conditions appears in a number of the transportation operations.

2

LITERATURE REVIEW

The theory has been widely held, particularly among those engaged in environmental prediction, that improvement in the reliability and range of ocean-atmosphere forecasts will generate social and economic benefits of high order, and that investment to achieve such improvement will be recovered many times. Optimism is a common characteristic of much that has been written on the subject, but the claims are often difficult to justify from the evidence presented.

Economic Benefits from Oceanographic Research, a publication of the National Academy of Sciences in 1964, states flatly that "a 50-percent improvement in the accuracy of long-range weather forecasting might well produce savings of two billion dollars a year. This could be accomplished in 15 years. . ." No description of the current ability in long-range forecasting is given, except to say that it is low, nor is it made clear what a "50-percent improvement" would be. Similarly, the details of how the benefits were computed are missing, although broad reference is made to a number of segments of the economy.

The World Meteorological Organization Bulletin for October 1968 contains summaries of the presentations made at the twentieth session of its executive committee by leading meteorologists from Australia, France, the United Kingdom, the USSR, and the United States. The common topic was the economic benefits of National Meteorological Services. Again, the stated benefits were large: 300 million dollars annually in Australia, 2 billion francs in France, 36 million pounds in the United Kingdom, 1 billion rubles in the USSR. There is no intention here of questioning these estimates, except to say that the logic by which they were derived is not presented. It should be pointed out too that these benefits are associated with the products of the National Meteorological Services as they existed at that time and not with the promise of improved prediction.

Two Planning Reports of the World Weather Watch (No. 4 [1966] and No. 17 [1967]) provide a summary of the work that has been done. Both of these reports were written under the direction of Professor J.C. Thompson of the World Meteorological Organization. Planning Report No. 4, in particular, is an excellent compendium of the types of benefits that may be derived from the proper use of environmental information. The treatment of transportation problems is limited; the rationale by which potential benefits have been computed (or estimated) is not given. Where reference is made to improved forecasts, there is no mention of what this improvement might be, or how it could be measured. For example:

> Improved forecasts for railroads, highway trucks and buses in the United States could reduce current annual losses of approximately $60 million by a maximum of perhaps $15 million.[1]

or

> For coastal and ocean-going shipping, it has been estimated that, for ships of United States registry, the saving due to better weather services could be as high as $40 million.[2]

In fairness, we should hasten to say that these weaknesses, if they can be called weaknesses, did not escape Professor Thompson and his group. He says in his introduction to the report:

> At present, only order of magnitude accuracy can be attributed to these estimates. Further studies are needed in order to provide more precise and meaningful figures.

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1. M.E. Senko, Weather Satellite Study: A Special Report, U.S. Weather Bureau (1966).

2. U.S. Weather Bureau, Plan for a National Marine Weather Service, ESSA (1967).

A report prepared for the National Aeronautics and Space Administration, 1969, lists areas in which "substantial benefits would accrue" in the fields of transportation, movie-making, recreation, agriculture, construction, water management and conservation, and public utilities.[1] But the report says also:

> Some research effort has been directed at identifying and quantifying the benefits in a few of the areas outlined above--but without marked success thus far. What is needed in this economic benefit area are user-oriented case studies in selected sectors that address the specific question raised above.

That question was: "What are the quantifiable dollar-benefits that would accrue to selected industrial sectors in the United States from a system that would provide a 5- to 7-day weather forecast with accuracy comparable to the currently available 1- to 2-day forecast within a two-county area?"

We agree entirely with the concept that the user's point of view must be obtained for any realistic analysis, but we suspect that responses to the query as it is stated would, in turn, include a list of hard questions.

In 1964 the U. S. Weather Bureau prepared a report for the Interdepartmental Committee on Atmospheric Sciences (ICAS) of the Federal Council for Science and Technology. Called The National Research Effort on Improved Weather Description and Prediction for Social and Economic Purposes, it recommended continuation of research on the scientific aspects of the prediction problems at the then current level, with special attention given to small-scale phenomena and global circulations. It asked that significant increases be made in the effort to develop systems that provide the links between the meteorological-oceanographic services and the users of the information they provide. Finally, in an area it termed synthesis, it recommended the immediate establishment of a long-range program of research on the economic and social impact of weather information on all segments of society:

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1. National Academy of Sciences, Useful Applications of Earth-Oriented Satellites (Washington, D. C., 1969).

This research should explore, quantitatively, the needs of user groups for weather information, the sensitivities of these groups to weather events, and the nature of the decision processes which are dependent on weather information.

Nevertheless, no research effort in this latter area could be identified.

The report also developed and presented the chart reproduced here as Figure 1 to show the relative positions within the national economy of thirteen user groups according to the economic benefits they might produce from the use of better environmental information. It is interesting to note that, from the computational method used, the three groups that comprise the national transportation sector of the economy fall collectively below the median in GNP and above the median in environmental sensitivity But the sensitivity ranking was established by the analysts themselves, and later confirmed by a survey of approximately 75 experienced meteorologists. The question arises as to whether the decision-makers within these user groups would also agree. Still, the report states the problem well; it would be hard to fault its recommendations.

An earlier report, in 1962, for the Federal Aviation Agency by E. Bollay Associates is entitled Economic Impact of Weather Information on Aviation Operations. The technique followed in this study was first to compile from operating data the total weather penalties to aviation, and then to isolate from this total those that could be attributed to inadequate weather information. This figure, for the base year (1960) was then projected for five-year intervals to 1975. A parallel analysis was made to project the costs of establishing and operating the Common Airways Weather System (CAWS) to show a rough cost-benefit ratio.

From a vantage point some nine years later, it would be unfair to criticize the conclusions of the report because some of the assumptions and projections have not been borne out by events. The approach was professional and there is a credible description of the ways in which weather conditions impact upon the economies of air operations. The potential benefits, however, are keyed to the assumption that CAWS would ultimately result in a 50-percent improvement in the

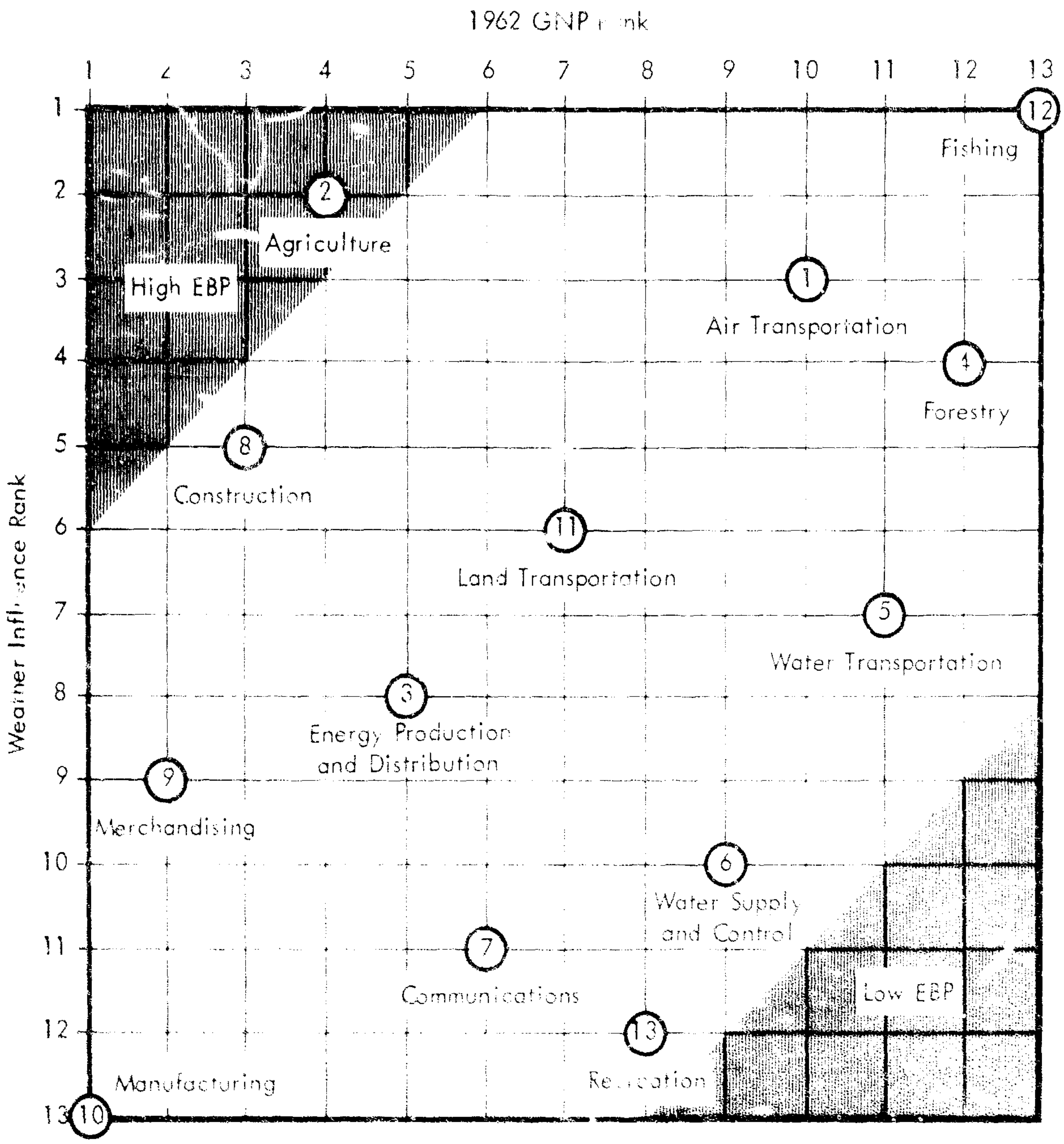

Figure 1: ECONOMIC BENEFIT POTENTIAL OF USER GROUPS

number of missed terminal weather forecasts, an assumption that many meteorologists would doubt. The projections are also distorted because insufficient importance was given to technological improvements that have greatly diminished the impact of weather on air operations. Congestion in the air space, particularly in the terminal areas, has grown at such an accelerated rate that its effects greatly overshadow those of adverse weather, and it limits the ability to react solely to the forecast, however good. Finally, air carrier marketing policies, generated by vigorous industry competition, have fostered operations to disregard rather than accommodate to the weather.

In 1965 a study for the U.S. Weather Bureau analyzed the impact of weather on the U.S. construction industry.[1] It identified and quantified this impact and, more important, quantified the amount by which the impact might be reduced with improved use of environmental prediction. To that point the methodology is adaptable to the transportation industry. It consists of identifying the particular operations within the industry that are adversely affected by weather, determining the characteristics of these weather phenomena and the frequency (from climatological data) at which they occur, and the ability of the meteorological services to predict their occurrence with adequate warning time. Weather-loss figures from six selected cities, over a five-year period, were extrapolated to the entire country, and a range of estimates were obtained from the industry for the portion that could have been saved using current predictive ability. Potential annual savings to construction were estimated to range from $0.5 billion to $1.0 billion, assuming full use of current forecast accuracy. It was further estimated that if perfect predictions could be made, these figures might increase to range from $0.8 billion to $1.3 billion. An update of this study in May 1969 suggested that if in addition to improved accuracy the range of the predictions was extended beyond 24 hours, the upper limit might be $1.9 billion to $2.2 billion.

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1. J.A. Russo et al., Operational and Economic Impact of Weather on the Construction Industry in the U.S., U.S. Weather Bureau (Washington, D.C., 1965).

The Russo study supports, primarily, the proposition that weather information, including predictions within the current ability of meteorologists, should be provided on a timely basis to the construction industry and that the industry should use it. The update paper of 1969 suggests that further potential benefits, from increasing the time range over which the forecasts will be effective, can be used in partial justification for expanding the environmental observation network.

Overall, this review permitted us to reach three conclusions that influenced the way we have gone about doing the analysis:

(1) A method needs to be devised by which predictive performance can be measured quantitatively, and in such a way that each level of performance can be related to its economic effect.

(2) Performance levels should, if possible, be given in terms that describe to the meteorologist or oceanographer what is expected of him, in light of the techniques and information available.

(3) The user's point of view is essential. Not only must the meteorologist understand the costs and risks of weather-oriented decisions, but he must know that unless his predictions influence decisions, they will have no impact on the user's operation.

3

ENVIRONMENTAL PREDICTABILITY

At the 49th Annual Meeting of the American Meteorological Society, January 1969, Dr. J. Smagorinsky, director of ESSA's Geophysical Fluid Dynamics Laboratory at Princeton, New Jersey, said:

> Over the past few years we have heard a great deal about predictability and even if the notions involved seem a bit fuzzy, it has become customary to hear of "2-week predictions."
>
> My concern is that many of the people doing the speaking may not be entirely clear in their own minds as to what it all means. What is worse is that the listeners get an even fuzzier idea of what it is all about, and may be hearing only what they want to hear.

In the previous chapter we have cited examples in which optimism, even conviction, is expressed for the economic benefits that will result from accurate long-range prediction. Obviously, we need to understand what is meant by accurate and by long-range, both from the point of view of the scientists who are seeking to improve the accuracy and extend the range of environmental prediction, and from that of the individuals to whom these predictions will be furnished.

Although correctness and exactness are both synonymous with accuracy, they can signify different realities. A situation may be predicted in broad or, as with the Delphic Oracle, vague terms. If subsequent events satisfy these terms, the prediction was correct. Its lack of expressed detail, however, will limit its utility for operational decisions.

In the course of its study for the National Aeronautics and Space Administration on Useful Applications of Earth-Oriented Satellites in the summer of 1967, a panel of the National Research Council asked the Pennsylvania Power and Light Company to say what economic benefits to power companies would result from an accurate 7- to 14-day forecast. Their response focused immediately on the definition of accurate:

> We are interested in temperature forecasts for the following day to be accurate within 1 or 2 degrees and we require the prediction of the time of the passage of a frontal system to be accurate within approximately 1 hour.[1]

We should then ask whether these requirements are compatible with the prospects for long-range prediction. What is meant by long range? Our present knowledge gives no indication that prediction for a period longer than approximately two weeks can demonstrate a skill that improves on climatology, despite the fact that there are, and have been, a number of sincere practitioners of the art. To be sure, no one has yet demonstrated an ability to predict for as long as two weeks ahead, but there is consensus that a limit does exist. E.N. Lorenz, Professor of Meteorology at the Massachusetts Institute of Technology, said some years ago:

> We must distinguish between intrinsic predictability, which depends upon the (atmospheric) flow itself; attainable predictability, which is limited also by the inevitable inaccuracies in measurement; and practical predictability, which is further limited by our present inability to identify the most suitable formulas.[2]

He was referring to the numerical, or deterministic, prediction technique. The theory upon which this technique is based says that motions and changes in the ocean atmosphere follow dynamic laws that can be expressed in mathematical models. When measured values that describe the present state of the ocean and

1. Letter from N. Curtis, Pennsylvania Power and Light Company, July 1967.
2. Transactions of the New York Academy of Science, XXV, Series 2 (1963).

atmosphere are inserted, the models can be exercised to compute the values that represent subsequent states. Application of this technique has been limited by a paucity of data, both for the development of the models and for testing them. It is estimated that not more than 20 percent of the atmosphere is now adequately covered by observations. A greatly expanded network of measurements will be required, involving satellites, constant pressure balloons, and buoys. The communications system necessary to assemble the information and computers that will operate at speeds a hundred times that of the fastest now available will have to be developed. In the meantime, additional refinement of the technique is planned within the Global Atmospheric Research Program.[1]

What the practical limitation of deterministic forecasting may eventually be is still a point of argument among its proponents, although the two-week range as an outside limit has general agreement. The kind of prediction envisaged at this range, however, will not have great economic utility for short-run operating decisions. It will project the large-scale movement of existing systems and the genesis of new ones. It is not intended to produce the kind of accuracy demanded by the Pennsylvania Power and Light Company. The previously cited letter also pointed out that forecasts could be helpful in scheduling maintenance outages for generating equipment and transmission facilities, but that reliance on them could be economically unsound or even catastrophic if they were inaccurate by a factor of 1 or 2 days.

But if the promise of long-range deterministic prediction does not show direct application to many operational problems, its impact on the accuracy of shorter range, more specific forecasts may be dramatic. Smagorinsky says:

> The feeling has . . . been generally prevalent that the limit of skill for the 1-day forecast was essentially attained a long time ago.

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1. National Academy of Sciences, Plan for U.S. Participation in the Global Atmospheric Research Program (Washington, D.C., 1969).

The recent experiments that were performed on the nature of the adjustment process in assimilating initial data, however, are beginning to lay questions on this conclusion. It appears that a significant portion of the remaining discrepancy between a 1-day forecast and reality may be due to the transients which are excited by transplanting data from the atmosphere into the more complex models.[1]

Certainly, the products of deterministic prediction will continue to serve as invaluable tools for those engaged in the traditional methods. Lorenz describes the traditional technique as a subjective procedure--a craft rather than a science:

> The forecaster begins with the present and recent past observations; so that they will not constitute an unmanageable jumble of facts, they are arranged as a set of weather maps. The forecaster first analyzes the most recent map--he or one of his colleagues will have analyzed the earlier maps before issuing the previous forecast--identifying such systems as high and low pressure areas, warm and cold air masses, and fronts. He then estimates the future position, intensity, and shape of each system, taking care to introduce new systems whose formation seems to be indicated, and to remove systems which appear to be disintegrating. From his prognosticated weather pattern he ultimately deduces the weather conditions at specific points of interest.
>
> At times he may make use of the governing physical laws, but ordinarily he bases his estimate on the way in which the existing systems have been behaving, and on his knowledge of how similar systems have behaved on previous occasions. He must be able to decide when the present weather situation truly resembles some earlier one with which he is familiar, and when the resemblance is only superficial. He must learn to recognize the various signs of storm development and decay, just as the physician learns the symptoms of specific illnesses.[2]

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1. J. Smagorinsky, "Problems and Promises of Deterministic Extended-Range Forecasting," Bulletin of the American Meteorological Society, L, No. 5 (1969).

2. E.N. Lorenz, "How Much Better Can Weather Prediction Become?" MIT Technology Review (July-August, 1969).

We can identify the forecasts produced by this technique with one or another of two categories, depending on the use for which they are intended. First there is the general information forecast distributed to the public. It includes those atmospheric and marine features of general interest--temperatures, precipitation, wind, tides, and sky conditions--and describes them for today, tonight, and tomorrow, in terms of conditions in the area of the forecast. Second there is the special, or operational, forecast, designed specifically to assist a particular decision. The operational forecast will emphasize those environmental features to which the decision is most sensitive; it will be precise instead of general as to intensity, time, and place, and it may even include a specific recommendation as to which way the decision should go, if the forecaster has sufficient knowledge of the risks involved.

The lead-time requirements for these operational forecasts are fixed by the nature of the operation they are intended to serve--specifically, the time required to implement the resulting decision. In transportation operations this may often be quite short, and a longer warning period will produce no significant additional advantage. Certainly, it will not compensate for lower accuracy.

In addition to the deterministic and traditional techniques, there are the statistical methods of prediction. Among these is prediction by analog, in which the historical record is searched to find a pattern similar to that leading to the current situation. The prediction is then made on the basis of what took place in the case of the analog. Lorenz explains the technique's limitations as follows:

> In practice the method has not been particularly successful. For predicting one day in advance, it might be sufficient to have the analogue state resemble the current state over a rather limited area; for predicting several days ahead the resemblance should cover a fair portion of the globe. Reasonably complete three-dimensional states of the atmosphere have been observed on a daily basis over the northern hemisphere for no more than 25 years. The chances of finding a good analogue

for a given state within this period are extremely small. To be competitive with dynamical forecasting as it is currently practiced, the analogue method would probably require many thousands of years of recorded weather data.[1]

Quite recently, the press has given coverage to the claims of a group of meteorologists in New England, led by a professor emeritus of meteorology at MIT:

> After years of research the three scientists have assembled 400,000 bits of weather information. The mass is fed into electronic computers for statistical relationships that become the basis for forecasts up to six months ahead.
>
> To determine what the temperature will be at a given point six months hence, for example, atmospheric pressure readings for 30 years at 1?? locations from England to Japan and Mexico to the Arctic are analyzed.
>
> Studie[illegible] show[illegible] the scientists claim, that atmospheric pressures at particular places and times are related to temperatures at other locations at later dates.[2]

The technique is illustrative of another approach to statistical prediction, new primarily in the size of the data bank and in the deduced relationships between current observations and expected conditions. There is no reason to believe, however, that the weaknesses described for the analogs will not apply, or that the six-month predictions will demonstrate a skill above climatology.

From this brief look at the different techniques employed in environmental prediction, and the forms in which the predictions are stated, we can conclude that the operational forecast is the only one to which economic impact may be ascribed. It may be quite short-ranged, but it must have both the detail and dependability to persuade the operators to use it; to convince them that by doing so their operations will, over time at least, be more efficient and so far, more profitab[illegible]

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1. Lorenz, p. 42.

2. Washington Evening Star (October 15, 1969).

At present most operational forecasts are prepared using traditional techniques, with some guidance from numerical projections, analogs, or statistical relationships. As we expand the synoptic observational network that describes our environment, we can expect that these assisting techniques, individually or in concert, may assume a greater portion of the task. But the relationship between the prediction and the user's decision will remain paramount.

To re-cap, the operational forecast must have the following essential characteristics:

- it must be decision-related--go-no-go,
- it must be delivered to the user with ample time for him to implement the recommended action, and
- performance reliability must be sufficiently high to justify responsive action, on an economic basis, at least over time.

4

MEASURING PREDICTIVE PERFORMANCE

Our requirement to assess the economic impact of improved environmental prediction sets us first to the task of finding the baseline from which improvement can be measured. Unless we can describe the current level of performance in some finite way, we cannot either describe a level of improvement or estimate the economic impact that that level may produce. The complexity can be reduced, however, if we confine our performance evaluation to those predictions made for the purpose of assisting particular operational decisions. These forecasts are normally outside the scope of U.S. Weather Bureau operations, although the Bureau furnishes much of the basic data and preliminary analysis upon which they are based. The military services and the major airlines operate their own meteorological-oceanographic departments to provide this kind of advice. There is a growing number of private consulting firms who furnish environmental predictions for various commercial enterprises and local government operations.

We described earlier the operational forecast as a special type used to predict the occurrence of an environmental condition, or set of conditions, which, with proper warning, should influence an operational decision. The operational forecaster must have determined from the operator what critical level of intensity the condition must reach before alternative or preventive action will have been justified and he must know the lead time required after receipt of the warning to put this action into operation. He should also have an appreciation for the impact a decision based on his prediction may have on the operation, not to influence the forecast but to ensure that essential elements will be included in it. His prediction then becomes a positive recommendation for taking one line of action or another and his performance can be measured by the number of times this recommendation is right or wrong.

Although the fact has not been emphasized in the claims for improved prediction, it is obvious that unless the forecast does result in some change in the way the operation is conducted, it will have no economic impact at all. Accuracy, or reliability, of prediction is only one consideration. If the condition to which an operation is sensitive is not expected, and if it does not occur, the prediction will be correct but it will have had no influence on any operational decision. Such predictions are excluded from our measures of performance.

For any particular operation, there are three separate sets of costs influenced by environmental conditions. First, there are the costs of delay, disruption, and damage, when the operation is overtaken by adverse conditions without warning. Second, there are the costs that accrue when warning is given with adequate time for preventive or alternative actions--alerting emergency crews, re-routing, postponing. Finally, there are the costs of these preventive or alternative actions. How these costs come into play in assessing the economic impact of environmental prediction will be treated in the next chapter. They are mentioned here because of the part they play in determining what environmental conditions are appropriate for the operational forecast and what conditions should be considered in measuring predictive performance. The cost savings as a result of taking the alternative action must be significant in relation to the cost of these actions or else the chance that the prediction might be wrong creates too great a risk. If the preventive action has a very small cost compared with the advantage it produced, and when the adverse condition occurs with high frequency, it will require no decision process to put into effect. Many people who once worried whether to mount tire chains when threatened by ice or snow now put on studded tires in the autumn and remove them in the early spring.

All of this serves further to reduce the opportunities in which environmental prediction can produce economic benefits. But for those situations in which such benefits may be generated we can demonstrate a method of measuring predictive performance both at current capability and postulated levels of improvement.

As an example, consider the problem of snow removal in a large urban area following a sudden, severe storm. We assume that the minimum lead time for the highway department to take the necessary preparatory actions has been established at, say, two to four hours, and that the intensity of a snowstorm requiring these actions is an accumulation of four or more inches in a 12-hour period. We then look at the record, for any given year, and determine (1) how many times the condition occurred, and (2) how many times it was predicted in time. Since there are costs involved, we also want to know how many false alarms were given.

In our example, there are five heavy snowstorms between November 15th (320th day) and March 15th (74th day of the new year). We can then represent current performance, perfect performance, and one or more intermediate levels as shown on Table 1. Current performance, from the record, shows two correct predictions, three misses, and two false alarms. At level 1 there are three correct, two misses, and three false alarms. In the next chapter we will show how the degree of improvement, in economic terms, becomes apparent when costs resulting from decisions these predictions lead to are put in.

The current level of performance in the example is based on statistics for one year at a single location. For the analysis we have to be certain that the year, or years, from which the statistics are chosen is representative. We have also to cover a sufficient number of locations to compensate for the natural variation of climatological characteristics.

We have established that we will measure performance for operational forecasts only since, by our definition, they alone will influence decisions that have economic impact. The phenomena we are interested in generally fall into the

Table 1

EXAMPLES OF PREDICTIVE PERFORMANCE[a]

Day of Year	Snow Occurred	Current (Recorded Forecasts)	Level 1 (Improvement)	Level 2 (Improvement)	No Misses
327	S+				P
352		P	P	P	
363	S+		P	P	P
7	S+	P	P	P	P
31			P	P	
43	S+	P	P	P	P
50		P	P		
63	S+			P	P

P = Warning Issued.

a. An interesting feature of this technique of performance measurement is that it permits the forecaster to reexamine the analysis he made on those occasions when either he missed or gave a false alarm, to see how his prediction might have been changed by the availability of additional observational data.

category of "bad" or "heavy" weather and can be finitely described.[1] There must be in each case a preventive or alternative measure to avoid or lessen the costs they would otherwise involve.

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1. There is a special type of operational forecast in which the problem is to recommend a period of specified duration, between a starting and ending time, in which there will be a minimum of environmental disturbance, or in which certain parameters will not exceed prescribed values in the operations areas. Predictive performance can be measured by the same method we have described.

5

MEASURING ECONOMIC BENEFITS

This chapter presents an approach to measuring those benefits to the transportation industry that can be expected to result from improved environmental predictive ability. The first section presents a sample approach to measuring direct benefits that builds upon the operational forecast example of Chapter 4. The second section defines in some detail those types of benefits to be measured in this study as distinct from those not within the scope of analysis.

SAMPLE APPROACH TO MEASURING DIRECT BENEFITS

In Chapter 3 we showed how performance can be measured for the operational forecast. Now we will expand the illustration to demonstrate how direct economic benefits are derived from this measurement technique. We will consider first snow removal in a single urban area as an example of benefits in a micro situation where actions based on improved predictions can be related to subsequent reductions in costs of operations. The snow removal example was selected because it is conceptually simple, data were available, and it incorporates all major elements of the problem (a cost associated with an unpredicted weather event, a cost associated with a predicted event, and a cost associated with preparatory action).

As the methodology used here is somewhat detailed and involves considerable effort in data collection and analysis, a useful first step in all cases before applying is to determine, in a gross way, the probable magnitude of the potential benefits.

This is done by assuming perfect prediction and perfect response by all decision-making; if the benefits of their actions are found to be negligible, further application of the detailed methodology is not deemed useful.

Given that the gross benefit potential is estimated to be non-negligible, there are three sets of costs that must have been obtained from operating experience. First is the cost of performing the snow removal operation when the storm has occurred without warning and there has been no opportunity to alert and deploy emergency crews and equipment. In our example we will call this 100 cost units. Second are the costs of the same operation when adequate warning has been received and preparatory actions have been taken--75 cost units. Finally, there are the costs generated by the preparatory actions themselves--5 cost units.[1] Thus if snow occurs without warning, the cost is 100 units; if snow is correctly predicted and action is taken, the cost is 75 + 5 = 80 units; and if snow is predicted and action is taken but the snowfall fails to materialize, the cost is 5 units. By totaling the annual operating costs for each array, we can see how such costs fall with improved predictive ability, ranging from 470 units at the assumed present level to 400 with perfect prediction.

If we were to reproduce Table 2 for each of the cities of the United States that has a significant snow removal problem, we could simply add up the results to achieve a range of potential benefits for the city snow removal operation. Since this would have been a formidable task, we sought a simplified procedure (the details of this and benefit analysis in other areas of transportation are presented in the following chapters).

For example, with actual snow removal operations over a three-year period in Washington, D.C., the relationships between direct costs (of snow fighting and

1. It will be noted that these hypothetical values satisfy the requirements described in the preceding chapter. The potential saving is large, compared with the cost of the alternative action, but that cost is still too high to allow building the procedure into the system as routine.

Table 2

COST EFFECTS OF IMPROVED PREDICTIVE PERFORMANCE

Day of Year	Snow Occurred	Recorded Forecasts	Costs	Level 1	Costs	Level 2	Costs	No Misses	Costs
327	S+		100		100		100	P	80
352		P[a]	5	P	5	P	5		
363	S+		100	P	80	P	80	P	80
7	S+	P	80	P	80	P	80	P	80
31				P	5	P	5		
43	S+	P	80	P	80	P	80	P	80
50		P	5	P	5				
63	S+		[illegible]		100	P	80	P	80
Totals			470		455		430		400

a. P = Warning Issued.

inconveniences due to snowstorms) and predictive ability were investigated. While a large number of factors were considered, it was found that only a few were needed to explain the cost behavior of the snow removal operation. In addition to the hit-and-miss record, the intensity of the storm and the lead time between mobilization and initial snowfall were the factors considered.

One can think of the analysis that was done as representing a model of urban snow fighting activity, calibrated for the specific case of Washington, D.C. Similar information was obtained for the cities of New York and Chicago. The purpose was to lend confidence to the approach derived for Washington, and to lend insight into those factors needed to scale the benefits to a nationwide basis. The factors used in the process of scaling benefits to a U.S. total were population, snow removal budget, and annual depth of snow.

This, then, is an example of how we would like to have measured direct benefits to U.S. transportation in all areas of interest--ground, sea, and air. In actuality, as we indicated in the introduction, many areas of potential benefits appeared, upon close scrutiny, to be poor candidates for analysis because the potential for benefits was just not there (because decision-makers would not use such information even when it is available), or the total potential dollar benefits were not significantly large In other areas of potential benefits, the type of data for doing an analysis similar to that above was not collected and therefore unavailable to the study. The snow removal case is the principal instance in which we were able to completely exercise the methodology initiated with the concept of an operational forecast in Chapter 4 and completed with the example described in the preceding paragraphs.

BENEFIT CONCEPTS AND ASSUMPTIONS

By study definition we are limited to transportation benefits, to economic benefits, and to projected benefits for the 1975 to 1985 period. Some other prediction effects are less clearly defined as program benefits. For example, some improved prediction effects are truly net economic benefits and others are simply transfer payments from some persons to others. In the following discussion, we provide the rationale for excluding several types of program effects as benefits of this study, while including other types of program effects. We believe that our experience and the experience of others in conducting similar studies have demonstrated that the procedures followed provide the most valid methodology for measuring program benefits.

Types of Benefits

The following simple taxonomy of benefits will guide the reader through the benefits discussion. Direct benefits are defined in this study as increased returns to the operators and users of a transportation system resulting from decisions based on improved environmental prediction. Indirect benefits are simply those that result from these transportation decisions for sectors of the economy other than transportation. The scope of this study limits our concern to the measurement of direct benefits only. Secondary benefits represent the induced effects of improvement from environmental prediction. Direct (and indirect) benefits are the immediate result of decisions to use improved prediction; by contrast, secondary benefits accrue only with the passage of time when those groups incurring direct benefits spend their additional incomes, thereby creating additional rounds of benefits. Secondary benefits are generally beyond the scope of this analysis because of the complexities of measurement. An exception to this is the case where direct benefits to transportation lead to secondary benefits that remain in transportation (for example, where travelers change modes of travel based on prediction of bad weather).

Parties Relevant to Direct Benefits

A person or organization that makes the decision to take an alternate action with respect to a transportation activity represents a transportation decision-maker for purposes of the following discussion. A transportation decision-maker may be the driver of an automobile, the director of a state highway bureau, the owner of a large railroad company, or the U.S. Secretary of Transportation; the identifying factor is that he has the power of changing resource allocation decisions with respect to his transportation activity in the light of predicted environmental conditions. Providing the information to influence such decisions falls in the same classification as any other type of technological change. Technological change may be broadly defined as a recombination of inputs (or factors of production) to achieve a greater output per unit of input. Technological change is often conceived of as the addition of new machinery to an economic enterprise. However, the use of improved environmental forecasting as the basis for altering resource allocation decisions has the same type of effect on the production of goods and services as does the institution of capital improvement technology.

The decision-maker provided with an improved forecast cannot be presumed to take an alternative action unless the benefits he anticipates exceed the costs to him of taking that action. Consider, for example, a fairly typical situation where the decision-maker's response to improved prediction is consistent with the effective and efficient use of resources. If a local government has the responsibility for snow removal, it could be expected to act generally in the interest of both the taxpayer and the transportation user. If the snow removal activity were not conducted in the most efficient (least cost) manner, the taxpayers would be expected to make their sentiments known to the government through elections and complaints. But snow removal activities also affect transportation users, and to them the major element of importance is that they get to where they are going in the safest and fastest manner. If there are major backups or accidents, they can be expected to complain to those responsible for snow removal. Thus, if the decision-maker has the opportunity to take a new set of actions based on improved knowledge of when and where a heavy snowfall will occur, he would likely do so both because of the users' possibility of lowering costs and because of the possibility of improving service. Both results are considered benefits in this study.

The nongovernmental decision-maker is subject to some of the same forces that guide governmental decisions to be responsive to effective and efficient use of resources. Competition among firms provides a check and balance on both the costs of providing transportation and the quality of the transportation service. Government anti-trust and regulatory actions attempt to foster such competition and protect the interests of transportation users and the public. However, cases may be found where private transportation decisions are not responsive to the best economic utilization of such resources from a total standpoint. Private transportation decisions, therefore, are reviewed somewhat more critically than public decisions in this study to determine whether they result in benefits to the nation.

An example of these types of improvements in efficiency and service is represented by the following hypothesis that was developed prior to the measurement phase of this study. Snowstorms often descend upon large cities with little previous notice of their arrival. Such storms could be expected to both tie up traffic and impose heavy costs upon city public works departments attempting to keep the roads open. With only a short but accurate warning of such storms, the public works departments might find it advantageous to mobilize their men and materials and place them at strategic locations to begin reducing the snow cover as soon as it begins to accumulate. Such prior action might reduce the department's costs for snow removal by reducing reliance on high-cost but untrained contractors, reducing overtime pay for regular crews, and making more efficient use of machinery and materials. Likewise, such prior action might improve the department's service for the highway users by such means as (1) more rapid transit of vehicles, saving the time and income of travelers and shippers; and (2) safer transit, resulting in reduced economic (and social) loss from accidents. The gross economic benefits in this example are the additive effects of the enumerated cost savings and service improvements. The net economic benefits are the gross benefits less the additional cost of the alternative action.

OTHER BENEFIT CONSIDERATIONS

In the preceding section we indicated generally the types of direct benefits that are the concern of this study. In this section, we elaborate on additional types of effects that must be considered in a complete benefit analysis.

For the most part our concern is not with noneconomic effects, since we do not know how to quantify them in most cases. Fortunately, in this regard most benefits accruing to transportation systems are economic in nature. But lives lost in accidents are an important type of noneconomic effect and are included in the analysis to the extent that data are available.

Secondary benefits represent the induced effects of improvement from environmental prediction. Direct (and indirect) benefits are the immediate result of decisions to use improved prediction; by contrast, secondary benefits accrue only after those groups incurring direct benefits spend their additional incomes, thereby creating additional rounds of benefits.

We are concerned in this study only with those types of secondary benefits to the transportation sector that result from the direct actions of transportation decision-makers. An example of this type of secondary impact is as follows. The transportation sector is characterized by highly competitive modes. Thus a change in weather forecasting that has a major economic effect on the usage or pricing pattern of one mode will also have an important effect on competing modes. For example, adverse weather currently has a very pronounced impact on the mode of passenger travel between major metropolitan areas, particularly in the Northeast. In bad weather, many persons switch from highways and air to rail, where travel delays are less pronounced. If better prediction affects all modes simultaneously, the net result may be that the total traffic congestion pattern in bad weather is improved for all modes. Although such types of effects were, from a conceptual standpoint, considered to be secondary benefits, it proved difficult to quantify them. As a result, the following chapters allude to such benefits where they presumably materialize in air, ground, and marine transportation, but do not successfully develop measures of such benefits.

Another consideration has to do with the projection of potential benefits. Quoting Professor Thompson: "It is important to note that one goal of industrial technology is to design an initially weather-sensitive operation so that it will become independent of such environmental factors as the weather."[1] We can expect these technological developments to continue; obviously, as they do, the benefits from improved prediction will diminish. The totals may continue to increase as the economy and the population grow, but not in direct proportion. In the process of measuring benefits, we identify and project such trends to the extent possible, but our analysis is necessarily crude.

Potential benefits also depend on the future level of transportation activity. The demand for transportation is derived primarily from the demand for other goods and services. Thus the long-term trend in the aggregate demand for transportation depends primarily on the long-term trends in the requirements for transportation on the part of businesses, industries, families, and government entities. To evaluate these long-run trends in the aggregate is clearly beyond the scope of this study. To the extent that such analyses have been conducted, they will be utilized in this study; but, in general, such long-run trends in the overall demand for transportation by the economy are not explicitly evaluated.

There is a final factor that should be noted in the introduction of benefits: For lack of a better title we call it suboptimization impact. In some cases of operational decision, the influences of factors other than environmental inconvenience may dominate. In other words, the value of improved predictive ability sometimes gets lost in the noise of more important influences. For example, delays in air transportation result primarily from a deficiency of traffic handling capacity in relation to the volume of traffic. Bad weather, of course, accentuates the problem; but there appears to be limited action open to the dispatchers or controllers,

1. J.C. Thompson, The Potential Economic and Associated Values of the World Weather Watch, World Weather Watch Planning Report No. 4, World Meteorological Organization (1966).

based on improved predictions, that enable the more rapid movement of passengers in bad weather.

The congestion of the airspace, particularly in the vicinity of the most important terminals, denies the airlines the flexibility they would need to minimize direct operating costs influenced solely by the weather.

6

AIR TRANSPORTATION

This chapter estimates the benefits that would accrue to air transportation as a result of improved predictive ability; it assumes that all necessary communications are in place. In this chapter we estimate the magnitude of these benefits and demonstrate how they were derived.

In discussing weather effects, one can think of air transportation operations in terms of technology, economics, and competition. Aircraft operations are highly sensitive to technological advances in equipment, both airborne and land-based. Over the past ten or fifteen years, substantial technological improvements have diminished the impact of weather on aviation operations. For example, icing conditions, a serious problem for propeller-driven aircraft, are a minor problem for turbojets; modern instrument landing systems have the ability to handle aircraft under near-zero visibility conditions.

However, it is not the purpose of this study to forecast technological improvements in aviation but rather to determine their potential economic effect as related to improved weather prediction. Even with no technological breakthrough over the next ten to fifteen years, the broader utilization of existing technology will lead to a decreased dependence of aviation operations on weather, a trend that will be reinforced by future technological innovations. This will decrease the amount of benefits that can be realized from improved weather prediction.

The economics of the air transportation industry are based on aircraft utilization. Revenue is only earned when purchased transportation is completed. However, a large proportion (approximately 60 percent) of the cost is incurred even if the airplane stays on the ground. Competition within the air transportation industry is based on passenger services, which in turn is based on adherence to schedules. There is, of course, a great effort to arrive on time, but adherence to departure schedules is equally important to the traveling public. These considerations have resulted in company policies, forced by the exigencies of competition, to initiate flights on schedule, even though there is a chance that weather may cause a delay or diversion. The potential risks of the alternative, lower aircraft utilization and loss of passengers to competing airlines, are too severe to allow sub-optimization due to weather delays.

To isolate operational decisions that may be influenced by environmental prediction, we must first determine the effects of weather on air transportation operations. Given perfect weather conditions, no traffic congestion, and 100 percent aircraft availability, airlines would essentially complete their published schedule exactly, and the dispatching decision would be tr[illegible]l. However, these conditions rarely occur; those that do act and interact to produce aberration in published schedule performance and to increase the operating costs.

Planes unable to land at destination terminals because of below minimum visibility are either diverted to alternate airports or hold their patterns and wait for the weather to improve. Obviously, poor visibility aggrevates congestion delays. In addition, flights can be cancelled or diverted because of poor runway conditions caused by accumulated snow or ice.

Applying the methodology described in Chapter 5 to air transportation involves, for the most part, one's success in predicting terminal conditions that change flight plans. Although the procedure is straightforward, the large number (over 10,000) of operating airports in the United States require a large sample. The analysis of each airport in the sample has to include all the operations into and out of the terminal for which some alternative action, with economic advantage, could be taken.

The first step of our analysis established the base case--the current effects of weather on air transportation operations (the number and costs of accidents, delays, cancellations, etc.). The next step established the nonrecoverable losses, those losses for which no practical alternative action is available, even with complete foreknowledge of the weather conditions. For example, if the composite wind vector in the flight plan is adverse, the flight will either take longer and require more fuel or it will be completed in normal flight time at a higher cruise setting. Both options represent an additional cost whether the winds were accurately predicted or not.

The third step, required by the terms of this study, eliminated from the total weather-incurred losses those losses that could have been prevented if the forecasts made with current predictive skills had been available and used. Full forecasting service is not convenient to all points at which air operations take place, and inexperienced pilots have been known to disregard its warnings. The remainder represents the losses, or costs, that could be avoided if all the uncertainties of weather were eliminated and appropriate operational decisions followed. These are the losses that improved prediction can help recover.

We divided U.S. air transportation activities into three groups--general, commercial, and military. The economic impact of weather is different on each group, and data have been accumulated separately for each.

General aviation consists of aircraft owned by private individuals, flying clubs and services, and corporations. They are used for sport, instruction, and personal and business transportation. Most are light aircraft with limited range and endurance and do not carry the sophisticated electronics required for instrument flying. A very small percentage of general aviation pilots are instrument qualified. In general aviation, the costs due to variations of schedules and operating inconvenience are dwarfed by the cost of accidents. We will look particularly at those accidents in which erroneous weather prediction was a contributing factor.

Commercial air operations consist of trunk and feeder routes in the United States, international flights by American-owned carriers operating to and from U.S. terminals, and nonscheduled contract carriers. The economic impact of weather conditions on these operations are the costs of delays, cancellations, and diversions. Theoretically, there are also costs involved in carrying extra fuel as a hedge against weather uncertainty. There are no recorded incidents in recent history of commercial carrier accidents attributed solely or primarily to erroneous weather prediction.

Although equipment and pilot qualifications are very similar, military air transport operations differ from those of commercial carriers. The Military Airlift Command does not operate between points within the continental United States. Domestic airlift requirements are met by commercial carriers. The domestic terminals of MAC, with the possible exception of McGuire Air Force Base, are remote from the heavy traffic in the large metropolitan areas, and MAC terminals are well equipped for handling their instrument operations. As a result, the effect of weather on landing and departure delays is much less than commercial operations. However, we were unable to find quantitative data to show exactly what the relation is, and our conclusion is based on the opinions of individuals with operating experience in MAC. We believe that the aggregated potential benefit of improved weather prediction for commercial air carrier operations will be only slightly increased by the inclusion of military air transport operations.

In the following sections, we have adopted the classification of problem areas from the Bollay report because it identifies all of the weather problems traditionally confronting aviation operations.[1]

GENERAL AVIATION ACCIDENTS

The National Transportation Safety Board collects data on U.S. general aviation accidents, including the cause-related factors. These factors are classified into the general areas of

- pilot,
- personnel,
- airframe,
- power plant,
- systems,

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1. E. Bollay Associates, Inc., Economic Impact of Weather Information on Aviation Operations (September 1962).

- instruments/equipment and accessories,
- rotorcraft,
- airports/airways and facilities,
- weather,
- terrain, and
- miscellaneous.

Table 3 summarizes these data for 1964 through 1967. This table presents the number of accidents (total and fatal), the number of accidents in which weather was a cause-related factor, and the number in which an incorrect forecast was a cause-related factor.

Table 3

GENERAL AVIATION ACCIDENTS

	1964	1965	1966	1967	Total
All accidents	5,069	5,229	5,738	6,115	22,151
Weather cause related	1,020	955	1,212	1,476	4,663
Forecast cause related	4	13	9	16	32
Fatal accidents	526	554	574	603	2,257
Weather cause related	330	436	357	413	1,536
Forecast cause related	3	13	5	4	25

Table 3 shows that even though 21 percent of all general aviation accidents are due weather, only 0.15 percent are due to an incorrect forecast. Therefore, within the scope of this study, the potential benefits to be gained from improved weather prediction are minor.

From 1964 through 1967, the data indicate that there were approximately two fatalities per fatal accident, or an average of 12 fatalities per year attributable to incorrect weather forecasts. The NTSB data regarding equipment damanged or destroyed in weather involved accidents in 1966 show 263 aircraft were destroyed and 633 aircraft were substantially damaged. The data for 1964 through 1967 show a total of 32 accidents in which an incorrect forecast was a cause-related factor, or an average of 8 accidents per year. Applying the factors for 1966, we get

$$\frac{263}{896} \times 8 = 2.4 \text{ aircraft destroyed per year}$$

$$\frac{633}{896} \times 8 = 5.6 \text{ aircraft damaged per year}$$

There were undoubtedly injuries sustained in some of the nonfatal accidents. The number of nonfatal accidents in which incorrect forecasts were a cause-related factor for these years was 7 (32 total minus 25 fatal), which averages approximately 2 per year. Assuming two persons were involved in each accident, we can estimate the injuries as 4 per year.

The table below presents a summary of the maximum potential benefits due to improved weather prediction (i.e., if all hazards were forecast accurately):

	Yearly Losses, 1968
Fatalities	12.0
Injuries	4.0
Aircraft Destroyed	2.4
Aircraft Damaged	5.6

Based on NTSB data, Table 4 presents the accident trend in terms of accident rates per hour and per plane-mile for 1957 through 1967. These data show a conclusive trend toward decreasing accident rates.

The linear extrapolation of this trend to 1985 shows an expected accident rate (per 100,000 hours) of 15, compared with a rate of 28.5 in 1968, thus giving a factor of 0.525 (15/28.5), which reflects the potential technological improvement. Using another linear extrapolation, based on FAA data, we can forecast 47.5 million hours of general aviation activity in 1985, compared with 20.5 million hours in

Table 4

ACCIDENT RATES

	100,000 Hours		Million Plane Miles	
	Total	Fatal	Total	Fatal
1957	38.4	4.0	2.9	0.31
1958	36.4	3.1	2.8	0.23
1959	35.5	3.5	2.7	0.26
1960	36.5	3.3	2.7	0.24
1961	34.0	3.1	2.5	0.23
1962	33.4	3.0	2.5	0.22
1963	31.0	3.2	2.3	0.24
1964	32.2	3.2	2.3	0.23
1965	31.4	3.2	2.0	0.21
1966	25.8	2.6	1.6	0.17
1967	27.1	2.6	1.7	0.17

1968, which results in a factor of 2.32 (47.5/20.5) and reflects the expected increase in general aviation activity.[1] These two trends tend to cancel each other out and result in a modest (0.525 x 2.32 - 1.22) factor for use in forecasting the increase in losses for 1985.

We have not placed a dollar value on fatalities and injuries.[2] However, assuming a value of $16,000[3] per destroyed aircraft and $6,000 per damaged aircraft, the total losses for 1968 and 1985 become

- 1968
  - 12 fatalities
  - 4 injuries
  - $72,000
- 1985 (1.22 x 1968 values)
  - 15 fatalities
  - 5 injuries
  - $88,000

There are approximately 1,000 general aviation accidents per year in which weather was a cause-related factor but the forecast of those weather conditions was essentially correct. This implies that some private pilots are either not receiving weather briefings or are not reacting properly to them.

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1. FAA Office of Policy Development, Aviation Forecasts Fiscal Years 1967-1977 (January 1967).

2. We are, however, familiar with a number of recent studies that do. But the assumptions they require to arrive at a quantitative figure are so open to question that we doubt the value of their results.

3. A 25-percent inflation of the Bollay values.

AIR CARRIER DELAYS

In addressing the question of the delays attributable to weather for commercial air carriers, we should understand that there are many factors that act and interact to cause all air carrier delays. According to a recent FAA study,

> Delays in terminal areas can be the result of a multitude of causes. Weather, runway capacity limitations, taxiway provisions, approach and departure routes, limited ramp space, ARTCC capacity limitations, and aircraft scheduling to name a few.[1]

The study goes on to say that some airport configurations have runway capacities that vary greatly depending on weather conditions. It emphasizes the strong dependence of weather delay on instrument landing system capabilities at an airport:

> A new parallel runway at an airport will add substantial VFR capacity. In IFR weather, however, the magnitude of the increase depends on whether or not the operations on one runway can be controlled independently from operations on the other. For example, a single runway in IFR can land about 35 aircraft per hour or about 40 mixed operations (i.e., landings plus takeoffs). The capacity for close parallel runways (separated by less than 3,500 feet or as specified in ATP 7110.8) is about 50 IFR operations per hour, whereas under VFR conditions the capacity of close parallels is about double that of single runway. If the runways are separated by more than 3,500 feet, the IFR capacity for handling approaches independently from departures is about 70 operations per hour, i.e., one four minute delay if arrivals equal departures. Additional close parallel runways will not increase the IFR capacity unless simultaneous instrument approach capability is provided. With simultaneous instrument approach capability, IFR capacity can be increased to about 140 operations per hour depending on the number of departure runways.

We collected data from a major U.S. trunk carrier showing its operating experience with respect to weather delays for 1968. These data are summarized in Table 5. Figure 2 shows the expected seasonal pattern for the percentage of

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1. FAA, Alternative Approaches for Reducing Delays in Terminal Areas, Report No. RD-67-70 (November 1967).

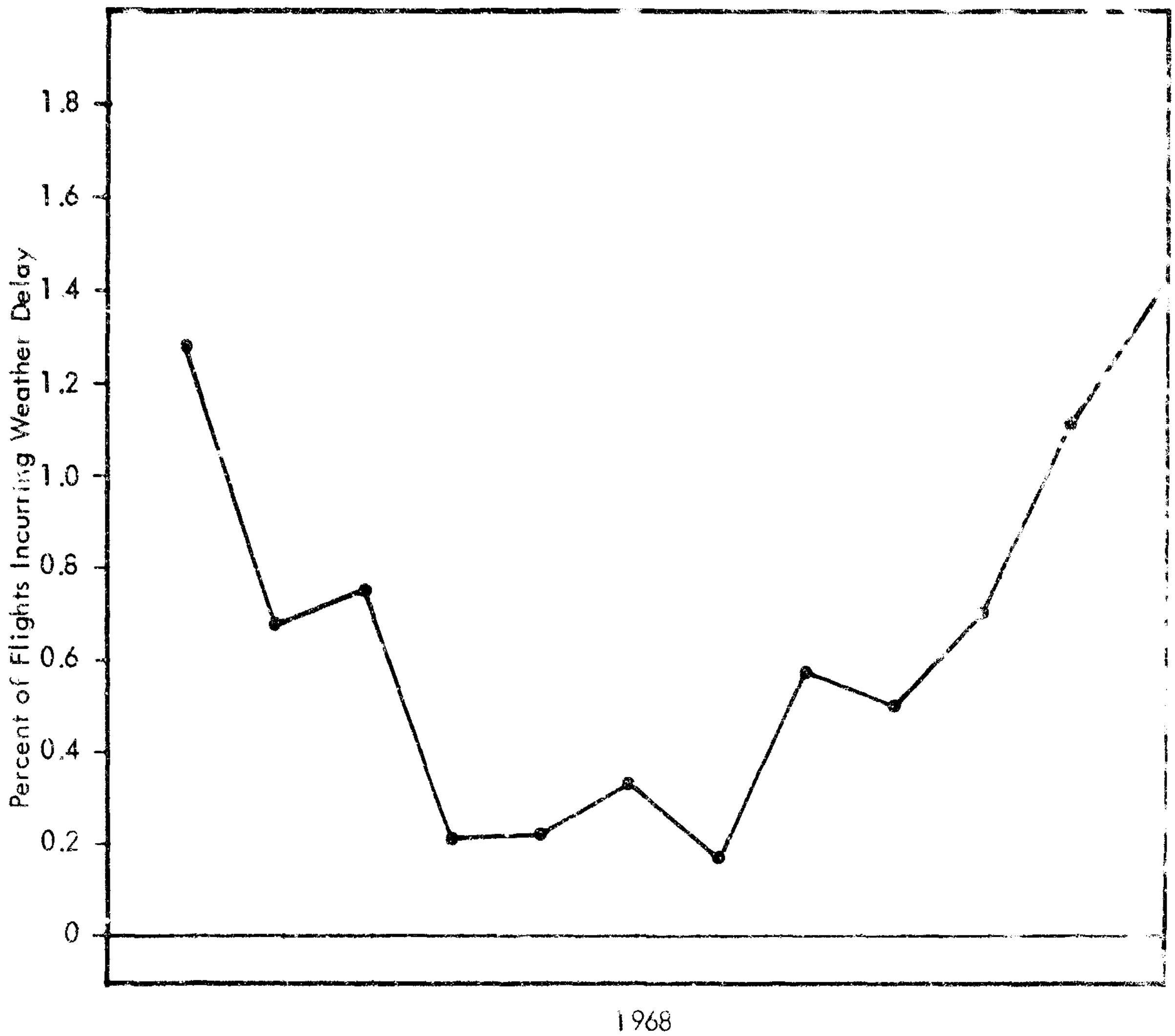

Figure 2: MONTHLY WEATHER DELAYS--MAJOR TRUNK CARRIER

flights experiencing weather delays. These data were aggregated to form the following yearly average factors for this carrier:

- 0.65 percent of all flights incur weather delays,
- 55 minutes is the average delay per incident, and
- 241,000 minutes of weather delays occurred in 1968.

Table 5

WEATHER DELAYS FOR A TRUNK CARRIER

	Number of Scheduled Flights	Number of Incidents of Weather Delays	Minutes of Weather Delay
January	55,935	713	34,737
February	55,281	374	17,597
March	55,544	415	23,330
April	54,257	115	5,346
May	55,814	123	3,755
June	54,511	183	7,991
July	56,824	102	3,488
August	56,648	319	20,586
September	54,211	261	16,145
October	56,623	394	25,529
November	53,668	598	37,572
December	55,688	785	44,906
1968	665,024	4,382	240,982

Assuming a cost of $20 per minute of delay, the total cost of weather delays to this carrier was approximately $2.4 million in 1968.[1] At the same time, flight delays from other causes are estimated to have cost at least $24 million in 1968, which represents a 10 to 1 ratio to the delays caused by weather.

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1. An average of four-engine and three-engine passenger jet costs from FAA report, p. 47.

Extrapolating this particular carrier's experience, we estimate that the total U.S. weather delay penalty to all U.S. trunk and local service airlines was approximately $11.8 million in 1968, on the basis of revenue miles. Unfortunately, the rules that define a weather delay are not precise; the pilot determines the cause of delay when he submits his report. Therefore, it is impossible to estimate what portion of the reported delays, if any, might have been avoided with improved prediction. However, we can assert that the total weather delay costs will be small in comparison with all delay costs. We will, therefore, assume that 50 percent of the delays reported as weather incurred could be avoided with complete foreknowledge of weather conditions.[1]

In addition to the cost of delays to the airline, there are the indirect costs to the passengers. There was a total of 22,000 hours of weather delay in 1968 (extrapolating the data we obtained), and the average number of passengers per plane was 50. If we assume a passenger's hour is valued at $20, the maximum cost of lost passenger time was $11 million. Applying our 50 percent assumption to the two delay cost totals, we arrive at a theoretically recoverable total of approximately $11 million for 1968 (50 percent of [11.8 + 11]).

The FAA document we used to project general aviation activity also contained projections of air carrier growth.[2] Using a linear extrapolation of these data, we found that the expected increase in air carrier operations results in a growth factor of 2.35 over 1968 traffic. To estimate the discounts associated with technology, we used a 50-percent improvement rate at airports with FAA control towers (322) and a 25-percent improvement rate at other airports receiving scheduled service (202). The requirement for improvement is universal, but we believe that the

1. We assume that this knowledge will be used to regulate traffic flow and match the flow with terminal acceptance rates. This will reduce the duration, not the number, of delays.

2. FAA report, Aviation Forecasts 1967-1977.

larger terminals, which have heavier air traffic, will receive greater attention. The result is a weighted technological improvement factor of 40 percent:

$$\frac{322(5) + 202(25)}{524}$$

The combined factor used for the 1985 projections of air carrier avoidable delay costs is 1.41 : (2.35 x 0.6).

The following are estimates of annual air carrier delay benefits for 1968 and 1985 associated with perfect prediction:

- 1968: $11 million
- 1985: $15.5 million

AIR CARRIER CANCELLATIONS

Flights are not cancelled unless absolutely necessary. This is due partly to the costs involved in having a plane sit idle on the ground and partly to passenger service competition within the industry. Short-haul flights are cancelled more frequently than long-haul flights, because the alternates may be as far away from the destination as the origin and feeder operations are often flown into airports with unsophisticated approach and navigation aids.

Table 6 shows the operating experience of a major U.S. air carrier (trunk and feeder) with respect to weather cancellations. These data are plotted in Figure 3, which shows the percentage of total flights cancelled and the percentage cancelled because of weather.

Figure 4 presents the direct relationship between cancellations and delays for this carrier. It is interesting to note the very similar pattern of these impact variables. In the winter months, when there is more likelihood of airports being shut down for long periods of time, there are more cancellations than delays. However, in the summer months, when weather interruptions are of relatively short duration, there are more delays than cancellations.

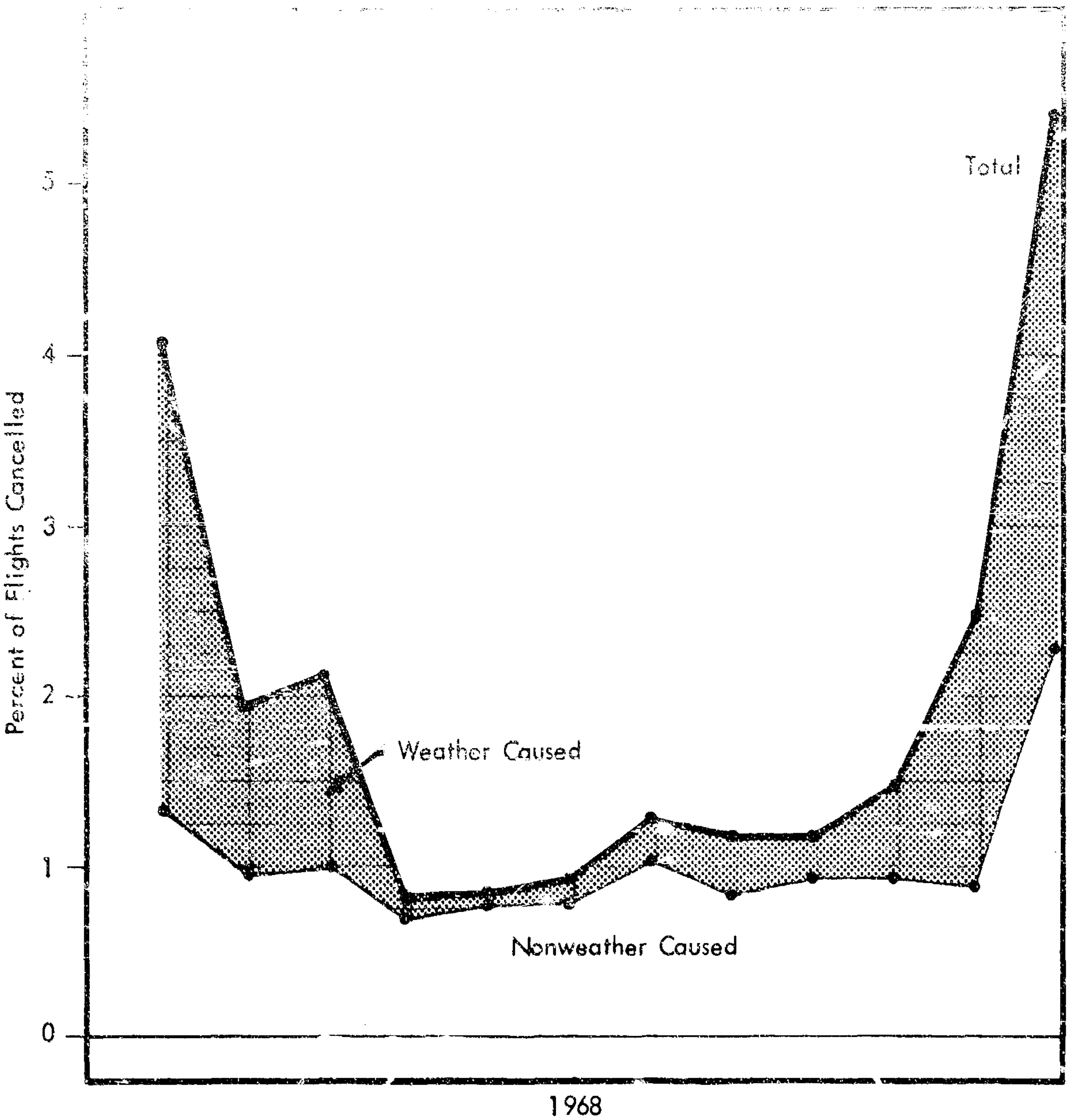

Figure 3: CANCELLATIONS

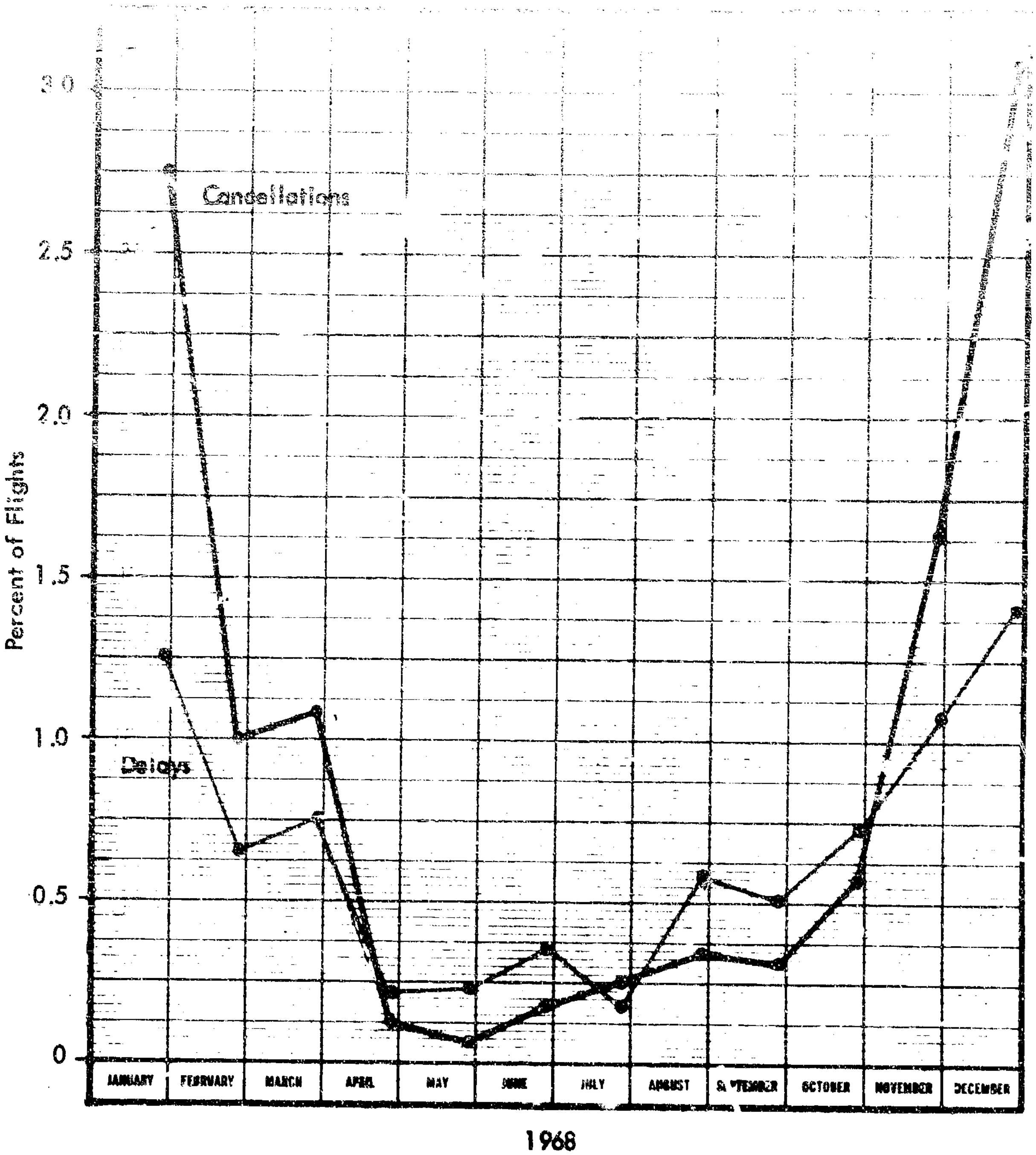

Figure 4: CANCELLATIONS AND DELAYS DUE TO WEATHER

TABLE 6

WEATHER DELAYS FOR A MAJOR TRUNK AND FEEDER AIRLINE, 1968

	Number of Scheduled Flights	Number of Flights Cancelled	Number of Flights Cancelled--Weather
January	55,936	2,289	1,[illegible]45
February	55,281	1,085	[illegible]33
March	55,544	1,135	628
April	54,257	455	69
May	55,314	470	40
June	54,511	513	92
July	56,824	727	134
August	56,648	663	176
September	54,[illegible]11	633	141
October	56,623	845	326
November	53,668	1,335	860
December	55,688	3,014	1,739
1968	665,024	13,214	6,303

According to industry spokesmen, weather cancellations are usually associated with existing conditions that are predicted to persist through the period in which the flight can be scheduled. These predictions have a very high degree of reliability, largely because of the nature of the weather phenomena--heavy and widespread snowstorms, snow and ice accumulation on the runways, etc. Recoverable costs would, of course, be associated with unnecessary cancellations, where conditions improve unexpectedly after a cancellation. However, our data provided no recorded instances of this, and therefore we can assume that it rarely occurs.

When destination conditions remain below minimum after a flight is underway, the potential for savings occurs in only two cases--when the aircraft is forced to return to its point of origin or when it has to divert to an alternate that represents no significant forward movement of passengers and cargo. Diversions were an important problem in the early days of commercial aviation. However, this is no longer true and most of the carriers we spoke with do not keep records of the frequency or cost of diversions.

Based on our analysis, we believe that the recoverable costs of cancellations and lost opportunities to cancel from improved environmental prediction will be negligible.

AIR CARRIER DIVERSIONS

Diversions occur when an aircraft cannot land at its primary destination and must proceed to an alternate facility. Diversions are caused by mechanical difficulties in the aircraft, approach system failure at the terminal, stronger than forecast headwinds, below minimum terminal conditions, and, more recently, hijackings.

Except for hijackings, there has been a steady and marked reduction in the number of unexpected diversions. Aircraft and electronic equipment have become extremely reliable, wind prediction is much more precise at jet altitudes, and landing weather minimums have been progressively lowered, reducing the number of hours that operations must shut down.

An expected diversion is acceptable to the carriers, particularly on long-haul flights, if the alternate is reasonably convenient to the intended destination and most of the forward movement has been accomplished. It is more acceptable than a cancellation that gives no opportunity to recover heavy fixed costs. As one airline official put it, "If our flight from New York lands at Ontario [California] instead of Los Angeles, our passengers are a lot closer to where they want to go than when they started. And we'll get them there as fast as we can."

There are, however, costs associated with weather diversions. The Air Transport Association gave a current average cost of $3,000 per diversion for a Boeing 707. There are also the costs to the passengers for the extra time required, but these may well be lower than the cost of a cancelled flight.

[illegible] significant, [illegible] considered diversions of sufficient importance to record their frequency or costs.[1] Another carrier told us that they had accumulated some statistics but they were reluctant to expend the effort necessary to break them out of the general file. Since the air carriers could not supply the data necessary to determine what portion of the costs could be recovered by improved prediction, we must discuss such costs conceptually.

As noted previously, there is no advantage to be gained by cancellation, except in rare cases when the aircraft accomplishes no real forward movement of its payload. The cost impact of an unexpected weather diversion can be partially reduced if the forecast allows more time to optimize the flight plan to the alternate destination and alert the receiving facility. Examples of these types of diversions occurred during a heavy snowstorm along the northeast coast in 1969. Such experiences are infrequent however, and we must conclude that the annual total of recoverable costs is insignificant.

CONCLUSIONS

In sum, the annual recoverable costs and losses for the several categories of activity in 1985 are as follows.

Category	Amount
General Aviation	
Fatalities	15
Injuries	4
Aircraft Loss	$88,000
Commercial Air Carriers	
Delays	$15.5 million
Cancellations	Negligible
Diversions	Negligible
Military (Transport)	
10 Percent of Commercial Air Carriers	$1.5 million

1. Hijacking diversions are undoubtedly an exception, but they lie outside the realm of this study.

Table 7 consolidates these potential savings and [illegible] pected at predictive improvement levels of 25 and 50 percent.

Table 7

ANNUAL RECOVERABLE COSTS--AIR TRANSPORTATION
(1985)

Level	Savings In	General Aviation	Commercial Carriers	Military Transport	[illegible]al
1	Fatalities	4			[illegible]
	Aircraft Losses	$22,000			
25 Percent	Operating Costs		$4.0 million	$0.4 million	$4.4 million
2	Fatalities	8			[illegible]
	Aircraft Losses	$44,000			
50 Percent	Operating Costs		$8 0 million	$0.8 million	$8 8 million
	Fatalities	15			15
3	Aircraft Losses	$88,000			
	Operating Costs		$[illegible].5 million	$1.5 million	$17.[illegible] million

7

GROUND TRANSPORTATION

This chapter is divided into two sections. The first presents our general findings, and the second presents an example of the study methodology.

GENERAL FINDINGS

This section discusses the types and amounts of economic benefits potentially available as a result of improved environmental prediction.

Railroads

Although environmental conditions affect railroad operations and costs, we found it impossible to assign a realistic dollar benefit to the role that improved environmental prediction might play in offsetting weather's adverse effects. However, we believe that the potential benefit from improved predictive ability is not significant. The reasons for this conclusion are enumerated below.

In 1968, the total snow removal budget for all railroads was $24 million, compared with the estimated $400 to $500 million snow removal budget for the nation's highways. Discussions with railroad officials resulted in few effective ways these snow removal costs might be lowered with improved predictability. Usually, snow removal equipment and crews are not deployed in advance of storms, so there appears to be little potential for economic gain from improved prediction. They further said that earlier and more accurate weather forecasts would have little effect on the efficiency and effectiveness of their current operations. However, it must be noted that railroad officials were unable to produce significant quantitative justification for their stand; they had not previously considered this type of problem.

A study of the effects of ice storms on railway operations evaluated the impact of ice storms on railway operations and examined the effects of ice storms on loss of communications and signal systems.[1] This study concluded that ice storms do not appreciably affect railway operations directly, but that communication and signal systems are significantly affected, thereby disrupting rail operations and delaying service, which affects passengers and perishables. In such situations, there appear to be few effective ways to take advantage of improved weather prediction. Perhaps better emergency-crew training and, in the long run, underground cables and conduits might help.

Hurricanes and floods have a significant effect on railroad operations. Recurring flood situations, such as along the Mississppi River, and flash floods resulting from hurricanes are two distinct types of problems. In a flood-prone area, measures are taken that are permanent in preventing destruction caused by high water. For example, tracks are usually built up and fortified at vulnerable locations to protect embankments and shoulders against the action of waves and currents. In addition, temporary measures are taken that must be repeated with each flood to be effective (e.g., sandbagging). Of the two, permanent protection is the more important in the total scheme of flood protection. Permanent protection, when developed and improved over a period of time, will diminish the potential magnitude of benefits possible from improved prediction.

In 1969, the Mississippi River floods were predicted well in advance. Apparently, the joint efforts of the Weather Bureau and the Army Corps of Engineers have over time become quite effective in predicting when, where, and how high floods will crest on the Mississippi. Thus, it appears that the potential for improving on present predictions in existing flood areas is quite limited.

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1. William W. Hay, "Effect of Ice Storms on Railroad Transportation," Section 2B of Climatic Criteria Defining Efficiency Limits for Certain Industrial Activities (University of Illinois, Department of Geography, undated).

The potential economic benefits appear to be greater regarding flash floods or hurricanes. If the time and intensity of such environmental effects could be predicted more accurately, several types of alternative actions are open to railroads to prevent loss of property and disruption of schedules. An article in Railway Age indicated the types of preparations made by railroads based on warnings of an impending hurricane:[1]

- Car brakes set and wheels chocked.
- Section crews stationed at key points for immediate repair.
- Standby power plants maintained.
- Signal and communications crews alerted and facilities protected.
- Wreck trains stationed at both sides of affected areas.

The amount of damage that might be prevented by such preparations will, of course, depend on the situation. However, we were unable to find any significant data on the amount of damage prevention.

In talking with C&O and B&O officials after Hurricane Camille, we learned what types of losses were incurred and which of these could possibly have been prevented with improved prediction. The C&O and B&O suffered an estimated loss of $1.2 million from damage to equipment, roadbeds, bridges, tracks, and other facilities. Additional losses were not included in the above figure, such as rerouting and rescheduling of passengers and freight, which resulted in higher costs of operations and losses of revenue. Included in the $1.2 million were the following:

- a freight train with perishables trapped for an extensive period of time,
- a major bridge washed out for more than two weeks, and
- 600 freight cars in a yard completely inundated.

The first and third situations could have been avoided. However, the cost of cleaning and repairing the freight cars was $10,000, and the loss attributed to the

1. Railway Age, 127 (1949), 1006.

stranded train was probably not much more. In dollar terms, the property losses, such as the bridge washout, were probably much more significant. But it is doubtful that early warning would have substantially reduced these property losses. At best, improved prediction would have added a few hours to the warning time. To have estimated the likelihood of bridge washout, railroad officials would have needed information on the height and velocity of the James River at flood crest stage, as well as up-to-date information on the stress resistance of the bridges. Even then, there would have been insufficient time to take the necessary preventive steps. Officials say that this type of damage, by far the largest economic losses in this and similar environmental disasters, could not have been prevented even with earlier and more accurate prediction.

The scheduling of additional passenger services in bad weather to pick up diverted traffic from air and highway modes was another type of benefit we investigated. However, railroads are not as conscious of passenger convenience and comfort as the airlines. The general attitude of railroad officials is that these passengers are only occasional railroad travelers and short delays while extra cars and trains were put together is not unreasonable. Further, they said that they would take little or no action to improve passenger service based on improved prediction. They pointed out that primarily commuter services and short-haul transit were affected by overflow traffic in bad weather. In general, the long-distance air passenger will delay or cancel his trip rather than go by rail.

In future analyses of this type, the effect of weather prediction on commuter services and short-haul transit should be investigated further, since the future trend to high-speed luxury trains may result in a rejuvenated demand for improved prediction. It should be noted, however, that the high-speed routeway may well be covered or undergro[illegible] over a sizable portion of its length, thereby reducing significantly potential economic benefits.

Railroad freight movements are also affected by major storms. We asked railroad officials whether there might be substantial benefits from rescheduling and rerouting freight traffic based on improved prediction. Their answer was generally negative, although they provided insufficient rationale for their response. One hypothesis might be that the railroads can normally do better than their closest freight competitor, the truckers, so they are under no compunction to expend additional funds to improve schedules, based on improved prediction. Officials say that customers will forgive slight delays of merchandise due to bad weather, but they will not accept excuses for other types of delays.

Railroad officials are unaccustomed to thinking about the contribution of weather prediction to their operations; consequently, our data did not enable a quantitative assessment of the potential benefits of improved forecasting. If someone attempted a definitive assessment of the benefits, he would have to design a data collection and analysis project and ask the railroads to provide the type of data needed. A partial guide to such types of data requirements is provided in our example of highway snow removal benefits in urban areas.

Highways

The potential benefits of improved prediction to those who use and maintain the highways is significantly greater than potential benefits to the railroads. The greatest potential benefit appears to result from the mobilization of removal crews in the event of an impending snowstorm; however, as we shall show, this is also the area where highway departments are currently utilizing private consultants to provide timely and specific predictions.

The types of benefits resulting from improved prediction for highway users are:

- potential profits for commercial carriers, bus, and trucking firms;
- fewer accidents, resulting in economic savings to life and property; and
- time savings and convenience for individual motorists.

The types of benefits for highway maintenance officials are

- increased efficiency of operations, resulting in lower costs, and
- reduced incidence of accidents and increased convenience to highway users resulting from more rapid clearing of highways.

Highway User Decisions

The trucking industry is one area where the benefit potential is significant; competition encourages efficient trucking operations. By proper use of weather information, truckers can in theory adjust schedules, plan alternate routes, postpone operations, reschedule personnel, select proper equipment, and brief drivers. Such actions could minimize delays caused by weather, and improve the overall efficiency of trucking operations. Minimum trucking delays and improved efficiency mean savings in operating costs. Additional savings could be realized because of reduced accidents.

We talked with officials of the American Trucking Association and several major trucking companies to determine whether the above benefits would result from improved environmental prediction. Currently, truckers use very little environmental prediction information in their scheduling operations. Schedules are very important to truckers, and every effort is made to meet these schedules, even if it entails the possibility of encountering bad weather. The ways by which weather information might be used by truck lines are many: reschedule times, reschedule routes, reschedule points of origin and destination, etc. All such scheduling decisions are highly interdependent. Once juggling begins, it is difficult to optimize scheduling based on improved predictability, especially since the prediction itself might change. Such scheduling decisions require expensive computer systems and supporting information systems to disseminate the results. Currently, the benefits from improved prediction cannot offset the costs involved, especially since the truckers do not, in general, take advantage of the types of time and route-specific forecasts currently provided by private consultants. It would take a concerted effort in the entire industry to implement, across the board, any improved scheduling systems based on weather prediction, since there are a large number of companies in the industry, many of which are too small to develop and use complex scheduling systems.

Buses have difficulty rescheduling their operations to take advantage of improved weather prediction. Bus companies must operate according to published time schedules and travel routes, and cannot change these schedules and routes on the basis of expected weather. During major storms, changes in schedules and routes are sometimes made; however, these changes are really adjustments on the basis of existing weather conditions rather than forecasts.

The reaction of individual highway motorists to improved predictability is an area of many unknowns. The relationship between accidents and weather has not been adequately established. It is very difficult to separate each of the causes of accidents (driver, highway, weather conditions, etc.) since all such causes are, to a certain degree, interrelated. The principal evidence we have is that more accidents occur in bad weather than in good.[1] The link between motorist behavior and improved weather prediction is even more of an unknown. Data have not been collected on the rescheduling decisions of motorists having information concerning impending storms. Information is needed concerning whether (and under what conditions) trips are postponed or cancelled, and whether alternate routes are chosen. In discussions with a Massachusetts Turnpike Authority statistician, we learned that revenues from tolls fall significantly when bad weather is predicted. In addition, the American Automobile Association operates a teletype system for disseminating predictive information to motorists in the Northeastern United States. Thus, there appears to be some potential for benefits in this area, but further research is needed to estimate the magnitude of such benefits.

The need for improved predictability for motorists is only a part of a total system that would enable motorists to have access to weather information. The improved predictive information, unless combined with extensive dissemination,

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1. To review the effects of weather on highway accidents, see United Aircraft Corporation, Highway Weather Service Preliminary Design Study, prepared for ESSA, U.S. Department of Commerce (December 10, 1965), pp. 6 and 7.

would not prove to be effective. It is likely that more environmental predictive information is currently being generated than is effectively being disseminated to the driving public. In addition, no mechanism provides motorists with a rescheduling and rerouting system similar to that potentially available to trucking firms.[1]

Highway Official Decisions

Highway maintenance operations are affected by weather to a much greater extent than we originally thought. Snow removal, in particular, absorbs a large part of city and state highway maintenance and operating budgets. A good deal of a highway department's equipment is specially designed for snow removal and cannot be converted to other uses. Large municipalities have complex snow mobilization plans that outline a year's activities to prepare for snowstorms; for example, salt and abrasives are purchased in the summer; contractors for emergency situations are hired in the summer and fall; men and equipment are tested in late fall to determine their degree of readiness; priority streets for removal, vehicular travel, and parking are identified; alert systems for removal and policing personnel are established; etc. Weather prediction is considered an important factor in this process. A recent article on the costs of snow removal in New York City notes the following complexities connected with conducting snow removal operations:[2]

> Undoubtedly, the greatest factor of cost control in snow and ice removal is the command requirement for decisions as to what operational procedures are to be employed in meeting any given snow situation. These decisions are based primarily upon the available pertinent data at the time of the storm. Some of these are: the day of the week and the time of day as relating to urban activities;

1. However, the weather service of the American Automobile Association may be a model for some more comprehensive and more widely available service.

2. Joseph T. Lennon, "Cost Analysis of Snow and Ice Control Operations," American Public Works Association Yearbook (1967), p. 158.

weather conditions; traffic conditions; predicted snow fall; rate of fall; duration of fall; long-range weather forecasts; and of paramount importance, the availability of manpower, equipment, and materials such as chemicals. Yet in order to be at a stage of maximum readiness of any snowfall, all of the above factors have to be studied in endless combinations well in advance of the snow season itself. In New York City we are concerned with the answers to these questions beginning with the end of the snow season in April right up to the time that a decision must be made on the methods to be employed for each snow situation.

In a following section, we develop the cost savings associated with improved weather prediction in urban areas. Data were not available to permit a similar quantitative analysis for the intercity problems of snow removal as affected by prediction. However, the analysis for the urban case will be used to estimate the benefits from improved prediction in the intercity setting, based on the similarities between the two situations.

State highway departments and transit authorities are the principal public bodies involved in the intercity problems of snow removal as affected by prediction. We contacted the following state operations and maintenance departments, which seemed to represent the areas of greatest traffic and snow hazards.

- New York State Department of Transportation (NYSDT)
- New York State Thruway Authority (NYSTA)
- Massachusetts Turnpike Authority (MTA)
- Pennsylvania Turnpike Authority (PTA)
- Illinois Division of Highways (IDH)
- New Jersey Highway Department (NJHD)

In addition, the Bureau of Public Roads, U.S. Department of Transportation, contributed to this facet of the study.

Some of the principal findings are as follows:

- Varying budgetary figures were provided by the agencies for the costs of their snow removal, but in all cases the estimated dollar amounts were quite large.

- NYSTA estimates that one half of its annual budget of $16 million is for snow removal.

- NYSDT estimates a snow removal budget of $18.6 million. Counties have the option of providing their own removal services.

- IDH spends about 15 to 20 percent of its annual maintenance budget of $64 million for snow removal.

- All agencies report that they rely heavily on forecasts for mobilizing their snow removal forces. For example, NYSDT reports that they are provided with estimates of the time of arrival of a storm by county and by the intensity of the storm. These estimates alert maintenance personnel. The nature of the forecast will determine how many people and trucks to employ as well as method of removal (plowing versus salting) and type of material (calcium chloride or a mixture of salt and calcium chloride).

- The alerting of crews in advance depends on the priorities established for highway traffic. Major expressways and intracity commuter arteries place a significant weight on maintaining dry pavements and, consequently, on the early alerting of removal crews. Rural and lower priority roads often do not begin operations until precipitation begins. A good example was provided by Illinois.

  - A center in Springfield controls snow removal operations of nine of the ten districts in Illinois. The tenth district, representing the Chicago area, has its own center. The Chicago Control Center is much more sophisticated than Springfield's because of the expressway system in and around Chicago and the need to move commuters in and out of the city. Chicago employs more removal personnel per mile of highway than the rest of Illinois. They mobilize salting crews approximately two hours before the snow starts. The remaining nine districts wait until a quarter or half inch of snow has fallen before initiating operations.

- The need for location and time specific forecasts was cited in several instances. Pennsylvania represents an example.

  - There are major county road commissions and garages operated in the state, so that the man in Altoona knows it is snowing 70 miles to the west. However, he does not know when it is going to hit him or how hard it will hit his area. It makes a difference whether it is going to start snowing at 5 p.m. or at 8 p.m. and how many inches will fall. This is where the forecast has an impact. The way one goes about planning and mobilization will be altered quite a bit.

- NYSDT, NYSTA, MTA, PTA, and NJHD all employ the weather prediction services of the Northeast Weather Forecasting Service (Bedford, Massachusetts). IDH utilizes two forecasting firms--one in St. Louis and the other in Chicago. Most of the agencies sampled believed that their requirements for environmental prediction were being met by the present consulting forecasts they receive. Typical comments are as follows:
  - NYSTA has a direct teletype line with Northeast. They get a daily forecast in the afternoon before the crews go home so that they know whether it will be necessary to work into the evening or night. Any change in weather conditions is transmitted immediately to NYSTA. In addition to reporting snowstorms, Northeast recently added a forecast for fog. NYSTA reports that forecasts are provided far enough in advance for them to plan and mobilize. They get forecasts with a "high degree of accuracy."
  - [illegible]A says that Northeast has been able to predict the occurrence, intensity, and time of arrival of snowstorms "95 percent of the time." This is probably a subjective estimate, but it does illustrate confidence in the service.
  - IDH was satisfied that present consulting services provided the accurate two-hour warning time needed.
  - NJHD reports 80 percent accuracy of forecasts and satisfaction with present services.

That the major highway users are satisfied with the forecasts they currently receive does not necessarily indicate that there is little or no benefit to be achieved from improved prediction. A shortcoming of the estimates is that their accuracy is generally based on best guesses rather than valid statistical measures of hits and misses. Highway departments in general have not developed such data over time. In addition, a system to improve predictability has not yet been developed, so that potential users of the system have not seen what the improved forecasts might look like and, consequently, have not considered how they might rearrange their operations to take advantage of them.

SNOWSTORMS IN METROPOLITAN AREAS

Snow and ice control in urban areas is a major activity in a large portion of the U.S. During the severe winter of 1960-1961, Washington, D. C., Philidelphia, and New York, which had a total population of 10.5 million, spent about $35 million fighting snow (and ice).[1] Of the 112.3 million people residing in all metropolitan areas in 1960, about 67 percent lived in regions that average more than ten inches of snow per year.[2] As a rough approximation, the three cities' snow (and ice) control costs represent 14 percent (= 10.5/[112.3][0.674]) of the national total for that year. Further, snow and ice control in metropolitan areas costs about $200 million per year, based on our calculations.

How much of these snow removal costs could be saved with improved environmental prediction, and how could improved prediction reduce the costs of accidents and traffic congestion? In speaking with municipal government officials and reading the studies dealing with the procedures of snow and ice control, we acquired an understanding of the mechanisms involved in determining the costs of fighting snow in urban areas. A detailed analysis was made of snow control costs, accident costs, and traffic delays in Washington, D. C., to see how improvements in predictive ability would affect these costs. We used Washington as a model for projecting these potential benefits to a national scale, including both the central city and suburban segments of metropolitan areas. These results were then projected to 1985.

Potential Benefits from Improved Prediction

Records of snow control activities for three winter seasons in Washington, D. C., were obtained and analyzed.[3] These records contained the U. S. Weather Bureau

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1. D. C. Office of the Engineer Commissioner, Traffic Snow Emergencies in Washington, D. C. (1961).

2. See derivation in Appendix C.

3. See Appendix A.

forecast that prompted the activities; the actual amount of precipitation; when the precipitation occurred; the timing of the mobilization and dispatch of spreading, plowing, and hauling units; the number of units participating; and a summary of the action. A report was made every time city forces engaged in snow control activity. From November 1966 to March 1969, 40 such events occurred. In addition, 15 minor storms occurred that required no mobilization activity.

We were fortunate to have been provided with such a comprehensive set of data on the many variables required to establish the links between environmental prediction and snow removal action. These data were collected in much the same form that we would have required if we had set up a research project to test the methodology developed in the beginning of this report. However, we have been unable to find comparable data for other cities, so we have made an in-depth analysis for Washington and scaled up the benefits to a national level.

Since our purpose was to relate snow control costs to the accuracy of the forecasts, a number of characteristics of each of the events were extracted in our search for significant relationships, according to the method in Chapter 4. First, we made a subjective judgment of the quality of the forecasts, based on a comparison between the predicted and actual events.[1] The 40 events involving mobilization were classified as having "low or missed" forecasts, "good" forecasts, or "high or false alarm" forecasts. Low forecasts result in inadequate initial actions, often causing more traffic delays and higher ultimate clean-up costs. High forecasts prompt an inappropriately high level of initial activity relative to the actual intensity of the storm, and therefore excess costs. The 15 events involving a small amount of snow and no mobilization activity were classified as having "good" forecasts. These totals and the percentage distribution among the three categories of forecasts are shown in Table 8. Nearly half the events had forecasts that could not be classified as "good." A similar calculation was made on data from the Illinois Division of

1. The basis for this classification scheme is indicated in Appendix A.

Highways. It is interesting to note that the quality of the forecasts is very similar in these two cases, both of which represent different kinds of activities and different climatic characteristics.

Table 8

RELATIONSHIP OF SNOW CONTROL TO FORECAST ACCURACY

Classification of Forecast		Washington, D. C.		Illinois Division of Highways
		Number of Occurrences	Percent	Percent
"Low or Missed"		10	18.2	18.4
"Good"	No Action Action	15 14	52.6	57.8
"High or False Alarm"		16	29.2	23.8
Total		55	100.0	100.0

Since we observed that slightly less than 50 percent of the forecasts missed their mark (either high or low)--i.e., 47 percent in Washington and 42 percent in Illinois--there is a potential for improving forecasts and, consequently, generating economic benefits. We examined this potential in significant detail as to alert and mobilization requirements for snow removal in Washington with various combinations of accuracy and lead time of forecast. (The details of the procedures used and the results obtained are contained in Appendix A.) A major finding was that snow operations require a lead time for mobilization of one to two hours for most efficient and effective operations. In actual events, there were numerous snow and ice storms when such lead times were not provided by the forecaster. In these cases there were potential disbenefits to society that could be overcome by more accurate prediction.

There are three types of benefits that could possibly result from improved predictability and a more timely mobilization of snow removal crews. The first, and most obvious, are the possible cost savings to the city from more efficient snow removal operations. Second, the number of accidents would probably decrease when removal operations keep abreast of a storm. Third, there is a potential reduction in congestion, and consequently savings in traveler inconvenience and time, when streets are kept clean.

Savings in Snow and Ice Control Costs

Snow control officials say that their operations can be carried out most efficiently if the forecasts accurately predict the approximate intensity of the storm with sufficient lead time to allow crew mobilization. If the predictions do not meet these criteria, excess costs may be incurred by the city in its snow control activity. To the extent that deviations from the desired conditions can be eliminated, benefits from reduced snow control costs may be realized.

Benefits to the city, in terms of reduced snow control costs, can be obtained by reducing the number of instances in which the forecast was of the "low" type; our investigations showed that these forecasts result in higher costs than "good" forecasts with one-hour lead time. A second type of cost saving to the city is the prevention of false alarms, i.e., predicting snow that does not materialize. A third is derived from the prevention of early warnings, when crews are called out too early and sit and wait until something develops.

Data from three years of snow control operations in Washington were analyzed to produce the relationship between number of truck hours (a proxy for costs) and intensity of storm for "good" forecasts and various lead times for mobilization. Also derived were estimating relationships of truck hours for "high or false alarm" and "low or missed" forecasts.[1] These relationships enabled us to make comparisons among the costs of snow control for different storm and forecast accuracy conditions.

To estimate savings in snow removal costs, we used the following procedure. We took the record of the 55 snow occurrences in this three-season time period and compared the results of present levels of forecasting accuracy with those of three levels of improved predictive ability. For the base case, we applied the appropriate estimating relationships to the storm characteristics and forecast category for each

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1. See Appendix A.

of the storms. For the three successively better levels of predictive ability, we observed the snow control cost differences as more storms move to the category of "good" forecasts with one-hour lead time for mobilization. (The exponential form is used for storms with snow measuring more than a trace. Zero truck hours is used for storms with no snow or a trace.)

The three levels can be roughly described as 25-percent, 50-percent, and 100-percent improvement in predictive ability, with 100 percent representing "perfect" forecasts, i.e., elimination of all high and low forecasts and forecasts with lead times other than one hour. (Table A-1 in Appendix A shows this process and shows the anticipated differences in truck hours over this three-year period for the three levels of improvement.) Table 9 summarizes these results. Each successive improvement indicates a higher cost savings of snow control.

To translate these improvements into annualized costs, the cost per truck hour avoided must be calculated. In this setting a "truck hour" has many aspects that reflect a cost. The trucks may be city-owned or contract trucks. They may be specialized equipment (rotary blowers, spreaders) or trucks usually used for some other activity (sanitation, hauling) but adapted for snow control. The adapting devices may be chemical spreaders, plows, etc. The activities engaged in by these trucks range from waiting (at city facilities or at critical sites such as bridges and hills) to actual spreading of abrasives, plowing, or hauling. Nonproductive but essential activities such as refueling, travel to work sites, and emergency repairs also account for some truck hours. The cost to the city of a truck hour consists of the materials, labor, and equipment depreciation.

The calculation of the cost per truck hour is presented in Appendix A. The figure used ($22.62) is an average cost, accounting for equipment, materials, and labor. This is a valid cost, since we are talking about relatively long-range changes in the operating environment of the snow control activity. During the period of time needed to realize a given change in predictive ability, it is assumed that the entire level of operations could be changed so as to gain the potential cost savings indicated by the average cost figure.

Table 9

ANNUAL POTENTIAL BENEFITS FROM IMPROVED FORECASTING TO SNOW CONTROL EFFORT IN WASHINGTON, D. C.

Level of Improvement, percent	Potential Reduction in Truck Hours[a]	Annual Savings in Truck Hours	Annual Cost Savings,[b] dollars
25	13,560	4,520	90,900
50	22,970	7,657	173,500
100[c]	52,740	17,560	397,000

a. Three-year period.

b. One truck hour costs $22.62, as explained in text.

c. "Perfect" forecast.

When this figure is applied to the differences in truck hours associated with the three levels of improvement (shown in Table A-1 of Appendix A), we arrive at a measure of the benefits that could be realized by improved prediction over the three winter seasons. The resulting annual average potential savings are $90,900, $173,500, and $397,000 for the three levels of improvement (see Table A-2).

Preventing Traffic Accidents

As a result of investigating the causes of traffic accidents associated with snowstorms, we found that there are two areas of potential benefits from improved forecasting--eliminating accidents occurring during the early portion of a storm and eliminating accidents after the storm. Both are related to delayed action on the part of the snow control forces. The preventable accidents early in a storm would occur on streets that had not yet been salted. Accidents occurring after a storm would be associated with a delay in clearing due to a late start or a "low" forecast. In either case, an increase in the warning time for mobilizing forces or eliminating forecast errors on the low side should reduce the incidence of these types of accidents.

It is important to remember, however, that weather and road conditions are only some of the factors involved in causing accidents. In fact, there may be some adverse effect from maintaining better road conditions by means of better forecasting. Studies have shown that the unit cost of accidents on dry pavement is higher than on snowy pavement, because drivers are more cautious on snowy streets and drive more slowly, resulting in less damage and fewer personal injuries when accidents do occur. Eliminating accidents on snowy streets by means of better forecasting will probably result in a smaller number of more severe accidents.

Potential savings with regard to accidents were calculated in two ways, which provided a check on our results. First, the savings for Washington were estimated by extrapolations of data collected for Chicago.[1] As enumerated in Appendix B, we estimated that approximately 1,300 accidents annually--at about a cost of $250 per accident--could be avoided in Chicago.[2] Perfect forecasts would save the motor vehicle sector of the Chicago transportation industry about $325,000 per year.

On the basis of differences in the scale of activities and intensity of snowfall in Chicago and Washington, a ratio of the costs of accidents preventable was estimated to be 6 to 1. Using the 6 to 1 ratio, we estimated that the maximum savings in snow-related accidents for the District of Columbia would be $54,000 per year.

To check this estimate, the record of accidents in the District of Columbia was studied for a three-month period, using data provided by the D. C. government. We estimated a maximum annual benefit from accident prevention of $64,000 per year. This corroborates the $54,000 extrapolated from the Chicago study.

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1. APWA Research Foundation, Snow Removal and Ice Control in Urban Areas, Report No. 114 (1965).

2. The unit cost of accidents on snowy streets was reported at between $210 and $295 in the 1965 APWA study.

Assuming a straight-line relationship between predictive improvement and benefit, we get the following benefit estimates from three levels of improvement (based on the Washington data):

Level	Improvement in Reducing Number of Low or Late Forecasts, percent	Benefit to Washington, D. C. in Reducing Accidents, dollars
1	25	16,000
2	50	32,000
3	100 (perfect forecast)	64,000

An estimate for excess fatalities due to improved weather prediction was found to be relatively insignificant--i.e., eliminating up to 180 such accidents per year would reduce the death toll by about 0.3 deaths per year.

Benefits from Reducing Transportation Delays and Inconvenience

The delays and inconveniences suffered by the road users are affected by traffic characteristics, the layout and state of repair of the road system, the intensity of the storm and resulting visibility and road conditions, the emergency procedures established to combat the effects of snowstorms, and compensatory actions taken based on forecasts. It is this last effect that is of interest here.

Our investigation showed that the areas for reduction in the cost of delays are the same as for traffic accidents; late or low forecasts will cause excess delays both during the early portions of a storm and in the aftermath. Both of these effects are related to the level of snow control activity, which in turn is sensitive to forecast accuracy. The delays early in a storm are also affected by the number of people choosing to travel during that period of time, and this is also related to the accuracy of the predictions.

A detailed study of the forecasting effects on user delays would require information on traffic levels and trip durations under varying road conditions that were influenced by forecasts of varying levels of accuracy. Such data were not available for the Washington, D.C., area. During snow emergencies, a great strain is put on both the operating and administrative personnel in a city government, with physical and labor resources being shifted to temporary emergency duties. It is not surprising, therefore, that these data are unavailable.

The effect of predictive levels on user delays can be approximated indirectly. From 1954 to 1961, federal and municipal employees working in the District of Columbia were excused from work for a total of $34\frac{1}{2}$ hours during periods of snow emergencies. The cost for the hours of work missed averaged $2 million per year.[1] Government officials take action in concert to excuse employees from work in response to forecasts of severe snowstorms because of the cost, inconvenience, and dangers involved in having more than 200,000 motorists trapped on impassible highways. It is assumed that, based on the information available, the government officials take action for early release of employees (and consequently incur a loss in productive labor) to offset a social cost (due to delays) of a magnitude equal to or greater than the cost absorbed by the government in the early release. Thus, the decision to dismiss employees early was made in the belief that the costs of the delays avoided would exceed $2 million annually.

If the release decisions are based on forecasts of the same relative accuracy as those affecting snow control operations, then these forecasts would be distributed in the following way:

Low or missed forecasts	18.2%
Good forecasts	52.6%
High or false alarm forecasts	29.2%

The "good" and "high" forecasts result in early dismissal and the "low" forecasts result in delay costs that are absorbed entirely by the road users. If approximately 82 percent of the forecasts result in an annual cost to the U.S. and District

1. D.C. Office of the Engineer Commissioner, Traffic Snow Emergencies in Washington, D.C. (1961).

governments of $2 million, then the remaining 18.2 percent of the forecasts imply a cost to the travelers of $445 thousand (= [18.2/81.8]$2 million). This estimate is based on 1960 wages and employment levels. However, employment by the U.S. and District governments in Washington rose from 250,000 in 1960 to 261,000 in 1967, an increase of 4 percent.[1] If we use the increase in hourly wages in manufacturing in D.C. as an indicator ($2.20 in 1960 to $2.94 in 1968), there is an increase of 34 percent in the cost per hour of employees released and the hourly cost of delays.[2] Thus, an estimate of the annual cost of delays caused by low or missed forecasts, adjusted to present levels, is $620,000 per year (= $445,000 x 1.04 x 1.34) for Washington, D.C. Assuming a straight-line relationship between reduction in the amount of these inaccurate forecasts and a reduction in the cost of traveler delays, the potential benefits for three levels of improvement in predictive ability can be summarized as follows:[3]

Level	Improvement in Reducing Number of Low or Missed Forecasts, percent	Annual Benefit to Washington, D.C., in Reduced Road-User Delays, dollars
1	25	155,000
2	50	310,000
3	100 (perfect forecast)	620,000

To some extent, these estimates understate the actual benefits to Washington, D.C., from reductions in traveler delay and inconvenience. Government employment in the District accounts for about 52 percent of all employment.[2] When the federal government authorizes the release of its employees, many other employers follow suit, thus implying higher benefits than are presented above. Also, the figures above

1. U.S. Department of Commerce, Bureau of the Census, Pocket Data Book--USA 1969.

2. Pocket Data Book.

3. The savings to employers from reducing the incidence of high or false claim forecasts is a significant benefit, but outside the transportation sector.

were derived by equating the cost of user delays to government losses, whereas these delays may be considerably greater than the government's losses.

However, the concentration of workers in one industry and under one centralized control makes Washington rather unique. The release of citizens in other employment centers is the result of many diverse decisions. We assume, then, than an improvement in predictive ability will have relatively less of an impact in other cities. Therefore, the scaling to national levels in the next section tends to overstate the impact of improved prediction. In the absence of more detailed information, we hope that the understatement will cancel out the overstatement.

Extrapolation to Nationwide Benefits

Improving predictive ability in forecasting the onset and the intensity of snowstorms should reduce snow and ice control costs, the costs of traffic accidents, and the disbenefits associated with traffic tie-ups. Our experience with Washington suggests the mechanisms that would produce these benefits.

The costs that result from snow falling in an urban area depend on many interacting variables, some of which are quite random (such as time of snowfall, rate of fall, number of travelers on the road, etc.). The cost of an individual storm can be greatly affected by small variations in weather phenomena (such as ground temperature). The annual cost of urban snowstorms in an area is the result of many mechanisms responding to a host of influences, only one of which is the quality of the forecasts. To model these mechanisms and collect the pertinent data for every area in the U.S. would be extremely difficult. Consequently, we looked for a simple way to relate the D.C. estimates to a national scope with readily obtainable data.

Obviously, the snow removal costs for an individual storm increase with the amount of snow that falls (see Figures A-1, A-2, A-3 in Appendix A). Annual snow control costs in Washington reflect this phenomenon (see Appendix C, Figures C-1 and C-2). In comparing annual costs among cities, the city size also has a direct relationship to snow control costs. Our scaling factor thus reflects the variations in snowfall over the country and the size of the areas affected.

Comparison of Washington, D.C., with Other Cities

A relationship between potential benefits for Washington and for a group of the 75 largest cities with significant snowfall was derived in Appendix C. Our experience with the District of Columbia guided us in selecting a relationship that makes intuitive sense and fits our data. We found that Washington's share of the potential benefits for these 75 cities is 1.100 percent of the total. However, several of the smaller cities were not included on our list, so scaling factors were devised to provide for inclusion of the remaining central cities (details in Appendix C). The factor for scaling District of Columbia benefits to the total annual benefits for all cities was calculated to be a multiplier of 128.7.

In 1960, 63 percent of the U.S. population lived in the metropolitan areas listed as SMSAs.[1] Of these 113 million people, 54.5 million lived outside the central cities, which compares with 58.3 million central city residents. This represents quite a large target for potential benefits.

For this study, the suburban areas were assumed to be similar to small cities, in terms of the expected benefit response to improved forecasting. The same mechanisms of cost incurrence (removal operations, accidents, and delays) exist, and the suburban areas resemble many of the smaller central cities in their characteristics of land use and population density. For 1968 levels of population, the scaling factor between Washington's benefits and those for all suburban areas was calculated to be 260.

The benefits for the nation as a whole are thus found by multiplying the benefits for Washington by a factor of 388.7 (128.7 for central cities plus 260 for the suburbs).

Projecting to 1968 Activity Levels

Trends in the growth rates of urban and suburban populations were extrapolated into the future. Since the incidence of snowstorms is not likely to change over the

1. Standard metropolitan statistical areas as defined by the Bureau of the Census.

next few decades, any changes in the magnitude of benefits (aside from variations in price) would have to be due to increased activity levels. Population was chosen as the indicator of activity levels. The scaling factors derived for central cities and suburbs were then adjusted for projected changes in activity levels.

The assumptions that are important for the calculations carried out in Appendix C are as follows: that there will be no change in the fraction of U.S. residents living in regions with significant snowfall (67.4 percent), central cities will experience little or no net growth, and 70 percent of the projected growth in total population will occur in suburban areas. The scaling factors for central cities and suburbs at assumed 1985 activity levels (1968 prices) are 128.7 and 486, respectively (see Appendix C).

Adjusting for Technological Changes

It can be expected that the benefits from improved forecasting in 1985 will be relatively less than at present for cities of comparable size. The reasons for this stem from the changes that are likely to occur in transportation operations and from technological innovations in fighting snowstorms and reducing costs.

We would anticipate some decrease in street level traffic as more cities take action to reduce urban congestion. Some cities, such as Washington, will have new underground rapid transit systems to relieve the burden on city streets. There will also be an effect on traffic in the surrounding suburbs served by these systems and extensions of existing rapid transit systems. Other innovations such as fringe parking for commuters at rapid transit terminals will become more widespread and consequently reduce the volume of traffic. Such a reduction will make the total cost target smaller, thus reducing the potential benefits.

Technological advances have lowered the cost of snow fighting. These include the widespread use of salt on streets,[1] the development of more efficient machinery for snow control,[2] and the use of heated pavements on bridges, hills, and other

1. Used extensively in Washington only after 1945.

2. For example, hydraulic powered spreaders, vibrating snowplow blades, front loaders for snow hauling, etc.

isolated trouble spots. Snow removal operations have been made more efficient by the use of radio controlled equipment. There is considerable movement towards making automobiles safer, and there continues to be pressure for reducing the cost of accidents, in terms of personal injury and mechanical damage. While it is impossible to predict exactly what improvements will come in the next 15 years, it is assumed that improvements will occur. These can only contribute to lowering the potential for benefits due to improved weather forecasting.

A subjective estimate of the reduction in potential benefits is that 20 percent per decade is entirely feasible. Thus, benefits calculated for 1985 will be reduced by about 35 percent to account for the changes in operations and technology between 1968 and 1985.

Benefit Computation--National, 1985

Table 9 shows the summation of benefits at the three levels of improved prediction for Washington, D.C. Table 10 summarizes the derivation of the scaling factors for projecting the benefits found for Washington, D.C., to a national scope for the 1985 time period. The annual benefits for the three levels of improvement for the District of Columbia are shown in 1968 dollars. The resulting expected national benefits are then shown in the lower right-hand column.

Extrapolation of Benefits to All Aspects of Ground Transportation

In deriving estimates of potential benefits from improved prediction for snowstorms in urban settings, we illustrated a technique that could be applied to other settings. Given sufficient time and resources to gather and analyze appropriate data, we could derive estimates of the benefits associated with other elements of ground transportation. Our analysis of the urban snow problems, however, permits us to make rough estimates for the other areas of importance. These estimates are arrived at by comparing the magnitudes of the activity levels between the urban snow problem and the other elements of potential benefits (railroads and inter-urban highway transportation).

Table 9

BENEFIT SUMMARY FOR WASHINGTON, D. C.

Predictive Improvement Level	Annual Benefits, dollars	Activities
Level 1	90,900 16,000 155,000 261,900	Removal Accidents Delays Total
Level 2	173,500 32,000 310,000 515,500	Removal Accidents Delays Total
Level 3	397,000 64,000 620,000 1,083,000	Removal Accidents Delays Total

Table 10

SUMMARY OF NATIONAL BENEFITS-- IMPROVED FORECASTING OF SNOW STORMS IN METROPOLITAN AREAS

	Scaling Factors from Washington Benefits		
	Central Cities	Suburban Areas	Total Metropolitan Areas
1968 Activity Levels and Technology	128.7	260	388.7
1985 Activity Levels, 1968 Technology	128.7	486	614.7
1985 Activity Levels, 1985 Technology	84.0	316	400.0
Washington, D. C. 1968 Benefits for Three Levels of Predictive Improvement	Benefits - 1985 Activity Levels and Technology		
	Central Cities	Suburban Areas	Total Metropolitan Areas
Level 1 (25 percent) $261.9 thousand	$22.0 million	$ 82.7 million	$104.7 million
Level 2 (50 percent) $515.5 thousand	$43.3 million	$163.0 million	$206.3 million
Level 3 (100 percent) $1,083.0 thousand	$91.0 million	$34[illegible].0 million	$432.0 million

As discussed earlier, railroads have certain small potential benefits such as snow control and property damage reduction. The potential savings in the cost of delays, however, seem to be negligible. We will assume that the benefits attainable for railroads are comparable with those of snow in urban areas on the basis of the relative mangitudes expended for snow removal: $24 million annually for railroads, $200 million annually for metropolitan areas. Thus we can apply a factor of 0.12 (= 24/200) to the benefit categories of snow control and accidents of urban areas to get the corresponding estimates for the railroads. In our judgment, this appears to produce reasonable, if optimistic, benefit estimates.

We found that intercity highways were a source of benefits very similar to those for urban areas; snow control, accidents, and delays are all important. Using the relationships derived in Appendix C for extrapolating benefits, we estimate that the annual cost of snow control for the eight New York State cities in the sample accounted to about $24 million.[1] This compares with a total of $26.6 million spent annually by the New York State Thruway Authority ($8 million of its $16 million budget) and the New York State Department of Transportation ($18.6 million).[2] If the snow control cost of the suburban areas were added to the urban costs, the relationship between intercity areas and the total of metropolitan areas would be represented by a ratio of less than 1:1 ($26.6/$24 million + suburban costs). New York State is atypical of the country as a whole, however, in its great urban and surburban population. We will assume, therefore, that an overall ratio of 1:1 between potential intercity benefits and metropolitan benefits exists, and we will apply a factor of 1.0 to get the intercity highway benefits, a judgment factor that seems reasonable.

Table 11 summarizes the application of these scaling factors and lists the total estimate of benefits for the ground transportation industry as a whole. These range from $214.6 million annually for a 25 percent improvement in predictive ability to $886.1 million for the case of perfect forecasts.

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1. This was on the basis of population and snowfall as factors for scaling up New York City's average of $7.9 million.

2. See the General Findings section of this chapter.

The estimated benefits to ground transportation shown in Table 11 do not, of course, represent the total potential benefits from improved predictability. Such benefits do represent that proportion of total effects that could reasonably be quantified using the methodology developed in this study. Further research and data collection are needed to provide the basis for quantification of benefits for weather phenomena other than snow and ice storms and for rescheduling and rerouting highway and railroad operations.

Table 11

SUMMARY OF EXTRAPOLATED BENEFITS FOR THREE LEVELS OF IMPROVED PREDICTIVE ABILITY--ALL GROUND TRANSPORTATION

Level	Activity	Total Annual Benefit--Metropolitan Areas	Factor for Railroads	Benefit for Railroads	Factor for Highways	Benefit for Highways	Total Benefit--All Ground Activities
1	Snow Control	$ 36.3 million	0.12	$4.4 million			
	Accidents	6.4	0.12	0.8			
	Delays	62.0	0	0			
	Total	$104.7 million		$5.2 million	1.0	$104.7 million	$214.6 million
2	Snow Control	$ 69.4 million	0.12	$8.3 million			
	Accidents	12.7	0.12	1.5 million			
	Delays	124.2	0	0			
	Total	$206.3 million		$9.8 million	1.0	$206.3 million	$422.4 million
3	Snow Control	$158.5 million	0.12	$19.0 million			
	Accidents	25.6	0.12	3.1			
	Delays	247.9	0	0			
	Total	$432.0 million		$22.1 million	1.0	$432.0 million	$886.1 million

8

MARINE TRANSPORTATION

For the most part, there are no quantitative studies of the effects of weather prediction and loss avoidance on marine transportation (setting aside for a moment a few recent papers on optimum ship routing). This chapter, then, begins with an overall assessment of weather and marine operations.

Normally, temperature extremes, snow, rain, or hail do not significantly alter ship operations outside of the high latitudes, although these environmental parameters can have a deterrent effect on ship speed and efficiency. On the other hand, wind and related wind waves have serious effects on a ship at sea. Port operations are theoretically unaffected by wind, humidity, and temperature extremes. Precipitation, though, can cause longshoremen to stop work, resulting in nonproductive labor costs. These effects suggested the following areas for investigation:

- reducing vessel transit time through ship routing;
- preventing vessel damages and
- preventing cargo damages and losses;
- more efficient icebreaking operations, due to improved scheduling of operations related to predictions of ice thaw and freeze-up;
- reducing fatalities due to adverse weather, and improving search and rescue operations;
- increasing passenger comfort by routing ships around bad weather; and
- reducing nonproductive port services--longshoremen labor costs during rainouts, for example.

In accordance with our methodology (see Chapter 4), we first assess the magnitude of all recoverable costs or losses, in each area, assuming complete elimination of environmental uncertainty. It should be understood, however, that by "all" we mean those that are not recoverable by proper use of current predictive skills. This procedure gives the upper limits of benefits that improved prediction might achieve; attainable benefits will be less than these. As before, we use these assessments to determine whether postulated levels of improvement should be described precisely, according to the remainder of the methodology in Chapter 4, or subjectively, as in Chapter 6.

REDUCING VESSEL TRANSIT TIME

The generic term for guiding a ship around adverse environmental conditions is optimum ship routing (OSR), which can best be described as the selection of an optimum track for ship transoceanic crossing by making use of predictions of wind, waves, and current.[1] Optimum is to be interpreted as a combination of least time, maximum safety (damage avoidance), or passenger comfort. The technique and results achieved have been well documented.[2] Basically, the optimum ship routing forecaster applies his knowledge of the ship's performance in a seaway to a forecast of sea-surface wind, wave, and current conditions in

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1. Because of boundary (i.e., land) and destination constraints, coastal ship routes do not benefit as significantly from ship routing as do those ships on transoceanic routes. Coastal voyages depend more on a surveillance watch than optimum routing. Similarly, inland (lake and river) transportation does not benefit from OSR.

2. R.W. James, Application of Wave Forecasts to Marine Navigation, U.S. Naval Oceanographic Office Publication SP-1 (Washington, July 1957); J.P. Powell, Weather Routing of Military Sea Transportation Service Ships in the North Atlantic, Winter Months 1957-1958 (May 1958); R.W. James and G.L. Hanssen, Evaluation of the U.S. Navy Hydrographic Office Ship Routing Program, U.S. Naval Oceanographic Office Publication TR-53 (Washington, July 1968); and R.W. James and G.L. Hanssen, "Optimum Ship Routing," Journal of the Institute of Navigation, XIII (July 1960).

the general path of transit, and constructs a chart of probable ship speed along any given track. With this information the methods of geometric optics are used to construct the optimum track. Constant surveillance is maintained over the routed ships and their routes are changed if necessary.

Despite a remarkable success with OSR, precision routing is limited by the decreasing accuracy of environmental prediction with time. Sea-state, wind, and current forecasts can be prepared in some detail for two or three days in advance. The reliability of the prediction, however, decreases progressively after the first day. Forecasts beyond three days must be issued in less specific terms.[1]

Optimum ship routing is performed for all Navy ships by Fleet Weather Central (FWC) in Alameda, California (Pacific crossings) and Norfolk, Virginia (Atlantic crossings). Included in the Navy routings are military manned ships, Military Sea Transportation Service ships, and all ships chartered to MSTS. In addition, commercial ship routing, provided by four major companies, is available to the merchant fleet.[2] Also, some steamship companies maintain an in-house environmental prediction capability. Despite OSR's demonstrated capability, many commercial steamship companies are reluctant to use a routing service due to insufficient confidence in environmental forecasting sources and techniques--ship captains are unwilling to accept a land-based meteorologist's advice over their intuitive seamanship.[3]

A classic example of OSR is the Bremerhaven to Norfolk case. Two MSTS ships departed Bremerhaven, Germany, for Norfolk, Virginia, within six hours

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1. Currently, OSR activities are constrained by the number of relevant observations to a greater degree than forecast agencies concerned primarily with the continent.

2. ALWEX (Allen Weather Corp.), Washington, D.C.; Bendix Commercial Service Corp., New York; Pacific Weather Analysis Corp., California; and Weather Routing Inc., New York.

3. RMC conducted a telephone survey of 30 large U.S.-controlled steamship firms in the New York and New Orleans areas. Of the total 1,500 transoceanic crossings per year reported by these companies, approximately 500 were routed by a commercial ship routing service.

of each other after receiving route recommendations from FWC NORVA. The first ship to depart ignored the recommendation because the route suggested transit through an area normally characterized by the Icelandic Low. The captain took the time-honored southern route. In doing so, the ship steamed directly into the Icelandic Low, which had moved abnormally south. By following the OSR recommendation, the second MSTS ship, although departing six hours after the first, arrived in Norfolk eight days before the first ship. Aside from time lost, the first ship experienced considerable damage.[1]

Although this example is not a normal occurrence, it illustrates the benefits of OSR. Average estimates of time saved on transoceanic voyages as a result of OSR are presented in Table 12 for Atlantic and Pacific crossings.

Table 12

TRANSOCEANIC TIME SAVINGS

OSR Source	Estimate of Time Saved (hours)[a]	
	Atlantic	Pacific
Allen Weather Corp.	10.0	25.0
Bendix Commercial Service Corp.	13.0	23.0
Fleet Weather Central (U.S. Navy)	13.0	19.0
Pacific Weather Analysis Corp.	12.0	24.0
Weather Routing Inc.	14.0	26.0
Average Hours Saved Per Crossing	12.4	23.4

a. These estimates represent time that has been saved due to OSR (i.e., historic) and should not be construed as potential time savings.

When a commercial or MSTS ship saves time as a result of OSR, this reduced transit time has the direct effect of reducing operating costs and would be a benefit

1. Mr. John Crozier, Fleet Weather Central, Norfolk, Virginia.

to the steamship company for commercial vessels or to the government for MSTS ships. Therefore, the remainder of this section will evaluate the effect that more accurate OSR would represent. As such, three estimates were required to be made:

- the number of merchant and MSTS voyages applicable to OSR,
- the average operating costs of merchant and MSTS ships, and
- the level of OSR improvement that could be expected as a result of improved environmental prediction.

The annual number of Atlantic and Pacific crossings made by the merchant and MSTS fleets was estimated from two sources--the Maritime Administration and U.S. Navy Fleet Weather Centrals. The Maritime Administration (Trade Route Studies Department) retains detailed statistics regarding the number of U.S. merchant ships traveling the essential trade routes of the world. The total number of U.S. merchant ships traveling these routes is presented in Table 13 for 1958 and 1965.[1]

COMSTSINST 3140.24 requires that all MSTS and MSTS-chartered ships utilize OSR.[2] Therefore, the annual summaries compiled by FWC Norfolk and FWC Alameda were assumed to represent total Atlantic and Pacific MSTS crossings, respectively. Table 14 presents these totals for 1959 through 1967 where available.

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1. The year 1958 was selected to depict trade route densities at the time of OSR inception; 1965 was used because it was the last year that MARAD had detailed statistics on trade route densities. Further, some routes cannot use OSR. With OPNAVINST 3140.498 and COMSTSINST 3140.2A as baselines for OSR qualification: ". . . the length of voyage should be 1,500 miles or more in unrestricted waters to realize significant benefit."

2. Subject to the 1,500-mile limitation.

Table 13

MERCHANT SHIP TRADE ROUTE DENSITY

Trade Route	A or B[a]	U.S. Coastal Area	Foreign Area	Density[b]	
				1958	1965
1	--	Atlantic	East Coast South America	162[c]	124[c]
2	--	Atlantic	West Coast South America	233[c]	167[c]
4	--	Atlantic	Caribbean	800[c]	469[c]
5	A	North Atlantic	United Kingdom/Continent	406	321
6	A	North Atlantic	Scandinavia/Baltic	111	83
7	A	North Atlantic	United Kingdom/Continent	261	337
8	A	North Atlantic	United Kingdom/Continent	170	391
9	A	North Atlantic	United Kingdom/Continent	312	296
10	A	North Atlantic	Mediterranean/Black Sea	611	543
11	A	South Atlantic	United Kingdom/North Europe	81	59
12	A	Atlantic	Far East	337	270
13	P	South Atlantic/Gulf	Mediterranean/Black Sea	238	296
14	A	Atlantic--Service 1	West Africa	47	51
14	A	Gulf--Service 2	West Africa	34	54
15A	A	Atlantic	South and East Africa	139	82
15B	A	Gulf	South and East Africa	39	33
16	P	Atlantic/Gulf	Australia/New Zealand	42	19
17	P	Atlantic/Gulf/Pacific	Indonesia/Malaysia	210	201
18	A	Atlantic/Gulf	India/Persian Gulf/Red Sea	334	423
19	--	Gulf	Caribbean/Eastern Mexico	434[c]	250[c]
20	--	Gulf	East Coast South America	112[c]	107[c]
21	A	Gulf	United Kingdom/Continent	275	172
22	P	Gulf	Far East	188	164
23	--	Pacific	Caribbean/Eastern Mexico	48[c]	29[c]
24	--	Pacific	East Coast South America	52[c]	41[c]
25	--	Pacific	Western Mexico/Central and South America	80[c]	183[c]
26	A	Pacific	Western Europe	16	15
27	P	Pacific	Australia/New Zealand	51	34
28	P	Pacific	Southwest Asia/Red Sea/Aden	188	144
29	P	Pacific	Far East	986	768
31	--	Gulf	West Coast South America	127[c]	42[c]
32	--	Great Lakes	Western Europe	0	15[c]
33	--	Great Lakes	Caribbean	0	0
34	A	Great Lakes	Mediterranean/Red Sea/India/Pakistan	0	34
Total Merchant Voyages				7,174	6,217
Number of Voyages Applicable to OSR				5,126	4,790

a. Subject to OSR in the Atlantic (A) or Pacific (P).

b. Represent sailings of ships over 1,000 gt engaging in ocean-going trade.

c. Due to 1,500 miles in unrestricted waters limitation, these routes are not applicable to OSR.

Table 14

MSTS OCEANIC CROSSINGS

Ocean/OSR Facility	Routings Provided								
	1959	1960	1961	1962	1963	1964	1965	1966	1967
Atlantic (FWCNORVA)	320	528	522	617	662	780	895	845	909
Pacific (FWCALA)	335	758	868	876	873	918	808	a	a

a. Data unavailable.

By utilizing the data in Tables 13 and 14, the total number of voyages applicable to OSR was estimated under the following assumptions:

- The average number of historic transoceanic voyages was assumed to remain relatively constant on an annual basis.[1] Further, the average breakdown of Atlantic and Pacific crossings in Table 14 was assumed to remain relatively constant.[2]
- The average number of Atlantic and Pacific routings provided by FWC for MSTS and MSTS-chartered ships was assumed to be indicative of future MSTS-oriented transoceanic crossings.
- The sum of the merchant average and the MSTS average was assumed to represent the total number of voyages applicable to OSR.

Thus, the approximate numbers of voyages applicable to OSR were 4,000 across the Atlantic (3,150 merchant and 850 MSTS) and 2,600 across the Pacific (1,800 merchant and 800 MSTS).

1. Mrs. K. VanLoon, Trade Route Studies Department, MARAD, stated that "the majority of transoceanic voyages are run on a scheduled basis year after year--much the same as the airlines." Analysis of 1965 trade route data resulted in 92 percent of transoceanic voyages being scheduled--the remaining 8 percent were of an unscheduled nature.

2. Comparison of the Atlantic and Pacific voyages listed in Table 13 did not yield a significant difference--Atlantic: 3,124 (1957) versus 3,190 (1965); Pacific: 2,002 (1957) versus 1,600 (1965). The apparent difference in Pacific crossings is a result of the Vietnam War. Ships making a voyage under MSTS charter would not be included in the 1967 total. They would be accounted for in the MSTS estimate, however.

To estimate the average operating cost of a merchant or MSTS ship, MSTS Report 3110-3, Summary of Chartered Ships, was used. This report contains per diem rates (as of September 1, 1969) on 203 ships that are available to MSTS for charter. Assuming the listed per diem rates to be representative of operating costs, the average daily operating cost of merchant or MSTS-oriented ships is approximately $4,500--or $190 per hour.

Two viewpoints were obtained in an attempt to assess the magnitude of OSR improvement that could be expected from improved environmental prediction--that of the user (i.e., the steamship companies) and that of OSR personnel.

As a result of the previously referenced survey of large U.S.-controlled shipping companies in New York and New Orleans, 10 of 30 companies acknowledged the use of OSR. These 10 companies were asked to estimate the additional time that could be saved per Atlantic or Pacific crossing should the data input to the ship routers be improved. Three examples, typifying the replies, are presented below:

- OSR is extremely accurate now. Improved environmental prediction would have only a marginal effect on reduction of transit time." (Mr. Joseph Winer, American President Lines, Inc.)
- "Environmental prediction is far from being a science. Anything additional learned about the environment will, of course, benefit everyone. However, how much ship routers will benefit is not certain." (Captain White, Isthmain Lines, Inc.)
- "Appreciably! The more inputs, the better the service. The North Atlantic inputs are extremely good due to the quantity of ships reporting immediate conditions. The South Atlantic, Pacific, and Indian Oceans, however, do not benefit from this quantity of reports. In summary, the more condition reports that are generated, the less ship routers are required to interpolate." (Mr. Robert Kron, Management and Shipping Transport, Inc.)

The assessments of OSR improvement by the ship routers were more tangible although none of the sources responded in the same manner. The various assessments are presented below:

- "Utilizing all presently available data, about 1 route in 10 to 12 needs some modification." (Allen Weather Corp., <u>This is ALWEX</u>)
- "Recent hindsight analyses have yielded accuracy as high as 95 percent when recommended routes were compared to historic optimum routes and allowing a 1-degree deviation. Practically speaking, however, OSR is probably 85-percent accurate now and will never improve much above 92 as approximately 8 percent of the environment must be considered purely random." (Mr. William Kaciak, President, Weather Routing, Inc.)
- Fleet Weather ...rals report the percentage of "routes completed without significant encounter with adverse weather" to be 71 percent in the Atlantic and 84 percent in the Pacific. (Fleet Weather Central annual summaries, 1959 through 1967)

Thus the total recoverable costs resulting from improved environmental prediction were estimated to be an additional 15 percent in the Atlantic and 10 percent in the Pacific. Therefore, equating time savings with OSR improvement, operating costs, and transoceanic voyages yielded the following equation:

$$T_{OSR} = C_h[(N_a)(H_a)(\Delta h_a) + (N_p)(H_p)(\Delta h_p)]$$

where

T_{OSR} = total recoverable costs attributable to optimum ship routing in transit time saved as a result of improved environmental prediction;

C_h = \$190 = cost per hour to operate a ship;

N_a, N_p = 4,000, 2,600 = respective number of trans-Atlantic and trans-Pacific voyages subject to OSR;

H_a, H_p = 12.4, 23.4 = respective number of hours currently saved on trans-Atlantic and trans-Pacific voyages by utilizing OSR; and

Δh_a, Δh_p = 0.15, 0.10 = respective percentage of additional time that could potentially be saved on trans-Atlantic and trans-Pacific crossings with an improvement in environmental prediction.

Exercising the preceding equation yields a total recoverable cost benefit of approximately $2.7 million per year. This estimate is assumed to be valid for the future as well because the future U.S. merchant fleet will be newer and faster (assuming present fleet revitalization efforts will be realized). Therefore, potentially higher operating expenses will be offset by more rapid transit time.

PREVENTING VESSEL DAMAGE AND LOSS

The study analyzed and estimated the economic value of damages and losses attributed to adverse weather for each of the following categories:

- merchant fleet,
- government fleet,
- small boats, and
- barge and towing.

Merchant Fleet

The merchant fleet, for the purpose of this study, includes those commercial ships chartered to MSTS as well as the basic merchant fleet.[1] The analysis of total recoverable losses in the merchant fleet was made under two assumptions:

- The losses in the MSTS-chartered fleet are analogous to those in the basic merchant fleet.
- With prior knowledge of adverse weather conditions (winds and associated wave heights), ships can frequently avoid heavy sea damage--the pounding that results in structural damage or breakup.

Under these assumptions, the total recoverable loss was estimated by summing the cost to repair those ships damaged by heavy weather and the cost to replace those ships lost due to heavy weather.

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1. The basic merchant fleet includes U.S. flag ships as well as U.S.-controlled ships under a foreign flag. ESSO's entire tanker fleet, for example, sails under a foreign flag.

Damage

In general, the analysis of heavy weather damage resulted in two assessments--one qualitative and one quantitative. The qualitative assessment was derived from questioning several steamship companies now using OSR (10 out of 30 companies queried). Each company was requested to quantify the reduction in their annual expenditures for maintenance and repair due to heavy weather since using OSR. However, the companies were either unable or unwilling to give up this information. They did, however, make qualitative assessments of one of the following three statement types:

- heavy weather damage has been reduced to almost nothing;
- heavy weather damage has been reduced somewhat; or
- have not used OSR long enough to adequately assess any reduction in heavy weather damage.

The quantitative assessment of structural damage reduction came from analyzing the results of a study performed by the United States Salvage Association in 1957, and comparing the study results to recent (1967 and 1968) heavy weather insurance claims provided by the American Hull Insurance Syndicate.

In 1957, the United States Salvage Association completed a comprehensive study of marine accidents to conventionally powered (i.e., non-nuclear) merchant ships of 5,000 tons displacement or over for the years 1953 through 1956. The purpose of the study was to delineate the accident causation factors and to quantify the extent of damage sustained by the ships. The portion of the study that analyzed heavy weather damage concluded--"given a ship is damaged by heavy weather, the average cost of repair ranges from $32,000 to $53,000."[1]

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1. The variance in repair cost is correlated with the hull configuration and rated speed of the ships analyzed. For example, a C-2 cargo ship would fall into the $32,000 category and the newer, faster (at that time) Challenger-class cargo ship would be in the $53,000 category.

The American Hull Insurance Syndicate is the largest underwriter of American hulls--55 shipping companies encompassing 900 large ships (no pleasure craft).[1] During the years 1967 and 1968 an average of 270 ships sustained some degree of heavy weather damage, resulting in claims totaling approximately $1.6 million. Based on the preceding data, those ships damaged by heavy weather filed an average claim of approximately $6,000.

Since the earlier statistics were generated before, and the later ones after, the initiation of optimum ship routing, it is not unreasonable to credit OSR for the impressive reduction. A great deal of the potential heavy weather damage has already been eliminated. However, using the data provided by the American Hull Insurance Syndicate and the total number of ships now in the U. S. merchant fleet (approximately 1,300), the total recoverable losses applicable to weather-damaged vessels was as follows:[2]

$$T_{MD} = (C_{md})(D_{md})(N_m)$$

where

T_{MD} = total annual value of damage to the merchant fleet,

C_{md} = $6,000 = average cost per incident of those merchant ships experiencing heavy weather damage,

D_{md} = 30 percent = estimated percentage of merchant ships experiencing heavy weather damage per year, and

N_m = 1,300 = total number of ships in the merchant fleet.

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1. These ships travel the major trade routes of the world. Therefore, the data provided by the American Hull Insurance Syndicate were assumed to be representative of the U. S. merchant fleet.

2. As of June 30, 1969, the Maritime Administration (Division of Ships Statistics) accounted for 963 U. S. flag vessels. Mr. Schumacher, Deputy Manager of the American Hull Insurance Syndicate, estimates that of the 900 U. S. hulls insured by AHIS, approximately 75 percent are U. S. flag vessels. This 75-percent factor was applied to the MARAD figure to derive the 1,300 ships in the U. S. merchant fleet.

Exercising the equation yields a recoverable cost, T_{MD}, of approximately $2.3 million per year.

Loss

The estimation of annual ship losses due to adverse weather conditions was accomplished in a similar manner. The sources of data were the Liverpool Underwriters Association, the U.S. Navy Salvage Office, and the U.S. Maritime Administration.

The Liverpool Underwriters Association publishes an annual report, by nationality, summarizing partial and total losses for all merchant ships of 500 gt and above. These losses are also stratified by the nature of casualty--i.e., weather damage, strandings, collisions, fires, and explosions. Of the two loss categories and the nine casualty stratifications reported by the Liverpool Underwriters Association, only the total loss category and the weather damage and stranding stratifications were considered relevant to estimating the total U.S. merchant fleet losses due to heavy weather. This conclusion was drawn for the following reasons:

- Partial losses due to heavy weather were considered analogous to the structural damage estimate in the preceding section.
- There is no indication that the U.S. merchant fleet has lost a ship from foundering, collision, or fire as a result of adverse weather since 1950.[1]

From 1960 through 1968, the Liverpool Underwriters Association reported an average annual loss of 4.8 U.S. merchant ships by all causes. To estimate the portion of these total losses attributed to adverse weather, the following factors were developed:

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1. A recent cost-benefit study (June 1969) performed by RMC for the Supervisor of Salvage, U.S. Navy, has shown that of 310 noncombat zone salvage operations (approximately 50 percent were non-Navy ships) logged by the U.S. Navy from 1959 through 1968, there were no total losses of U.S. merchant ships from sinking, collisions, or fire as a result of adverse weather.

- the worldwide heavy weather losses, expressed as a percentage of total worldwide losses, has averaged approximately 4 percent; and

- the portion of stranding losses attributed to weather--again expressed as a percentage of total worldwide losses--has averaged approximately 22 percent.

Table 15 enumerates the data base from which the preceding factors were derived.

Table 15

WORLDWIDE SHIP LOSSES[a]
(vessels of 500 gt and over)

Year	Total Losses	Weather Losses		Stranding Losses		
		Number	Percent of Total	Number	Weather-Related[b]	Percent of Total
1960	114	2	1.8	61	31	26.2
1961	78	0	0.0	32	16	20.5
1962	124	4	3.2	68	34	27.4
1963	148	1	0.7	71	36	24.3
1964	117	6	2.0	47	24	20.5
1965	154	8	5.2	69	35	21.4
1966	159	14	9.1	52	26	16.3
1967	163	8	4.9	64	32	19.6
1968	157	15	9.6	61	31	19.7

a. As reported by the Liverpool Underwriters Association.

b. Based on the study results of salvage incidents involving the Supervisor of Salvage, U.S. Navy; approximately 50 percent of ship losses due to stranding are weather-related (see RMC Report UR-076, Cost-Benefit Analysis of U.S. Navy Salvage Operations [June 1969]).

Assessing the value of a lost merchant ship depends on a number of parameters such as ship type (i.e., cargo or tanker), size, speed, and age. The Ship Valuation Committee of the Maritime Administration maintains information on the market values of approximately 500 merchant ships.[1] In their assessment of ship value, the Ship Valuation Committee considers the ship characteristics noted above and the nature of the domestic open market for ships. Using this information, the average value of 500 ships in the U.S. merchant fleet was found to be \$2.4 million, with values ranging from \$100,000 for a World War II victory ship to \$16 million for the SS Manhattan (prior to the recent icebreaker conversion). For the purpose of estimating the value of a merchant ship lost due to heavy weather, \$2.4 million was used.

Therefore, the total recoverable costs with respect to merchant vessels lost in heavy weather is the multiplicative sum of the preceding estimates, as follows:

$$T_{ML} = (C_{ml})(W_{ml} + S_{ml})(N_{ml})$$

where

T_{ML} = total annual value of losses to the merchant fleet,

C_{ml} = \$2.4 million = average worth of a merchant ship,

W_{ml} = 4 percent = estimated percentage of ship losses explicitly due to heavy weather,

S_{ml} = 22 percent = estimated percentage of stranding losses attributed to adverse weather, and

N_{ml} = 4.8 = average number of merchant ships lost annually due to all causes.

Exercising the preceding equation yields a total recoverable value, T_{ML}, of approximately \$3.0 million per year.

The estimates of weather-related damages and/or losses to the U.S. merchant fleet total approximately \$5.3 million per year. This estimate is believed reasonable for present and future time frames for two reasons:

1. "Values for War Risk Insurance," Federal Register, General Order 82, Title 46, Chapter II, Subchapter G, Part 309.

- As the average age of the present U. S. merchant fleet continues to increase (now 23 years), the fleet will become less tolerant of adverse weather.[1]
- The present Administration has proposed a plan to revitalize the U. S. merchant fleet. Should this plan be realized, the fleet tolerance will increase. However, a loss involving a new ship will be more noticeable from an economic point of view.

Although the percentage of ships lost due to heavy weather (W_{ml}), the percentage of ship strandings attributed to adverse weather (S_{ml}), and the number of merchant ships lost annually (N_{ml}) should decrease, the average worth of a merchant ship (C_{ml}) will increase. These factors will thus offset one another.

Government Fleets

Assessment of recoverable costs applicable to the U. S. government fleet was accomplished by analyzing the heavy weather damage and/or loss experienced by the U. S. Navy/MSTS complex. This approach was taken since other government fleets are more or less special-duty-oriented and, in terms of fleet size, represent a minority. For example:

- Much of the heavy weather damage experienced by U. S. Coast Guard ships cannot be avoided due to operational requirements (i.e., search and rescue, icebreaking, salvage assistance, etc.).[2]
- The U. S. Coast and Geodetic Survey ships are primarily designated for oceanographic/hydrographic research and/or reconnaissance. The various phenomena to be studied are normally well defined and, at times, dictated by the environment (e.g., the examination and recharting of Alaskan waterways after the earthquake in 1964)[3]

1. Government Executive (August 1969).

2. Cdr David Kaetzel, Chief of Maintenance Branch, U. S. Coast Guard.

3. Assistance and Recovery in Alaska: 1964, published by the U. S. Department of Commerce under the joint authorship of ESSA and USC&GS (March 1965).

The evaluation concentrated, therefore, on heavy weather damage and ship losses that may be expected for U.S. Navy military manned ships and MSTS vessels. The records of heavy weather damage do not say whether it occurred at sea or in port. Probably some did occur in port and, because of the mission's military urgency, could not have been avoided. To the degree that this may have been so, the estimate of potential recoverable losses is inflated, but the amount should be small. Most of the damage takes place in storms on the high seas; with forewarning safer routes can be chosen so that losses will be reduced. Data were gathered from Fleet Weather Central Norfolk, MSTS Atlantic, and the U.S. Navy Salvage Office.

Fleet Weather Central, Norfolk, Virginia (FWCNORVA), and their Pacific coast counterpart, Fleet Weather Central, Alameda, California (FWCALA) provide optimum ship routing for all U.S. Navy and/or MSTS vessels making voyages of 1,500 miles or more in unrestricted waters. From 1959 until 1967, these ship routing facilities tabulated the annual number of routings provided to U.S. Navy and/or MSTS ships, as presented in Table 16.

During FY 1968 and FY 1969, the total cost to repair heavy weather damage experienced by the MSTSLANT cargo ships averaged approximately $60,000.[1] Therefore, applying this cost to repair average to the average number of MSTS cargo ship routings made annually by FWCNORVA resulted in a heavy weather damage cost estimate of approximately $220 per routing per ship. The preceding estimate was applied to all U.S. Navy MSTS routings under the following assumptions:

- the routing service provided by FWCALA was assumed to be identical to that of FWCNORVA; and
- the routing service rendered to MSTSLANT cargo ships was assumed to be representative of that service rendered to all U.S. Navy MSTS ships.

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1. LCdr M.E. Ruggiero, Assistant to the Engineering Officer, Maintenance and Repair, MSTSLANT.

Table 16

NUMBER OF FWC ROUTINGS

Year	U.S. Navy[a]		MSTS						Total MSTS	
			Passenger		Cargo		Tanker			
	NORVA	ALA	NORVA	ALA	NORVA	ALA	NORVA	ALA	NORVA	ALA
1959	100	85	130	148	90	102	--	--	220	250
1960	172	354	176	210	119	158	61	36	356	404
1961	133	358	163	197	129	246	97	77	389	520
1962	195	325	179	201	186	275	57	75	422	551
1963	194	285	152	204	259	298	57	86	468	588
1964	191	285	159	208	352	341	78	84	589	633
1965	239	[illegible]	159	223	372	301	71	114	602	638
1966	245	b	92	b	410	b	98	b	600	--
1967	288	b	14	b	531	b	76	b	621	--
Average Per Year	195	279	136	199	272	246	66	67		

a. Routings provided for the U.S. Navy military manned ships may be applicable to a single ship or a task force. FWCNORVA estimates that a factor of 3 should be applied to determine the actual number of ships routed.

b. Tabulations not available.

Therefore, the total estimated heavy weather damage experienced annually by the government fleets, T_{GD}, was estimated as follows:

$$T_{GD} = (C_r)(N_{mp} + N_{mc} + N_{mt} + 3N_n)$$

where

C_r = \$220 = average annual cost to repair heavy weather damage per routing per ship,

N_{mp} = 335 = average number of MSTS passenger ships routed per year,

N_{mc} = 518 = average number of MSTS cargo ships routed per year,

N_{mt} = 133 = average number of MSTS tankers routed per year, and

N_n = 474 = average number of U.S. Navy routings provided per year.

Exercising the preceding equation yielded an annual recoverable cost of approximately \$530,000. This relatively low figure again emphasizes the impact that optimum ship routing has had since inception.

The evaluation of annual government fleet losses was accomplished by analyzing the records retained at the U.S. Navy Salvage Office under the following three assumptions:[1]

- the incident was correlated with adverse weather;
- the incident occurred after 1959 (i.e., after the inception of OSR); and
- the incident occurred outside a combat zone.

Based on the preceding assumptions, only four U.S. Navy ships and no MSTS ships suffered total losses, none of which resulted from an OSR misjudgment. These losses are presented in Table 17.

1. The terms governing this study did not include environmental effects on combat-type vessels. However, available data included combat vessels, thus providing another check on the magnitude of potential benefits.

Table 17

GOVERNMENT SHIP LOSSES DUE TO ADVERSE WEATHER[a]

Year	Ship Lost	Loss Location	Cause
1961	USS Balwin (EX DD-624)	New York	While under tow, a storm caused the tow ship to drift and the Balwin grounded.
1963	USS Grouse (EX MSCO-15)	Cape Ann, Massachusetts	The Grouse grounded and inclement weather prevented successful salvage operations.
1966	USS Johnson (EX DE-583)	San Francisco	The Johnson was driven aground after tow line parted during a storm.
1968	USS Bache (EX DD-470)	Rhodes, Greece	50 knot winds and attending seas caused anchor to drag. The Bache was driven aground, breaking on rocks.

a. Source: U.S. Navy Salvage Office.

In view of the casualty frequency, the average annual loss due to adverse weather was assumed to remain constant through 1985. To quantify this loss average, the value of the ships lost was estimated to be $23.2 million for destroyers and $1.2 million for mine craft.[1] Therefore, the total annual loss experienced by the government fleet, T_{GL}, was estimated as follows:

$$T_{GL} = \frac{1}{Y} \sum_{i=1}^{i} \left(N_{gl_i}\right)\left(C_{gl_i}\right)$$

where

N_{gl_i} = number of type i government ships lost due to adverse weather (for this particular study i = 1 = destroyers and i = 2 = mine craft);

C_{gl_i} = cost to the government to lose a ship of type i; and

Y = 10 = number of years from which data were analyzed.

Exercising the preceding equation yielded a potential loss of approximately $7.1 million per year.

Consequently, the total economic loss applicable to the government fleet, T_G, is the sum of heavy weather damage, T_{GD}, and heavy weather losses, T_{GL}. This sum is estimated to be approximately $[illegible].6 million per year.

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1. Resource Management Corporation, Cost-Benefit Analysis of U. S. Navy Salvage Operations, RMC Report UR-076 (1969), estimates that the average cost to replace lost destroyers or mine craft is $46.4 million and $2.1 million, respectively. However, the salvage value of a military ship is approximately 50 percent. Correspondingly, the loss value to the government was assumed to be 50 percent of the replacement cost.

Small Boats

The estimation of total recoverable losses applicable to small boats was performed in two parts--pleasure craft and commercial craft under 500 gt (i.e., tugs, passenger ferries, fishing boats, and harbor service craft).

Pleasure Craft

Pleasure craft losses were estimated by analyzing accident data compiled by the U.S. Coast Guard and qualitative assessments provided by small craft underwriters. The U.S. Coast Guard publication, Boating Statistics (Report CG-357), summarizes annually the number, causes, and value of pleasure craft accidents that resulted in loss of life, personal injury incapacitating any person for more than 72 hours, and property damage in excess of $100. In this section only the damage criterion will be analyzed. The total recoverable losses applicable to pleasure craft were estimated using the property damage values presented in the 1967 and 1968 editions of Boating Statistics and the following assumptions:

- the average dollar cost of total boating accidents during 1967 and 1968 was assumed to be representative--approximately $6.18 million;
- the total cost of future boating accidents will increase in direct proportion to the historic growth rate of registered boats--approximately 4.5 percent per year from 1963 to 1968; and
- the percentage of future boating accidents attributed to adverse weather conditions will remain the same as the 1967 to 1968 average: approximately 6.2 percent.
- Boating Statistics accounts for 80 percent of all pleasure craft accidents. (LCDR Harold B. Summey, Chief of the Accident Review and Statistics Branch, USCG, attributes this high percentage to a national newspaper clipping service that forwards boating accident articles to the U.S. Coast Guard Headquarters. If an investigation of the accident has not been recorded, the Coast Guard district is notified, an accident investigation is made, and a report filed.)

Based on the preceding assumptions, the total recoverable pleasure craft loss was formulated as follows:

$$T_{PC} = \frac{(D_{pc})(W)}{R} \left[1 + (G)^{Y_n} \right]$$

where

T_{PC} = total recoverable losses among pleasure craft in year n ,

D_{pc} = \$6.18 million = present value of total damage to pleasure craft,

W = 6.2 percent = percent of damage attributed to adverse weather conditions,

R = 80 percent = percent of pleasure craft accidents accounted for,

G = 4.5 percent = annual growth rate of registered boats, and

Y_n = number of years between 1968 and year n .

Thus, in 1985 the total recoverable losses applicable to pleasure craft is estimated at approximately \$1.0 million. This relatively small sum is substantiated by small boat underwriters who regard the insuring of pleasure craft as a "necessary evil"[1] and feel that damage could be greatly reduced if the general public would heed present weather warnings.[2]

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1. Fireman's Fund American Insurance Company states that only one half of one percent of their total business contends with pleasure craft underwriting and they pay out less than \$25 thousand in claims each year (due to all causes).

2. Exemplifying this point is a report prepared by the U.S. Coast Guard Marine Board of Investigation following the Lake Michigan squalls of September 23, 1967. On the morning of September 23, 1967, small craft warnings were posted and an advisory bulletin stated that fishing boats under 18 feet in length were not considered safe on the exposed waters of Lakes Michigan and Superior. Of the 16 boats reported with substantial damage or loss, 15 were less than 18 feet in length.

Commercial Craft

The U.S. Coast Guard (Office of Merchant Marine Safety) publishes the Proceedings of the Merchant Marine Council (Report CG-129), which summarizes the annual casualties to U.S. merchant vessels according to the nature of the casualty (i.e., collision, explosion, grounding, etc.) under three different classifications:

- primary cause (storm, personnel error, equipment failure, etc.),
- number of damaged vessels classified by gross tonnage, and
- number of vessels totally lost.

To isolate the amount of damage and the losses applicable to commercial vessels under 500 gt required integrating the three matrices, under the following assumptions:

- Environmental conditions were assumed to encompass the "storms--adverse weather" and "unusual currents" categories listed under primary cause.
- For the purpose of quantifying the annual damage inflicted on small commercial craft by adverse weather--the percentage of 500 gt (or less) vessels in the "gross tonnage-versus-nature of casualty" matrix was assumed to be directly proportional to the number of weather damage incidents in the "primary cause-versus-nature of casualty" matrix.[1]
- For the purpose of estimating the annual losses of small commercial craft due to adverse weather--(a) the percentage of vessels under 500 gt totally lost in the "vessels totally lost-versus-nature of casualty" matrix was assumed to be in direct proportion to the number of vessels under 500 gt damaged in the "gross tonnage-versus-nature of casualty" matrix; (b) the percentage of casualties resulting

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1. For example, in 1967, 336 vessels of various gross tonnages grounded with damage. Of the 336, 189--or approximately 56 percent--were vessels of 500 gt or under. This percentage was then applied to the 41 incidents caused by storms or unusual currents that resulted in grounding with damage, thus yielding 23 vessels under 500 gt grounded with damage. This methodology was similarly applied to each of the 17 "nature of casualty categories" involving damage inflicted by storms or unusual currents.

from storms and unusual currents was derived by using the "primary cause-versus-nature of casualty" matrix; (c) the number of vessels under 500 gt lost by all causes (a) was then multiplied by the percentage of casualties involving adverse weather (b).[1]

The results were averaged to estimate the total number of small commercial craft anticipated to be damaged and lost in future years.[2] This exercise yielded an average annual casualty rate of 175 small craft damaged and 25 small craft lost due to adverse weather. To evaluate these casualties, the following estimates were made:

- Damage: no specific data source was located to assess the average cost to repair small commercial craft damaged by heavy weather. Therefore, the average repair cost was estimated to be the same as that to repair a large merchant ship--$6,000.[3] This assumption was based on a smaller vessel, although not normally subject to mid-ocean environment, being vulnerable to a lower level of unfavorable environmental conditions than a large merchant ship.
- Loss: the Ship Valuation Committee of the Maritime Administration evaluates the market value of small craft as well as that of large merchant ships. The average value of the small vessels contained in this source is $117,000.

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1. As an example, in 1967, 225 vessels of various gross tonnages foundered, capsized, or flooded. Of the 255, 207--or approximately 81 percent--were vessels of 500 gt or under. This percentage was then applied to the 94 vessels totally lost by foundering, capsizing, or flooding, thus yielding 76 small vessels lost by the referenced natures. Of the total number of foundering, capsizing, or flooding incidents (255), 26--or 10.4 percent--were due to storms or unusual currents. Thus, 10.4 percent of 76 small vessel losses (approximately 7.9 vessels) were attributed to adverse weather. This procedure was applied to each of the 17 "nature of casualty categories" to quantify the small craft "weather losses."

2. The 1967 and 1968 casualty data were averaged to depict an intermediate level of environmental magnitude. 1967, largely due to the extensive damage inflicted by Hurricane Betsy on the Gulf Coast, was a severe year with respect to weather related damage. 1968, in comparison, was mild. For example, storms or unusual currents accounted for 36 small craft losses in 1967, compared with 14 similar losses in 1968.

3. The American Hull Insurance Syndicate. For the development of this value, refer to the Merchant Fleet section of this report.

Therefore, as a result of the preceding analysis, the total economic loss applicable to small commercial craft, T_{CC}, was formulated as follows:

$$T_{CC} = (N_{cd})(C_{cr}) + (N_{cl})(C_{ci})$$

where

N_{cd} = 175 = number of small commercial craft estimated to be damaged per year due to adverse weather conditions,

C_{cd} = \$6,000 = cost to repair heavy weather damage to small craft,

N_{cl} = 25 = number of small commercial craft estimated to be lost annually due to adverse environmental conditions, and

C_{cl} = \$117,000 = average value of small craft.

The preceding equation yielded a total recoverable cost applicable to small commercial craft of approximately \$3.9 million.

Therefore, by summarizing the pleasure craft and commercial craft results, a total recoverable cost of approximately \$4.9 million per year is estimated for small boats.

Although environmental forecasting will undoubtedly become more accurate between now and 1985, the estimate of \$4.9 million is assumed to be relevant to the 1985 timeframe. This assumption considers the present state of the forecasting art and the recent havoc left by Hurricane Camille in September (of which no data were available for this study). The damages and losses due to Camille itself will more than likely exceed the small boat estimate presented here.

Barge and Towing

The total losses pertinent to the barge and towing aspects of marine transportation were estimated in two parts--inland oriented and ocean oriented.[1]

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1. This section considers only the towed portion of barge and towing. Weather damage to tugs and towboats was estimated in the Small Boat section of this study.

Inland[1]

In general, the contacted companies state that present weather prediction is more than adequate for inland waterways.[2] They also stated that although adverse weather conditions cause underway delays, these conditions have rarely, if ever, caused severe damage or loss to tugs or tows. With respect to river traffic (versus intercoastal waterways), weather forecasts and river stage forecasts[3] are used to estimate arrivals; departures, however, are never rescheduled on the basis of either forecast. The reasoning behind this never-stop philosophy is that a tug windbound in port is not making money while an underway barge-train, although temporarily weather-bound, is.[4]

Adverse weather encountered on the relatively narrow intercoastal waterways (124 feet wide) is circumvented by towing empty barges along the leeward side of the waterway and the loaded barges along the windward side. In the presence of a storm the loaded barges are virtually unaffected, due to the stability induced by the cargo, and the empty barges, if affected, are bounced against the shore and not blown into oncoming traffic. Thus, as was the case with river towing, none of the companies contacted could recall losing or severely damaging a towboat or barge.

Based on our replies from the barge and towing companies, the economic losses were considered negligible and no further attempt was made to quantify this particular sector of marine transportation.

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1. Inland was defined as including tows on the major tributaries and inland waterways.

2. Ingram Barge Company and Chotin Company (New Orleans); Crowly Launch and Tugboat Company (San Francisco); and Pudget Sound Tug and Barge Company (Seattle).

3. A river stage forecast predicts the rise or fall along a river for a five-day period. This forecast is used to determine the optimum barge load (i.e., maximum draft allowable) as well as estimating transit time.

4. In the opinion of Mr. Verner (Ingram Barge Company) and Mr. Leche (Chotin Company), only under dire circumstances will a towboat tie-up along a river to ride out a storm. This is because river fog-rain-or-snow storms are usually of short duration. However, maintenance costs would probably be reduced by rescheduling towing operations in the face of an adverse environment, although corresponding reductions in revenue would rapidly pass a point of imbalance.

Ocean[1]

Total recoverable losses applicable to ocean-oriented barging or towing were assessed as the sum of three components: ocean barging, oil rigs, and dredging.[2]

Ocean Barging. The quantitative evaluation of adverse weather effects on ocean barging operations was made by averaging detrimental weather factors provided by three large ocean towing companies representative of the industry: Foss Launch and Tug Company (Seattle); Gulf Mississippi Marine Corporation (New Orleans); and Moran Towing and Transport Company (New York).

These companies indicated that little attention is given to the quality of environmental predictions now received (or to the possibility of realizing benefits from improved prediction), since ocean tows rarely confront heavy weather without forewarning. In essence, the companies were satisfied with the lead time and reliability of present forecasting.[3] An exception to this general observation is in the Arctic regions, where predictions are notoriously unreliable: predictions of ice movements and ice cover are poor and barges are often trapped and damaged without warning.

Quantitative estimates of heavy weather damage or loss to oceanic barges were not made by the representative companies since these casualities have not occurred often enough to justify detailed statistics. However, as most ocean tows are performed on a *per diem* basis, estimates of incremental costs due to environmental

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1. Research for this portion of the study was performed by Ocean Science and Engineering, Inc., under subcontract to RMC; ocean was defined as including coastal and transoceanic towing operations.

2. Only the transportation aspect of these operations was considered (i.e., while an oil rig or dredge is under tow to an offshore site).

3. For short-term coastal barging (two to three days) present prediction is satisfactory. However, for long-term transoceanic barging (average 25 days) present prediction of storms and storm movements is not sufficient to effectively plan tows prior to departure.

delays were available.[1] These delays were estimated to be approximately 3 percent and encompassed time lost putting to sea and time lost during transit.

The number of trips by ocean-going barges was estimated to be about 1,000 per year and the average duration of an ocean barge trip is 25 days at a cost of $1,000 per day. The trip duration estimate of 25 days (based on an average underway speed of 8 kts) could be reduced to about 10 days should the now proposed sea-going barge-train become a reality (speed estimated to be 22 kts).[2] Should this approach prove feasible, the effects of adverse weather on ocean barging would be reduced. Assuming that future ocean barging will be influenced by the barge-train concept, the following adjustments were made:

- Present operational delays will be reduced from 3 percent to an estimated 1 percent.
- The number of barge trips will initially decline due to the 10 barge capacity of the proposed barge-train. However, after the initial decline the 1,000 trips per year will be re-established by 1985 due to mounting requirements.
- The average barge trip duration, as previously stated, will be approximately 10 days.
- The average *per diem* cost will increase from the present level of $1,000 to an estimated $3,000. This estimate considers the present barge per diem (i.e., $1,000) and present merchant ship operating costs (approximately $4,500 per day).[3]

Formulating the preceding estimates, the potential average annual cost in 1985 for operational delays as a result of adverse weather, T_{OD}, was estimated as follows:

$$T_{OD} = (N_t)(N_d)(C_{pd})(P_{od})$$

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1. The threshhold of operational delay is a wind exceeding a Beaufort force 6 or 7 (22 to 23 kts) or prediction of a storm within 24 hours of scheduled departure.

2. As reported in "Oceangoing Barges Set for Tryout," *The Washington Post* (August 25, 1969), the Straddler Ship Company expects to commence prototype construction of a 128,000 ton catamaran capable of straddling 10 12,000-ton barges for transoceanic use. The Straddler will be capable of transporting any kind of cargo--wet bulk, dry bulk, general, or containerized.

3. See the Reducing Transit Time section of this chapter.

where

N_t = 1,000 = number of ocean-going barge trips per year,

N_d = 10 = average number of days per ocean barge trip,

C_{pd} = $3,000 = average *per diem* cost per barge trip, and

P_{od} = 1 percent = amount of trip time spent in delays.

Exercising the preceding equation yields a total recoverable cost of $0.3 million per year.

Oil Rigs. Here, only the towing of a rig to an offshore site was considered. Oil rig losses due to adverse weather while operating on station or upon construction or implantation of the oil rig on station were not considered.

Offshore rigs are particularly susceptible to environmental conditions due to their inherent instability while under tow. Also, oil rigs can only be towed at speeds up to 4 kts, thus subjecting the rig to any environmental changes for some time.[1] Therefore, as oil production proceeds farther offshore and into different environments, long-range forecasts will become increasingly important. The following assessments exemplify this point:

- The Gulf of Mexico currently offers the most accurate environmental forecasts of the several areas in which extensive oil drilling operations take place.[2] However, even in the Gulf, these forecasts are becoming marginal for predicting optimum towing times due to operations farther out on the Continental Shelf.[3]

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1. Mr. W.A. Boudreaux, Transportation Section, Offshore Division, Shell Oil Company.

2. Mr. Carl LeBoeuf, Marine Superintendent of the Gulf Mississippi Marine Corporation, estimates the accuracy of forecasting storms in the Gulf to be about 90 percent for a 24-hour period. Mr. LeBoeuf attributes this level of accuracy to "the ring of land encompassing the Gulf and to in-situ reports from each offshore rig, construction site, tug, etc., operating in the Gulf."

3. Mr. D.G. Russell, Production Manager, Shell Oil Company, estimated that "substantial drilling will be conducted to the 1,000 ft water depth and some beyond prior to 1985."

- Oil and hydrocarbon discoveries made recently by the Joint Oceanographic Institution Deep Earth Sampling (JOIDES) expendition by the Glomar Challenger in the depths of the Gulf, Atlantic, and Pacific[1] indicate that by the 1980's oil rigs may be operating up to 1,000 miles offshore. Rigs for use in deep ocean, however, will require special design to withstand the oceanic environment.[2]
- The continuing oil exploration of Alaska has already presented an environmental prediction problem. Lead time predictions in the Pacific Northwest are very poor and even a 12-hour prediction is marginal.[3]

Although much of the present and past damages and/or losses experienced by oil rigs has been attributable to adverse weather, the majority of these casualities while under tow are due to factors other than weather.[4]

The evaluation of recoverable costs applicable to oil rig towing was expressed as the sum of the following two estimates:

- damage and/or loss of oil rigs while under tow due to adverse weather,
- delays in oil rig transport due to adverse conditions or false predictions.

To estimate the damages, founderings, and losses of rigs under tow due to heavy weather, a listing of all rig casualties valued at $1 million or greater was obtained from the Insurance Company of North America for 1955 to 1969. Evaluation of casualties valued under $1 million were not obtainable as rig operators

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1. "The Deep Sea--A Habitat for Petroleum?" Undersea Technology (October 1969).

2. Deep Ocean Technology, Inc., for example, has designed an offshore rig for deep sea operations down to 2,500 ft.

3. Mr. S. Pederson, Marine Superintendent, Foss Launch and Tug Company, states that "weather prediction is generally quite poor in the Pacific Northwest. For example, it is difficult to get a 12-hour prediction in Seattle for the mouth of the Straits of Juan de Fuca. Tugs leaving Seattle with a tow generally proceed to the north of the Straits (about an 18-hour run) and then intuitively decide whether or not to continue based on observed conditions."

4. Mr. J.A. Armstrong, Secretary-Underwriting, Insurance Company of North America, estimates that about 25 percent of major oil rig casualties are a direct result of adverse weather during tow. The remaining 75 percent is attributed to human misjudgments such as underestimating towing stresses.

and owners are reluctant to acknowledge any casualties. However, losses over $1 million generally become public knowledge in a rather short time. Therefore, only casualties of over $1 million could be considered in this analysis.[1]

INA listed 29 rigs damaged or lost from 1955 to 1969. Of the 29, 17 were listed as damaged or lost due to adverse weather and eight were listed as occurring during transport.

The average annual damage/loss for the 1955 to 1969 time period is approximately 1.3 million. However, six of the eight towing casualties occurred from 1965 to 1969. This would seem to be indicative of tows proceeding farther out to sea, subjecting an unstable rig to a greater chance of encountering unforeseen environmental changes. Therefore, the 1965 to 1969 average of about $2.9 million per year is used to typify the magnitude of recoverable costs in 1985. This estimate considers the fact that the new generation oil rigs are being built to better contend with adverse weather, which would tend to lower the loss rate. However, these new rigs are also more costly, and any heavy weather damages (because of this high cost) would tend to offset the gain in losses.

To evaluate the economic effect of environmental delays and false environmental predictions, four major drilling companies were contacted:

- Aquatic Contractors and Engineers (New Orleans),
- Ocean Drilling and Exploration Company (ODECO) (New Orleans),
- Sante Fe Drilling Company (Los Angeles), and
- Western Offshore Drilling and Exploration Company (Los Angeles)

The following estimates of delays and false alarms represent the collective opinion of these four companies.

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1. Mr. W.A. Boudreaux, Shell Oil Company, indicated that oil rig insurance premiums can be as high as 10 percent of the total rig value. Operating companies sometimes self-insure their own rigs--particularly if their historic loss rate is below the industry average.

At present, the cost per day to tow an oil rig is approximately $7,000. This cost is derived from the number of tugs normally required to tow a bulky and unstable rig and the tug per diem costs. Present tug requirements vary from three to four, depending on rig size and type; the per diem rate for each tug is approximately $2,000. These towing costs are paid by a drilling company on a per diem basis such that underway environmental delays or false environmental predictions at tow commencement are costly.

The average percentage of underway time spent in unforeseen environmental delays was estimated to be approximately 3 percent. Since oil rigs have a relatively low environmental acceptance level, forecasts of limiting conditions that subsequently fail to materialize (i.e., "false alarms") are not uncommon. The referenced drilling companies indicated that false alarms cost as much annually as do underway delays. The percentage of tows now subject to environmental delays or false alarms was estimated to be 6 percent.

To determine the total number of tows performed per year, the ratio of the number of rigs owned by the contacted drilling companies (47) to the annual number of tows (73) was assumed to be representative of the drilling industry. By equating the sample ratio to the total number of American-owned rigs (approximately 350),[1] the present number of oil rig tows per year was estimated to be approximately 540.

The average tow duration reported by the four drilling companies was 17 days. This duration was also assumed to typify the drilling industry as long tows (transoceanic) and short tows (several hundred miles on the Continental Shelf) were included in the sample average.

The preceding estimates depict present operations only. To estimate the total costs applicable to oil rig towing in the 1985 timeframe, the following assumptions were made:

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1. As listed in the 1969 edition of the Offshore Drilling and Construction Contractors Directory.

- [illegible] to cope with deep ocean drilling. However, even with an increase in stability these rigs will require three to four tugs for towing purposes.
- Improvements in environmental prediction will be offset by longer term towing requirements so that unforeseen environmental delays and false alarm rates will remain at the present level.
- The number of rigs will increase from the present 350 to an estimated 450 by 1985 due to Alaskan requirements and deep sea drilling. The ratio of rigs to annual tows will remain the same, yielding approximately 710 tows per year.
- The Alaskan and deep ocean developments will result in a tow duration increase of about 25 percent. Therefore, the average tow will require about 21 days to complete.

Based on the preceding assumptions, the total annual cost applicable to delays and false alarms, T_{DFA}, was formulated as follows:

$$T_{DFA} = (C_{dt})(P_{dfa})(N_t)(L_t)$$

where

C_{dt} = \$7,000 = cost per day to tow an oil rig,

P_{dfa} = 8 percent = amount of time spent in environmental delays and contending with false alarms,

N_t = 710 = number of oil rig tows anticipated in 1985, and

L_t = 21 days = duration of the average tow in 1985.

Thus, the preceding equation yields a recoverable cost of approximately \$8.3 million for the 1985 timeframe. Summing the estimates for oil rig damage/loss and oil rig delay/false alarm a total recoverable cost applicable to towing oil rigs is approximately \$11.2 million.

Dredging. The following evaluation of environmental prediction applicable to offshore dredging operations was obtained through the following dredging firms:

- Ocean Science and Engineering, Inc. (Bethesda, Maryland),
- Potomac Sand and Gravel Company (Washington, D. C.),

- Shellmaker, Inc. (San Francisco), and
- William McWilliams Industries, Inc. (New Orleans).

At the present time little dredging work is done offshore in unprotected waters. For this reason, dredge operators consider present weather conditions adequate as coastal dredge movements extend only a few hundred miles at the most. Also, dredges are stationed at a number of locations along all coasts, thus minimizing tows of any length.

Future sea bottom mining, however, may require dredges to move farther offshore and to work a greater percentage of the time in relatively unprotected waters. The most likely product to be mined in the near future is sand and gravel for construction purposes and for use in replenishing eroded beaches. As offshore dredges begin to be operated farther offshore, damage and/or losses during tow due to adverse weather will become more prominent. However, future mining dredges are being specially designed for offshore work. These designs include completely submersible dredges that would be essentially immune to the environment. Until these new generation dredges become available, however, the more conventional dredges will be used in offshore mining and construction projects. A need for improved weather prediction will exist although total economic savings will be small and are not estimated.

Summarizing the three preceding components of ocean-oriented barge and towing, the total recoverable costs are estimated to be $11.5 million.

PREVENTING CARGO DAMAGE AND LOSS

There are three types of damages or losses that can be attributed to weather: cargo lost overboard, cargo shifting, and water damage. If heavy weather could be accurately forecast before a ship departs, avoidance tactics could be employed or the departure could be rescheduled, thus minimizing the chance of cargo damage or loss.

The [illegible] of total recoverable losses was estimated by considering data provided by Insurance Company of North America, government officials, and the Liverpool Underwriters Association.

The Insurance Company of North America, largest domestic underwriters of American cargo, classifies cargo claims into two major categories--preventable and unpreventable.[1] Heavy weather claims are included in the unpreventable category and, expressed as a percentage, amount to approximately 3 percent of the total claims paid. Table 18 quantifies the heavy weather claims processed by INA from 1962 through 1968.

Table 18

HEAVY WEATHER CLAIMS PROCESSED BY INA

Year	Value of Claims, thousands of dollars
1962	312
1963	467
1964	341
1965	581
1966	465
1967	651
1968	987
Total	3,[illegible]4

Since INA underwrites about 15 percent of U.S. cargo insurance written in this country, this volume was assumed to be sufficiently large to represent a typical spread of claims. Heavy weather cargo losses, projected to encompass the heavy weather claims paid by the entire American marine insurance market,

1. Preventable claims amount to approximately 55 percent of the total claims and includes those claims regarding contamination, leakage, pilferage, etc. The remaining 45 percent are unpreventable claims. These claims result from cargo damage and/or loss involving stranding, collision, fire, and heavy weather.

were estimated to be approximately $26 million for the seven-year period. A further projection evolved from the realization that only about 40 percent of U.S. cargo is insured by American underwriters. On this premise the seven-year cost of U.S. heavy weather cargo losses was extrapolated to a sum approximating $65 million.

Referring again to Table 18, heavy weather cargo damage is observed to be increasing with time. This trend appeared to be out of context in view of the declining heavy weather damage and loss to the U.S. merchant fleet. The probable answer as to why heavy weather cargo losses portray this increasing trend was provided by Mr. A.E. Gibson, U.S. Maritime Administrator. In a recent interview, Mr. Gibson stated: "The U.S. today is carrying only about 5 percent of its foreign commerce on American flag bottoms. This percentage has been dropping sharply every year from a high of 57.5 percent in 1960. . . . The present U.S. fleet is simply not configured to compete in today's trading environment."[1]

In an attempt to assess the possible detrimental effect of transporting American cargo by foreign ships, historical world-wide ship casualty data compiled by the Liverpool Underwriters Association was analyzed for the 1962 to 1968 timeframe (i.e., the same seven-year period represented by the INA claims data). This analysis was performed under the hypothesis that ship damage and loss due to adverse weather are correlated with heavy weather cargo damage or loss. Analysis of the Liverpool Underwriters Association data revealed that approximately 1,000 ships per year experienced substantial heavy weather damage (i.e., partial or total loss). To estimate the number of U.S. merchant ships included in this annual statistic, the percentage of total U.S. merchant fleet losses was assumed to be representative. From 1962 through 1968, this was only about 4 percent. Therefore, a very high percentage of heavy weather damage to U.S. cargo can be equated with foreign shipping.

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1. "The American Merchant Marine: There are Causes for Deep Concern Militarily, Industrially, Politically," Government Executive (August 1969).

Considering the preceding assessment, the referenced trend of increasing cargo damage due to adverse weather could be retarded (or reversed) should the present Administration's efforts to revitalize the American merchant fleet be realized. The revitalization plan calls for construction of 30 merchant ships annually for the next ten years. Presumably, these new merchant ships will be capable of transporting a more substantial share of U. S. and foreign commerce, thus decreasing U. S. dependence on foreign shipping that has historically been more susceptible to heavy weather damage. Based on the assumption that the total heavy weather damage to cargo in 1985 will approximate the 1962 to 1968 average, a total annual cost of approximately $9.3 million was estimated. This considers that the amount of commerce transported by U. S. merchant ships will increase with time, subjecting a larger volume to the environment.

ICE OPERATIONS

The importance of environmental prediction of ice are discussed in two parts--government and commercial. The government aspect, for the purpose of this study, was limited to the resupply of U. S. polar outposts (military and scientific) and the reliance on U. S. Coast Guard icebreaking operations to optimize seasonal access to these outposts.[1] The commercial aspect presents a speculative estimate of the dependence that the commercial sectors of marine transportation will place on environmental prediction in the future.

Government

Initially, improved prediction of ice freeze and ice thaw in the polar regions were thought to be potentially beneficial for the purpose of correlating icebreaking with resupply schedules on an optimum-environment basis. Now, however, these Arctic and Antarctic operations are not heavily dependent on freeze/thaw prediction.

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1. Polar resupply is performed by MSTS ships--primarily tankers providing fuel oil.

Arctic

While the early warning sites were under construction in the Arctic, the accurate prediction of freeze/thaw was extremely critical to optimize the movements of crews, materials, and supplies. However, since completion of these early warning sites, these predictions are not as critical because resupply of the existing military and scientific outposts (primarily oil) can now be accomplished during the summer, when environmental conditions are historically favorable (normally August 7 to September 7). Also, polar bases (Arctic and Antarctic) retain an 18-month supply of vital resources, further indicating the lack of dependence on optimum forecasting.[1] Therefore, knowing the environmental conditions prior to a resupply operation does not significantly aid in planning icebreaking operations.[2]

Ice operations performed during the Arctic winter are of scientific nature for the purpose of determining environmental parameters and were considered immune to any potential benefits of improved environmental prediction.

Antarctic

According to MSTS personnel, there is only one resupply mission that presents any problem to scheduling--the resupply of the McMurdo Sound outpost, which now requires four POL trips annually. This past year, while making the fourth POL to McMurdo Sound, the tanker was delayed in New Zealand for a week more than scheduled. This delay resulted in considerable ice damage to the tanker (over $100 thousand to repair). Next year, however, MSTS will assign a larger tanker to the McMurdo Sound resupply route. Thereafter, the necessity for accurate freeze/thaw prediction will be de-emphasized as the larger tanker will be of sufficient capacity to require only one trip per year into McMurdo Sound.[3]

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1. Mr. Donald Dahl, Tanker Division, MSTS Headquarters.
2. LCdr D. Super, Polar Operations Branch, U.S. Coast Guard.
3. Dahl.

To exemplify the minimal recoverable costs that would result from improved environmental prediction, the Maintenance and Repair Section of the MSTS Tanker Division provided the annual costs to repair MSTS tankers experiencing ice damage in the polar regions from 1963 through 1969. These data are presented in Table 19.

Table 19

ICE DAMAGE TO MSTS TANKERS

Year	Total Number of Ships Involved in Polar Operations	Total Number of Port Calls	Total Number of Ice Casualties	Total Repair Costs, thousands of dollars
1963	9	25	0	0
1964	8	18	6	1[illegible]
1965	10	15	0	0
1966	8	19	1	16
1967	8	18	1	39
1968	11	24	0	0
1969	10	16	2	130

Commercial

Before the oil discovery on the North Slope of Arctic Alaska, there was little commercial interest in the polar regions. However, the magnitude of this discovery will increase the importance of Arctic environmental prediction in the future. The following excerpt is indicative of the importance of fully utilizing environmental prediction to optimize Arctic Alaska operations:

> With 10 wells now completed and twice that many now being drilled demands for supplies have caused a race against time for oil companies trying to get supplies to the north slope before winter. Recently a fleet of 31 seagoing barges was towed to the north slope from Seattle. Now 130 longshoremen are working against the clock to get the barges unloaded and back to Seattle before the winter sets in.[1]

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1. "Rush on to Tap New Alaskan Oil Fields," The Washington Post, September 1969.

Also directly related to the North Slope oil discovery is the recent success of the icebreaker/tanker, S.S. Manhattan, in traversing the icebound Northwest Passage. Although this historic voyage was of an experimental nature, a precedent has been set and an environmentally dependent trade route has been created. Already several major oil companies are making plans to procure $50 million (250,000 dwt) ice tankers[1] to transport Alaskan oil to the East Coast.[2] Thus with volume shipping challenging the Arctic environment, a sophisticated environmental routing service (ice routing) will undoubtedly be required.

The present state of the ice routing art is represented by that service provided by Fleet Weather Central Norfolk to the MSTS ships on polar resupply missions.[3] Even this service, however, does not wholly contend with the problems that will confront a 250,000 dwt tanker in the icebound straits of the Northwest Passage. For example, the 10 percent ice-coverage limitation placed on MSTS ships[4] presents a lesser prediction problem to ice-routers than did the nonprediction of the giant ice floes pushed by 50 mph winds that temporarily trapped the <u>Manhattan</u> and the Canadian icebreaker, <u>Sir John MacDonald</u>.[5]

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1. Humble Oil and Refining Company anticipates that the ice tanker fleet built to transport the Alaskan crude could number 25 to 30 by 1980 ("Northwest Passage . . . What It Could Mean," <u>Ocean Industry</u> [July 1969]).

2. Oil economists estimate the cost of shipping oil to the East Coast via the Northwest Passage to be approximately half of the $1.66 per barrel required to transport the oil via pipeline and ship to the West Coast (U.S. Coast Guard, <u>Polar Transportation Requirements</u> [November 1968]).

3. Mr. George Frances, Head of OTSR-FWCNORVA, states that the accuracy of present ice routing in the Atlantic Arctic (Goose Bay, Sondrestrom, Thule, etc.) is directly related to the NWCED (Naval Weather Center--Environmental Detachment--Argentina, Newfoundland) budget. Prior to providing an ice routing FWCNORVA requests NWCED to perform an air reconnaissance from which the routing is made. These ice-reconnaissance missions are performed upon request until the budget is exhausted. Thereafter, FWCNORVA must rely on other sources--local condition reports, satellites, etc.

4. Mr. Donald Dahl, Tanker Division, MSTS Headquarters.

5. "Manhattan Reaches Prudhoe Bay," <u>Ocean Industry</u> (October 1969).

REDUCING FATALITIES AND IMPROVING SEARCH AND RESCUE

During 1967 and 1968, Boating Statistics reported an average of 66 pleasure craft fatalities involving adverse weather conditions.[1] Future weather fatalities were assumed to remain at a level approximating 60 to 70 per year. This estimate was assumed to be valid for the following reasons:

- The number of registered pleasure craft has increased at a rate of approximately 4.5 percent per year from 1963 through 1968. Also increasing along with the quantity of pleasure craft is the number of naive owners who are likely to fall prey to adverse conditions.[2]
- Fatalities could be avoided now if the general public would heed existing weather warnings.[3]
- Sudden storms will continue to catch pleasure craft unaware.[4]

As was the case in pleasure craft fatalities, the analysis of 1967 and 1968 data formed the basis for estimating merchant marine fatalities. In the years cited, the Proceedings of the Merchant Marine Council attribute only one death to adverse weather conditions. Therefore, the future reduction in fatalities was assumed to be zero.

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1. LCdr Harold B. Summey, Chief of the Accident Review and Statistics Branch, USCG, is confident that all pleasure craft fatalities are accounted for in Boating Statistics. The U.S. Coast Guard subscribes to a national newspaper clipping service that forwards boating accident articles to U.S. Coast Guard Headquarters.

2. Capt Howard Saffer, small craft underwriter for Fireman's Fund American Insurance Company.

3. Exemplifying this point is a report prepared by the U.S. Coast Guard Marine Board of Investigation following the Lake Michigan squalls of September 23, 1967. On the morning of September 23, 1967, small craft warnings were posted. The subsequent storm claimed seven lives--all pleasure craft operators or passengers.

4. For example, the sudden and unforeseen storm on Lake Erie on July 4, 1969 caught hundreds of pleasure boats unaware in 100 mph winds. (The Washington Post, July 5, 1969).

Search and rescue missions rely on accurate local condition reports and near term forecasts. Environmental data required to formulate search and rescue missions includes wind force and direction, current speed and direction, and wave heights. These environmental parameters used in conjunction with the stricken vessels' destination and last point of contact serve to determine optimum search patterns. Thus, the more accurate these environmental parameters are, the greater the chance of rapidly finding a vessel in distress.

INCREASING PASSENGER COMFORT

Passenger comfort was analyzed from a qualitative viewpoint since this topic is highly subjective and opinionated. This study attempted to assess the degree of improvement that could be expected. To accomplish the preceding, two general sources were investigated:

- commercial steamship companies offering passenger liner service, and
- Fleet Weather Central (Norfolk, Virginia, and Alameda, California), who provide routings for MSTS passenger ships.

Five steamship companies were contacted: American President Lines, Central Gulf Steamship Company, Cunard Steamship Company, Grace Line, and Moore-McCormack Lines. Assuming a voyage not encountering adverse weather to be indicative of passenger comfort, each of the companies was asked to qualitatively evaluate OSR techniques in relation to passenger comfort. The answers ranged from ". . . a great deal of improvement since OSR services were introduced" to "we have provided comfortable Atlantic crossings for 150 years without OSR and do not need the service now."

Next, the annual routing statistics provided by fleet Weather Central (NORVA and ALA) were analyzed. Again assuming that passenger discomfort is correlated with adverse weather, the accuracy of forecasting should be directly related to passenger comfort. Therefore, the percentage of routes encountering adverse weather considered avoidable by more accurate forecasting was deemed a proxy for passenger comfort improvement. Table 20 summarizes this percentage on an annual basis and indicates the number of routings from which this percentage was derived.

Table 20

ADVERSE WEATHER AVOIDABLE BY MORE ACCURATE FORECASTING

Year	Total Routings Provided		Routes Encountering Adverse Weather Considered Avoidable by More Accurate Forecasting, percent	
	NORVA	ALA	NORVA	ALA
1960	528	758	5	2
1961	540	878	4	2
1962	617	876	3	2
1963	662	873	3	1
1964	780	918	1	2
1965	841	908	1	2
1966	845	Data Not Available	1	Data Not Available

In view of these small percentages, it would appear that passenger comfort is becoming asymptotic with the optimum, and potential benefits will be negligible.

IMPROVING PORT SERVICES

Initially, reduction of nonproductive longshoremen labor costs (rainouts) was thought to be a direct benefit of improved environmental prediction. However, closer investigation of the real-world situation revealed that these potential savings would not be realized.

A cargo ship in port is loaded and unloaded by members of the International Teamster Union. By 3 p.m. each day, a shipping company must notify a stevedore company, who in turn orders longshoremen for the following day. In New York, although the slightest precipitation will cause work stoppage (rainout), the longshoremen are still paid in four-hour increments; whenever rain occurs and longshoremen are scheduled, they are paid for this nonproductive time. Ideally, a shipping company using precipitation forecasts could elect not to order longshoremen if a rainout were predicted. However, two factors preclude this potential cost savings from being realized:

- A union agreement includes an annual work guarantee clause ranging from 1,600 hours (Norfolk) to 2,080 hours (New York). These guarantees do not include a rainout clause. Every longshoreman who reports for work and cannot work for a variety of reasons beyond his control can obtain pay by applying for the guarantee. This guarantee is managed by shipping associations in each port and is fulfilled by taxing the stevedoring companies for their appropriate share. To compensate for this tax the stevedore employer includes a factor for rainouts in the rate charged to the shipping company. Thus, the savings that would appear to result from a steamship company's canceling cargo operations because of precipitation are only superficial.
- One experienced stevedore employer mentioned that even if he did not schedule cargo operations on a day of precipitation, he would find it very difficult to obtain longshoremen on the following day due to his diversion from the unwritten rules of the game.

CONCLUSION

Summarizing the results of the analyses presented in this chapter, the total annual recoverable costs and losses in marine transportation for the 1985 timeframe are as follows:

Category	Annual Recoverable Costs, millions of dollars
Vessel transit time reduction	2.7
Vessel damage/loss prevention	
Merchant fleet	5.3
Government fleet	7.6
Small boats	4.9
Barge and towing	11.5

Category	Annual Recoverable Costs, millions of dollars
Cargo damage/loss prevention	9.3
Ice operations	Negligible
Fatalities	60-70
Passenger comfort	Negligible
Port services	Negligible

Table 21 consolidates these potential savings and indicates what might be expected at predictive improvement levels of 25 percent and 50 percent.

Table 21

ANNUAL RECOVERABLE COSTS--MARINE TRANSPORTATION (1985)

Level	Savings In		Total
1 25 Percent	Vessel Transit Time Vessel Damage/Loss Cargo Damage/Loss Fatalities	$0.7 million $7.5 million $2.3 million 15-18	$10.5 million 15-18
2 50 Percent	Vessel Transit Time Vessel Damage/Loss Cargo Damage/Loss Fatalities	$1.4 million $15.0 million $4.6 million 30-35	$20.6 million 30-35
3	Vessel Transit Time Vessel Damage/Loss Cargo Damage/Loss Fatalities	$2.7 million $29.3 million $9.3 million 60-70	$41.3 million 60-70

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APPENDIX A

BENEFITS FROM REDUCED SNOW AND ICE CONTROL

This Appendix contains the detailed analysis of snow control costs and the anticipated benefits from improved weather forecasting for the Washington, D. C., area. Washington, aside from its proximity to RMC's facilities, was chosen largely because detailed data were available from sources within the District government. To project benefits from improved forecasts, it was necessary to analyze the costs associated with individual storms of varying intensity and forecast quality. The Washington data fit well into our analytic framework. The size of the data collection and analysis task would preclude doing a similar analysis on more than a few cities in any practical study.

DATA COLLECTED FOR WASHINGTON, D. C.

Records of the snow control activity for three winter seasons were obtained and analyzed.[1] These records contained the U. S. Weather Bureau forecast that prompted the activity, the actual precipitation that fell and its timing, the timing of the mobilization and dispatch of spreading, plowing and hauling units, the number of units participating, and a summary of the action. A report was made every time city forces engaged in snow control activity. During the period of November 1966 to March 1969, 40 such events occurred. In addition, 15 minor storms occurred that required no mobilization activity.

1. These were made available through the courtesy of the Department of Highways and Traffic, Government of the District of Columbia.

Forecast History		Classification of Forecast		Washington, D. C.		Illinois Division of Highways
Prediction	Event			Number of Occurrences	Percent	Percent
No	Yes	"Low or Missed"		10	18.2	18.4
	No	"Good"	No Action	15	52.6	57.8
Yes	Yes		Action	14		
	No	"High or False Alarm"		16	29.2	23.8
		Total		55	100.0	100.0

The rationale behind the classification of forecasts as "good," "low or missed," or "high or false alarm" followed from our position that forecasts should be judged in relation to the use made of them. Snow control officials respond to forecasts of impending snowstorms by mobilizing some portion of the snow control force at a particular time. The streets generally require control activity if more than a trace of snow actually falls. Thus, timing and amount of snow are both important to the snow control officials, the resulting costs, and the effectiveness of the actions taken. A forecast was termed "low or missed" if it predicted substantially less snow than actually fell, predicted rain rather than snow, or failed to predict any precipitation that would require action. A forecast was classified as "high or false alarm" if it prompted a much larger initial mobilization than was necessary for what actually occurred or if a predicted storm never materialized. All other storms fell into the category of having "good" forecasts. "Good" forecasts with a one-hour lead time are "hits"; all others are shades of "misses."

The events falling into the three forecast quality categories were analyzed as separate groups, on the assumption that different mechanisms would be operating in the production of costs between the groups From the records, a number of items of information relating to the storm characteristics and the control activities were collected. These include the following:

- depth of snow (intensity),
- storm duration,
- time between first mobilization and precipitation (lead time, mobilization),
- time between first dispatch and precipitation (lead time, dispatch),
- duration of snow alert, and
- number of truck hours worked.

In a number of cases, approximations had to be made, but we believe that these approximations were in line with the facts. From these data values, a number of measures were derived, in hopes that they might help to explain the cost behavior as related to forecast accuracy. These included

- storm duration/alert duration;
- truck hours/storm duration;
- rate of snow fall (intensity/duration);
- lead time, mobilization/alert duration; and
- lead time, dispatch/alert duration.

Hypotheses were developed for functional relationships between a number of variables. We believed that truck hours should be an increasing function with some measure of storm severity, and that the quality of the forecast should also affect the cost outcome. Graphical displays of many of the potentially relevant relationships were used to eliminate some, while helping isolate a few relationships that had good descriptive power.

Linear regressions and regressions on transformations of some of the variables were run to determine the best relationships in terms of the standard statistical measures.

For the category "high or false alarm" forecasts, the only useful relationship is an arithmetic average of the number of truck hours. The record of these events is shown in Figure A-1, which plots truck hours versus storm intensity. The average number of truck hours for these events is 695. Potential explanatory variables, such as predicted intensity or forecast lead time, were not uniformly available in quantifiable form for these events (e.g., "Chance of snow by morning.").

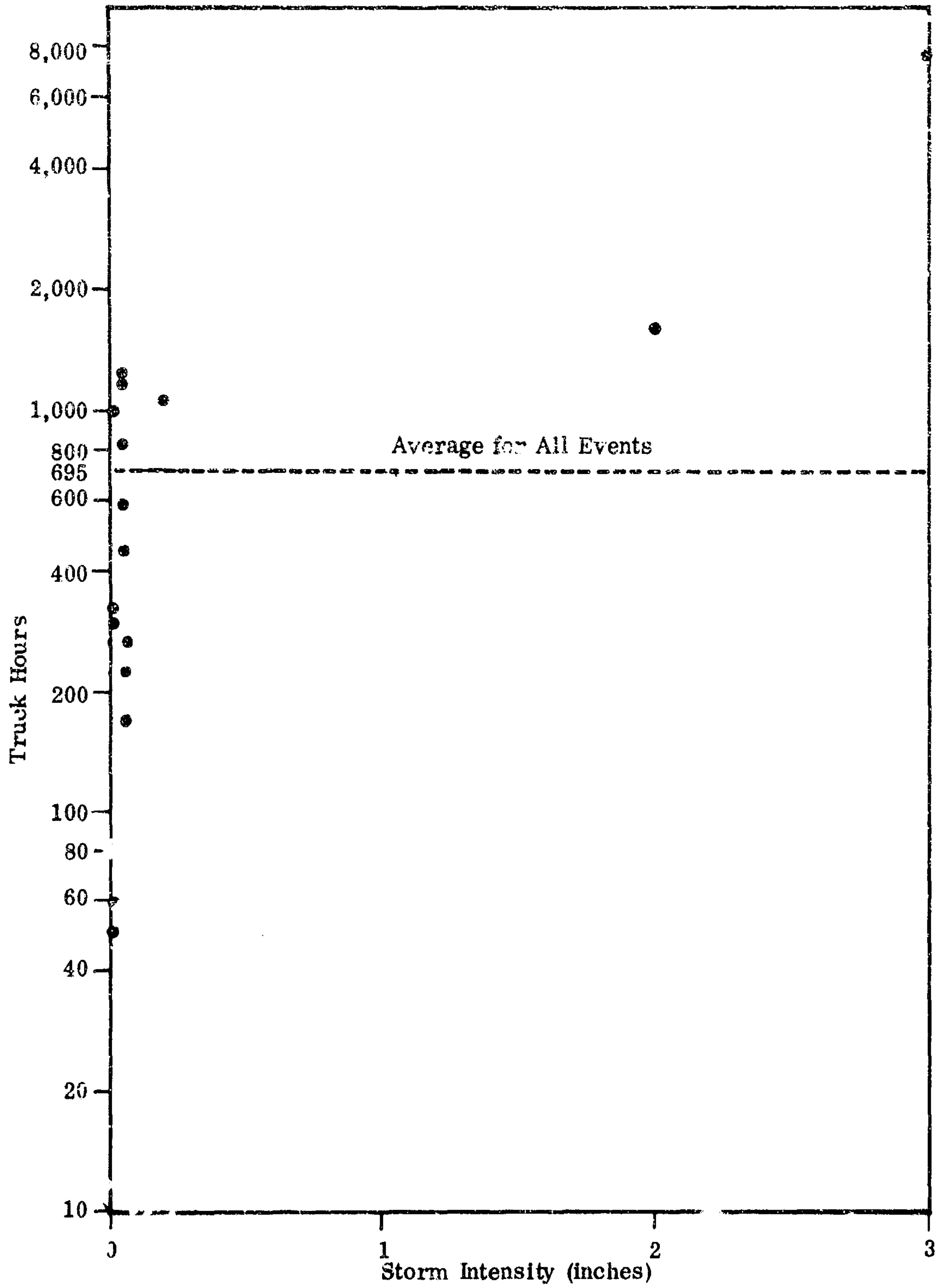

Figure A-1: MOBILIZATION EVENTS WITH HIGH FORECASTS OR FALSE ALARMS

The group of "low or missed" forecasts is best described by a relationship between storm intensity and the logarithm (base 10) of truck hours. In this form, a linear relationship exists, with reasonably good statistical measures. A transformation of the equation results in an exponential form

$$TH = (494)\ 10^{.1558I}$$

where

TH = truck hours

I = intensity of storm (inches)

Figure A-2 displays this relationship, along with the data points.

The mobilization events that fell into the category of "good" forecasts related best to both intensity of the storms and the parameter "lead time, mobilization." The relation is also log-linear, and the linear form of it has fair statistical measures. This relationship is plotted along with the data points and statistical information in Figure A-3. A transformation to exponential form predicts truck hours by the equation:

$$TH = 640 \cdot 10^{.03167I}\ 10^{.1342LTM}$$

where

LTM = lead time, mobilization.

Snow control officials in Washington try to have a mobilization lead time of one to two hours. This permits the ability to respond quickly to the first affects of a snowstorm. If they operated with lower (zero or negative) lead time, their costs would be lower, which indicates that there are substantial disbenefits to society from such delayed reaction, as discussed under the sections on traffic accidents and road user delays.

Assuming that snow control operations proceed most efficiently when lead time for mobilization is one hour, then the equation derived can be used to measure the

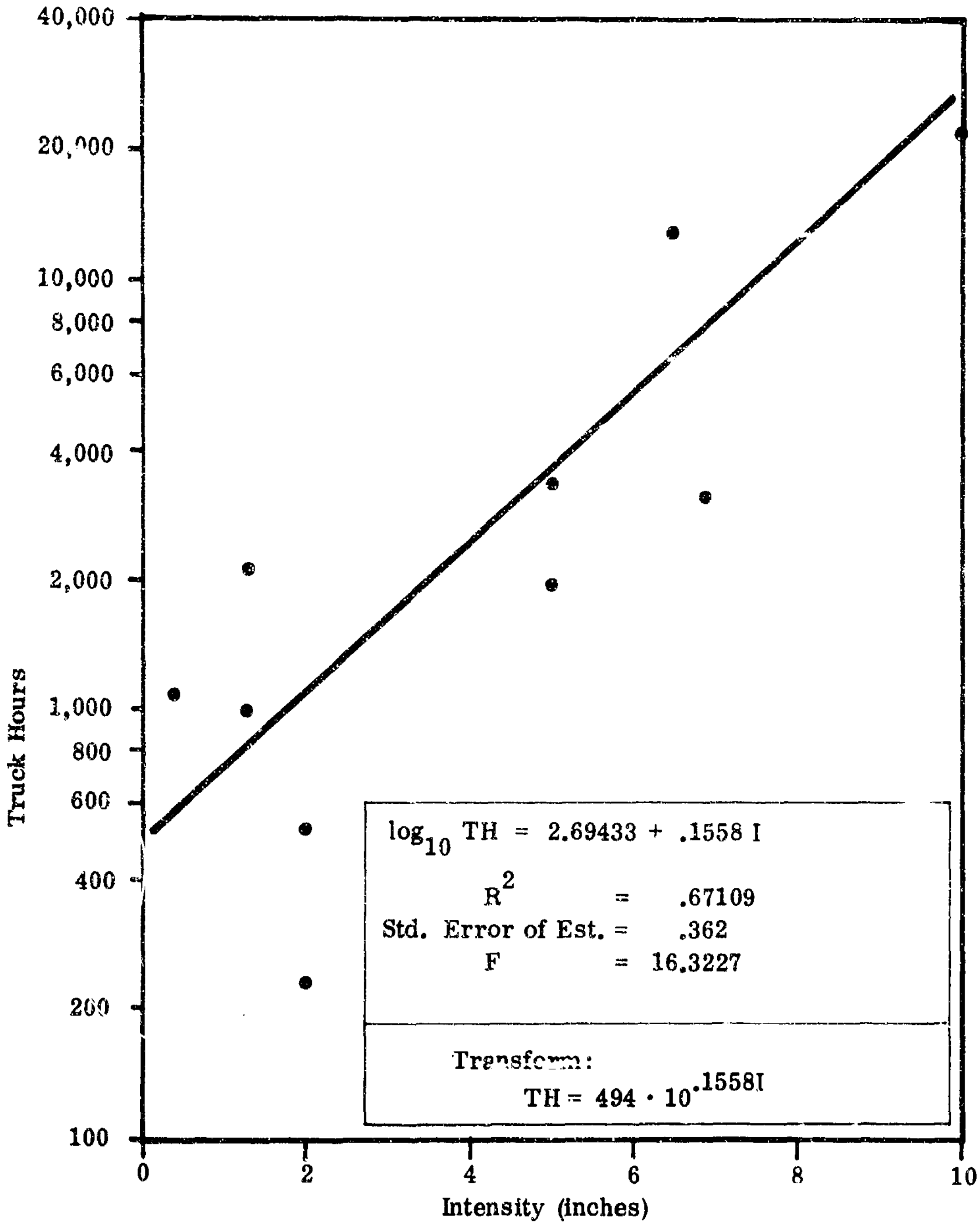

Figure A-2: RELATIONSHIP BETWEEN STORM INTENSITY AND TRUCK HOURS--MOBILIZATION EVENTS WITH LOW OR MISSED FORECASTS

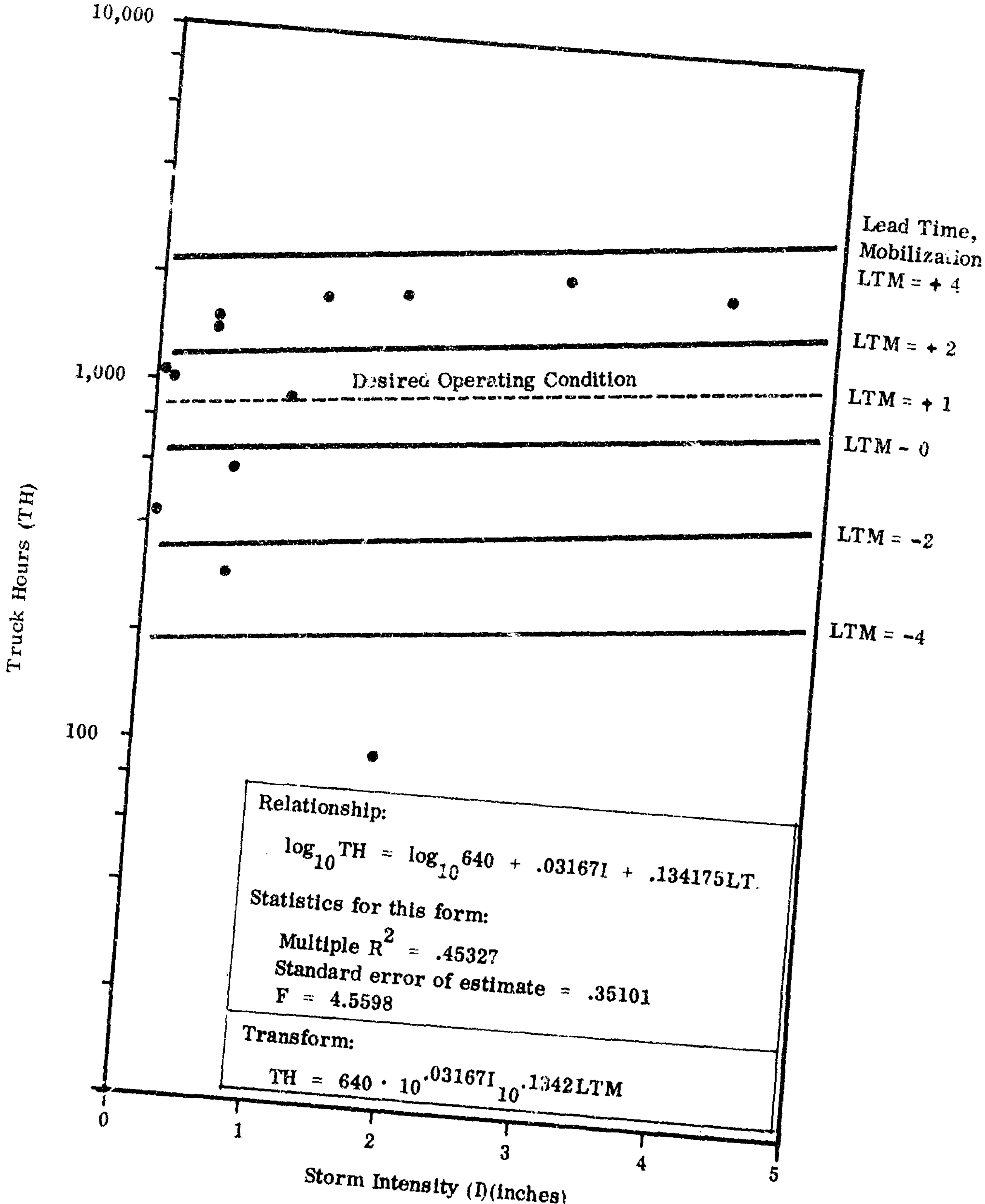

Figure A-3: MOBILIZATION EVENTS WITH GOOD FORECASTS excess cost incurred in snow control operations from deviations above this level of operation. Deviations below this level would result in extra costs incurred by other sectors of the transportation industry.

The difference in magnitude between the ideal situation (good forecasts with one hour lead time) and that of the low forecasts also is an added cost to the city from inadequate forecasts. Finally, high forecasts or false alarms is the third component of the excess costs caused by present levels of predictive ability.

To illustrate an application of our methodology, we will take the record of the 55 snow occurrences in this three-season time period and compare the results of present levels of forecasting accuracy with those of three levels of improved predictive ability. For the base case, we will apply the appropriate estimating relationships to the storm characteristics and forecast category for each of the storms. For the three successively better levels of predictive ability, we will observe the snow control cost difference as more storms move to the category of "good" forecasts with one hour lead time for mobilization. (The exponential form is used for storms with snow fall above a trace. Zero truck hours is used for storms with no snow or a trace.)

The three levels can be roughly described as 25 percent, 50 percent, and 100 percent improvement in predictive ability, with 100 percent representing "perfect" forecasts, i.e., elimination of all deviations from normality. Table A-1 summarizes these results and shows the anticipated differences in truck hours over this three-year period for the three levels of improvement. As can be seen from the table, each successive improvement indicates a lower net cost of snow control.

To translate these improvements into annualized costs, the avoidable cost per truck hour avoided must be found. In this setting a truck hour has many aspects to it, which then have a reflection in cost. The trucks may be city-owned or contract trucks. They may be specialized equipment (rotary blowers, spreaders) or trucks whose major purposes are some other activity (sanitation, hauling) equipped with some device to adapt it to the snow control activity. These devices may be chemical

Table A-1

REDUCTION IN TRUCH HOURS FOR SNOW CONTROL
FROM IMPROVEMENTS IN PREDICTIVE ABILITY

Storm Code	Precipitation (inches of snow, sleet)	Base Case			Level 1-- 25% Improvement			Level 2-- 50% Improvement			Level 3-- 100% Improvement Perfect Forecast		
		Forecast Category	Lead Time, Mobilization	Truck Hours, Base Case	Forecast Category	Lead Time, Mobilization	Truck Hours Level 1	Forecast Category	Lead Time, Mobilization	Truck Hours Level 2	Forecast Category	Lead Time, Mobilization	Truck Hours, Level 3
1.66	5.0	L	NA	3,700	G	1.0	1,200	G	1.0	1,260	G	1.0	1,260
2.66	.6	G	- .92	520	G	- .92	520	G	1.0	900	G	1.0	900
3.66	6.5	L	NA	6,650	L	NA	6,650	G	1.0	1,410	G	1.0	1,410
4.66	1.8	G	+ .1	725	G	+ .1	725	G	+ .1	725	G	1.0	990
5.66	1.3	L	NA	840	L	NA	840	L	NA	840	G	1.0	960
6.66	10	L	NA	27,500	L	NA	27,500	L	NA	27,500	G	1.0	1,320
7.66	2	H	NA	695	H	NA	695	H	NA	695	G	1.0	1,000
8.66	5	L	NA	3,700	L	NA	3,700	G	1.0	1,260	G	1.0	1,260
9.66	T	H	NA	695	G	NA	0	G	NA	0	G	NA	0
10.66	4	L	NA	575	L	NA	575	L	NA	575	G	1.0	890
11.66	T	H	NA	695	H	NA	695	H	NA	695	G	NA	0
12.66	T	G	NA	0	G	NA	0	G	NA	0	G	NA	0
13.66	T	G	NA	0	G	NA	0	G	NA	0	G	NA	0
14.66	T	G	NA	0	G	NA	0	G	NA	0	G	NA	0
15.66	T	G	NA	0	G	NA	0	G	NA	0	G	NA	0
16.66	T	G	NA	0	G	NA	0	G	NA	0	G	NA	0
1.67	0.0	H	NA	695	G	NA	0	G	NA	0	G	NA	0
2.67	6.9	L	NA	7,900	G	1.0	1,470	G	1.0	1,470	G	1.0	1,470
3.67	1.8	G	-3.3	260	G	1.0	990	G	1.0	990	G	1.0	990

Table A-1
(Continued)

Storm Code	Precipitation (inches of snow, sleet)	Base Case			Level 1--25% Improvement			Level 2--50% Improvement			Level 3--100% Improvement Perfect Forecast		
		Forecast Category	Lead Time, Mobilization	Truck Hours, Base Case	Forecast Category	Lead Time, Mobilization	Truck Hours Level 1	Forecast Category	Lead Time, Mobilization	Truck Hours Level 2	Forecast Category	Lead Time, Mobilization	Truck Hours, Level 3
4.67	.3	G	+1.63	1,100	G	1.0	880	G	1.0	880	G	1.0	880
5.67	4.3	G	+1.63	1,450	G	1.63	1,450	G	1.63	1,450	G	1.0	1,200
6.67	T	H	NA	695	H	NA	695	G	NA	0	G	NA	0
7.67	1.2	G	+2.12	1,350	G	2.12	1,350	G	1.0	940	G	1.0	940
8.67	.3	G	+1.92	1,190	G	1.92	1,190	G	1.92	1,190	G	1.0	880
9.67	T	H	NA	695	H	NA	695	H	NA	695	G	NA	0
10.67	1.3	L	NA	840	L	NA	840	L	NA	840	G	1.0	960
11.67	T	G	-2.32	310	G	NA	0	G	NA	0	G	NA	0
12.67	.8	G	- .22	625	G	- .22	625	G	- .22	625	G	1.0	920
13.67	T	H	NA	695	H	NA	695	H	NA	695	G	NA	0
14.67	3.0	H	NA	695	G	1.0	1,080	G	1.0	1,080	G	1.0	1,080
15.67	2.0	L	NA	1,100	L		1,100	G	1.0	1,000	G	1.0	1,000
16.67	T	G	NA	0	G	NA	0	G	NA	0	G	NA	0
17.67	T	G	NA	0	G	NA	0	G	NA	0	G	NA	0
18.67	T	G	NA	0	G	NA	0	G	NA	0	G	NA	0
19.67	T	G	NA	0	G	NA	0	G	NA	0	G	NA	0
20.67	T	G	NA	0	G	NA	0	G	NA	0	G	NA	0
21.67	T	G	NA	0	G	NA	0	G	NA	0	G	NA	0
1.68	T	H	NA	695	H	NA	695	G	NA	0	G	NA	0

Table A-1
(Continued)

Storm Code	Precipitation (inches of snow, sleet)	Base Case: Forecast Category	Base Case: Lead Time, Mobilization	Base Case: Truck Hours, Base Case	Level 1-- 25% Improvement: Forecast Category	Level 1: Lead Time, Mobilization	Level 1: Truck Hours Level 1	Level 2-- 50% Improvement: Forecast Category	Level 2: Lead Time, Mobilization	Level 2: Truck Hours Level 2	Level 3-- 100% Improvement Perfect Forecast: Forecast Category	Level 3: Lead Time, Mobilization	Level 3: Truck Hours, Level 3
2.68	0	H	NA	695	H	NA	695	H	NA	695	G	NA	0
3.68	T	G	+1.12	880	G	NA	0	G	NA	0	G	NA	0
4.68	0	H	NA	695	G	NA	0	G	NA	0	G	NA	0
5.68	.2	H	NA	695	H	NA	695	G	1.0	880	G	1.0	880
6.68	T, glaze	H	NA	695	G	NA	0	G	NA	0	G	NA	0
7.68	T	H	NA	695	H	NA	695	H	NA	695	G	NA	0
8.68	1, glaze	G	+1.62	1,050	G	1.62	1,050	G	1.62	1,050	G	1.0	875
9.68	0.0	H	NA	695	H	NA	695	H	NA	695	G	NA	0
10.68	1.0	G	- .67	630	G	- .67	630	G	1.0	930	G	1.0	930
11.68	.6	G	- .92	510	G	- .92	510	G	- .92	510	G	1.0	910
12.68	T	H	NA	695	H	NA	695	G	NA	0	G	NA	0
13.68	3.0	G	+4.90	3,700	G	1.0	1,080	G	1.0	1,080	G	1.0	1,080
14.68	2.0	L	NA	1,100	L	NA	1,100	L	NA	1,100	G	1.0	1,000
15.68	T	G	NA	0	G	NA	0	G	NA	0	G	NA	0
16.68	T	G	NA	0	G	NA	0	G	NA	0	G	NA	0
17.68	T	G	NA	0	G	NA	0	G	NA	0	G	NA	0
18.68	T	G	NA	0	G	NA	0	G	NA	0	G	NA	0
Total Truck Hours				79,325			65,765			56,355			52,740
Reduction Over Base Case, Truck Hours							13,560			22,970			52.740

Table A-1
(Continued)

Precipitation:	T: Trace	
Forecasting Categories:	G: Good forecast	
	H: High forecast or false alarm	
	L: Low forecast or miss	
Lead Time, Mobilization:	Positive number:	mobilization occurred before first snowfall
	Negative number:	mobilization occurred after first snowfall
	NA:	Not applicable for low, high forecasts or storms with 0.0" or trace

spreading devices or plows, and there is a variety of types and ages of these in use in the District of Columbia. The activities engaged in by the trucks range from waiting (at city facilities or at critical sites such as bridges and hills) to actual spreading of abrasives, plowing, or hauling. Non-productive but essential activities such as refueling, travel to work sites, and emergency repairs also account for some truck hours. The cost to the city of a truck hour consists of the elements materials, labor, and equipment depreciation.

The materials expended through truck usage are fuel, repair materials, and salt and other materials spread on the streets. The sand and salt used in fighting snowstorms is related most closely to the actual storm characteristics and not to the accuracy of the forecast; officials in charge of snow and ice control say that these materials are not spread until snow actually starts falling, and they are spread until the snow reaches a depth of about two inches. Therefore, the cost of these materials are of no concern in differentiating between actions taken on forecasts of varying qualities. The costs of fuel and materials for repair are relevant items, however.

Most of the costs are covered in the truck rental paid to contractors on the snow control effort. In 1968, this rate was $17.50 per hour plus a $150 annual retainer and includes the use of the truck, one operator, and all fuel and maintenance costs. We will assume that the contract rate is a fair representation of the costs of these elements for the city-operated vehicles, too. To the hourly cost must be added the cost of the attached specialized equipment, administrative costs, and the cost of supervisory personnel.

The major specialized equipment items are spreaders and plows. Abrasive spreaders can be bought for about $2,500. They require about two hours of cleaning and maintenance between uses and a comparable amount of time for maintenance between seasons. A ten-foot reversible plow with the "A" frame and axle bracket necessary for attachment costs about $750 and requires about half the cleaning and maintenance of a spreader unit.[1]

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1. Personal communication from Mr. C. Carroll, Department of Highways and Traffic, District of Columbia.

Both items have useful lifetimes of around ten years. Assuming $50 as the annual cost of maintenance and cleaning of a spreader unit, our estimates of the annualized costs of owning and operating these equipment items are

Spreader:	$2,500/10 + 50 = $300
Plow:	$ 750/10 + 25 = $100

If the $150 retainer fee reflects administrative costs to the contractors, which are mirrored by comparable costs for the city, then the total annual costs for these items is

Spreader:	$450
Plow:	$250

During the storm of February 6, 1967, 90 spreader units and 253 plows were deployed. If the total annual cost reflects this peak, then the use of spreaders and plows indicates an annual expenditure of $103,700 (= 90 x $450 + 253 x $250). Over the three-year period studied, the number of truck hours averaged 25,140 per year. Thus, the average cost per truck hour of these equipment items amounts to $4.12.

The estimated cost of supervisory personnel allocated to truck hours is about $1.00, based on an approximation of 20 to 25 headquarters and field personnel and about 100 vehicles.

Adding together all the elements gives us $22.62 (= $17.50 + $4.12 + $1.00) per truck hour as the estimate to apply to the reductions shown by the three levels of improvement in predictive ability. It is fair to use this average cost, since we are talking of relatively long-range changes in the operating environment of the snow control activit During the period of time needed to realize a given change in predictive ability, it is assumed that the entire level of operations could be changed so as to gain the potential cost savings indicated by the average cost figure.

When this figure is applied to the differences in truck hours associated with the three levels of improvement shown in Table A-1, we arrive at a measure in the benefits that could be realized by improved prediction over the three-year period in question. The resulting annual average potential savings are reported in Table A-2.

Table A-2

ANNUAL POTENTIAL BENEFITS
FROM IMPROVED FORECASTING
TO SNOW CONTROL EFFORT IN WASHINGTON, D. C.

Level of Improvement	Potential Reductions in Truck Hours - Three-Year Period	Annual Savings in Truck Hours	Annual Cost Savings
1 - 25% improvement	13,560	4,520	$ 90,900
2 - 50% improvement	22,970	7,677	$173,500
3 - 100% improvement (perfect forecast)	52,740	17,560	$397,000

APPENDIX B

BENEFITS FROM REDUCED TRAFFIC ACCIDENTS

As a result of investigating the causes of traffic accidents associated with snowstorms, we found that there are two areas for potential reduction in costs from improved forecasting: (1) eliminating accidents occurring during the early portion of a storm, and (2) eliminating traffic accidents after the storm. Both are associated with delayed action on the part of snow control activities. The preventable accidents occurring early in a storm would occur on streets that had not yet been salted. Accidents occurring after a storm are associated with a delay in the clean up of streets, due to a late start or a low forecast. In either case, an increase in the warning time for mobilizing forces or the elimination of forecast errors on the low side should reduce the incidence of these accidents.

An important point to remember, however, is that weather and road conditions are only some of the factors involved in causing accidents, and that other factors will still be present to cause accidents, even if an improvement can be made in weather forecasting. In fact, there may be some adverse effect from maintaining better road conditions. Studies have shown that the unit cost of accidents on dry pavement is higher than on snowy pavement, because drivers are more cautious on snowy streets and drive more slowly, resulting in less damage and fewer personal injuries when accidents do occur.[1] Eliminating accidents on snowy streets by means of better forecasting will generate a smaller number of more severe accidents.

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1. Robert K. Lockwood, ed., Snow Removal and Ice Control in Urban Areas, APWA Research Foundation Project No. 114, (Chicago 1965), and Motor Vehicles Accident Costs--Washington Metropolitan Area, Wilbur Smith & Associates, (1965).

Some indication of the magnitude of the potential savings can be determined by examining data collected for Chicago.[1] It was estimated that an inch of snow caused about 200 accidents in excess of what would have occurred under good conditions. Of these, 72 percent occurred after the storms ended. If the weather forecasts for Chicago are as accurate as those in Washington, this indicates that about 32 percent of all storms are predicted on the low side or without ample warning.[2] Thus, a maximum of 32 percent of the snowstorm accidents might be attributable to these forecasts. In Chicago, with a mean annual snowfall of 37.6 inches, there would be a maximum target of 2400 accidents that could be eliminated (32% x 200 x 37.6). A more reasonable assumption is that the effect of a low or late forecast on accidents occurring after a storm is much less than on those in the first hours of the storm. This is so because the persons in charge of snow control operations make adjustments in their plans as a storm progresses. If we assume that low or late forecasts have an effect on only 25 percent to 50 percent of the target accidents occurring after a storm, then the net annual target number of accidents that may be eliminated is 1110 to 1540 = 2400 x (28% + 25% x 72%) or = 2400 x (28% + 50% x 72%).

Thus, if forecasting could be improved so as to eliminate all such errors, approximately 1300 accidents annually, at about a cost of $250 per accident, could be avoided.[3] Perfect forecasts would save the motor vehicle sector of the transportation industry in Chicago about $325,000 per year.

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1. Lockwood.

2. In the 1966-1969 period, 10 storms in Washington had low forecasts and seven of the 55 were not predicted with sufficient warning.

3. The unit cost of accidents on snowy streets was reported at between $210 and $295 in the 1965 APWA study.

Chicago has twice the annual snowfall and five times the population of Washington, D. C. The monthly accident rate in the Chicago APWA study was 12,200 (1963 to 1969), while for Washington it ranged between 2,640 (1966) and 2,960 (1969).[1] On the basis of these differences in scale, an appropriate ratio between the potential savings for Chicago and Washington would be between 4:1 and 10:1. Taking 6:1 as a compromise, we arrive at an estimate of the maximum savings in snow-related accidents for the District of Columbia of $54,000 per year.

To corroborate this estimate, the record of accidents in the District of Columbia was studied for a three-month period during 1969. During this time, Washington snow control units were mobilized 11 times, and 6.9 inches of snow fell. For each of the storms, the reports of the individual accidents occurring at that time or in its aftermath were studied and the prevailing weather and road conditions tabulated. These are listed in Table B-1.

By associating the time of the snowstorms and the warning times available to snow control forces, we estimated that 49 of the 280 accidents occurring in snowy or sleeting weather might be attributed to a late or low forecast. This is 17.5 percent of that category. It was assumed that virtually none of the 222 accidents occurring under conditions of fog, mist, or rain was preventable by improved forecasts. If we apply the 17.5 percent figure to the category of clear, wet, or icy, we get 18 accidents occurring after the storms that might have been prevented by improved forecasts. The estimate, then, is that 67 (49 + 18) accidents during this period were the result of low or late forecasts.

This time period sustained 6.9 inches of snow, or 37 percent of a median year's annual accumulation. This suggests that in an average year, there would be

1. Metropolitan Police, District of Columbia, Official Traffic Accident Summary Reports, 1966, 1967, 1978, January, February, March, 1969.

Table B-1

SUMMARY OF ACCIDENTS IN WASHINGTON
ASSOCIATED WITH SNOWSTORMS -- Jan. - March 1969

		Road Condition		Total
		Wet or Icy	Dry	
Weather	Snow, Sleet	275	5	280
	Fog, Rain or Mist	222	0	222
	Clear	102	1	203
Total		599	6	605

about 180 acci-dents potentially preventable. Using a previously derived figure for the fully allocated direct cost per accident of $328 (1965), we get $59,000 as the estimate for Washington, D.C.[1] This compares with the $54,000 estimate arrived at indirectly from the Chicago information.

Using the wholesale price index of motor vehicles and equipment to arrive at 1968 dollars,[2] we have $59K (104.5/100.7) = $64,000 maximum annual benefit. Assuming a straight-line relationship between predictive improvement and benefit, we get the following estimates for benefits due to three levels of improvement.

Level	Improvement in Reducing Number of Low or Late Forecasts	Benefit to Washington, D.C. in Reducing Accidents
1	25%	$16,000
2	50%	32,000
3	100 % (perfect forecast)	64,000

We believe these estimates are fair reflections of the potential benefits in this area. Simplifying assumptions were made in deriving these figures, but a fair balance seems to have been struck between assumptions that would inflate the estimates and those which would tend to deflate them. We made no accounting of the number of accidents on dry pavement that would replace some of those prevented from occurring on icy or wet pavement. The judgment applied to the accident figures tended to be on the conservative side in attributing accidents to low or late forecasts.

One further factor to be considered is the number of fatalities that may be eliminated. By the police record, between .1 percent and .2 percent of all accidents occurring on snowy or icy streets are fatal. Thus, the elimination of up to 180 such accidents per year would reduce the death toll by about .3 deaths per year.

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1. Motor Vehicle Accident Costs--Washington Metropolitan Area.

2. U.S. Department of Commerce, Bureau of the Census, Pocket Data Book--USA 1969.

APPENDIX C

EXTRAPOLATION TO NATIONWIDE BENEFITS

This appendix presents how factors were derived for extrapolating the benefits found for Washington, D. C., to national totals.

We found that the snow removal costs for an individual storm in Washington were an increasing function with the depth of snow (see Figures A-1, A-2, and A-3). Annual snow control costs also reflect this phenomenon (see Figures C-1 and C-2). In comparing annual costs among cities, the city size also has a direct relationship to snow control costs. Table C-1 shows the snow fighting costs for three eastern cities during one season, along with their 1960 population and land area. Our scaling factor will reflect the variations in snowfall over the country and the size of the areas affected.

COMPARISON OF WASHINGTON, D. C., WITH OTHER CENTRAL CITIES

With this in mind, we looked for a relationship that seemed reasonable for use as a scaling factor. A sample of 75 cities was chosen for investigating potential relationships. These were the 75 largest cities (by 1960 population) with mean annual snowfalls of more than 10 inches. As measures of size, statistics on population, land area, total municipal expenditure (1964-1965), and highway expenditure (for the same years) were compiled. Measures of snowstorm intensity that were collected for each city were mean annual depth of snowfall and mean annual number of days with snowfall greater than one inch.

We assume that the magnitude of benefits attainable for a city from a given improvement in predictive ability will be a function of the city's size and the

Table C-1

SNOW FIGHTING COSTS FOR 1960-1961 SEASON--
COMPARISON FOR THREE CITIES

City	Population	Land Area (sq. mi.)	Total Municipal Expenditure on Snow Fighting
Washington, D. C.	763,956	61	$ 1,420,000
Philadelphia	2,002,512	129	$ 5,000,000
New York	7,781,984	300	$22,500,000

Sources: 1960 Census; "Traffic Snow Emergencies in Washington, D. C.," Office of the Engineer Commissioner, Government of the District of Columbia, 1961; "Cost Analysis of Snow and Ice Control Operations," J. T. Lennon, APWA Yearbook, 1967.

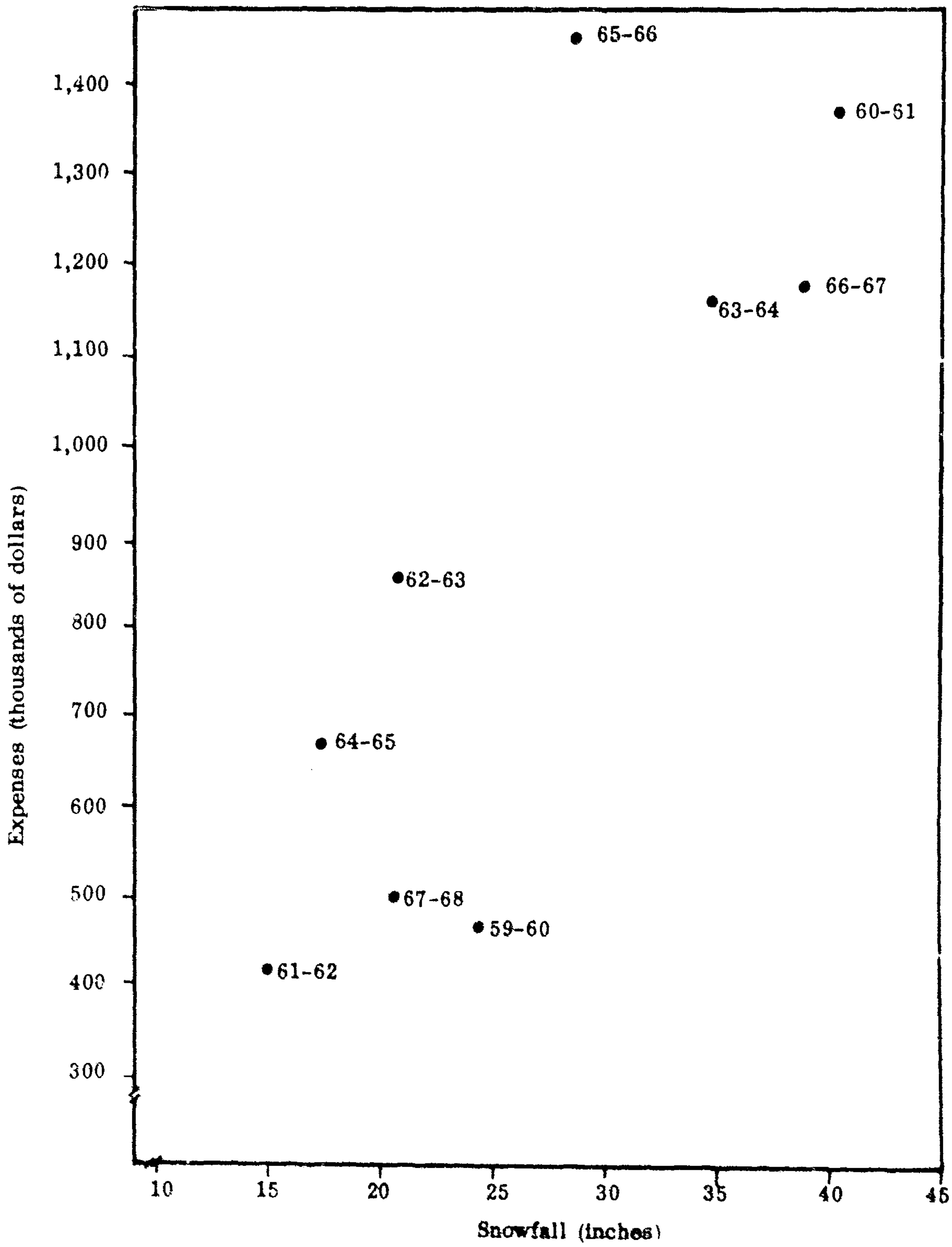

Figure C-1: NON-FIXED COSTS OF SNOW CONTROL OPERATIONS WASHINGTON, D. C. -- NINE YEARS (NORMALIZED TO 1960 DOLLARS)

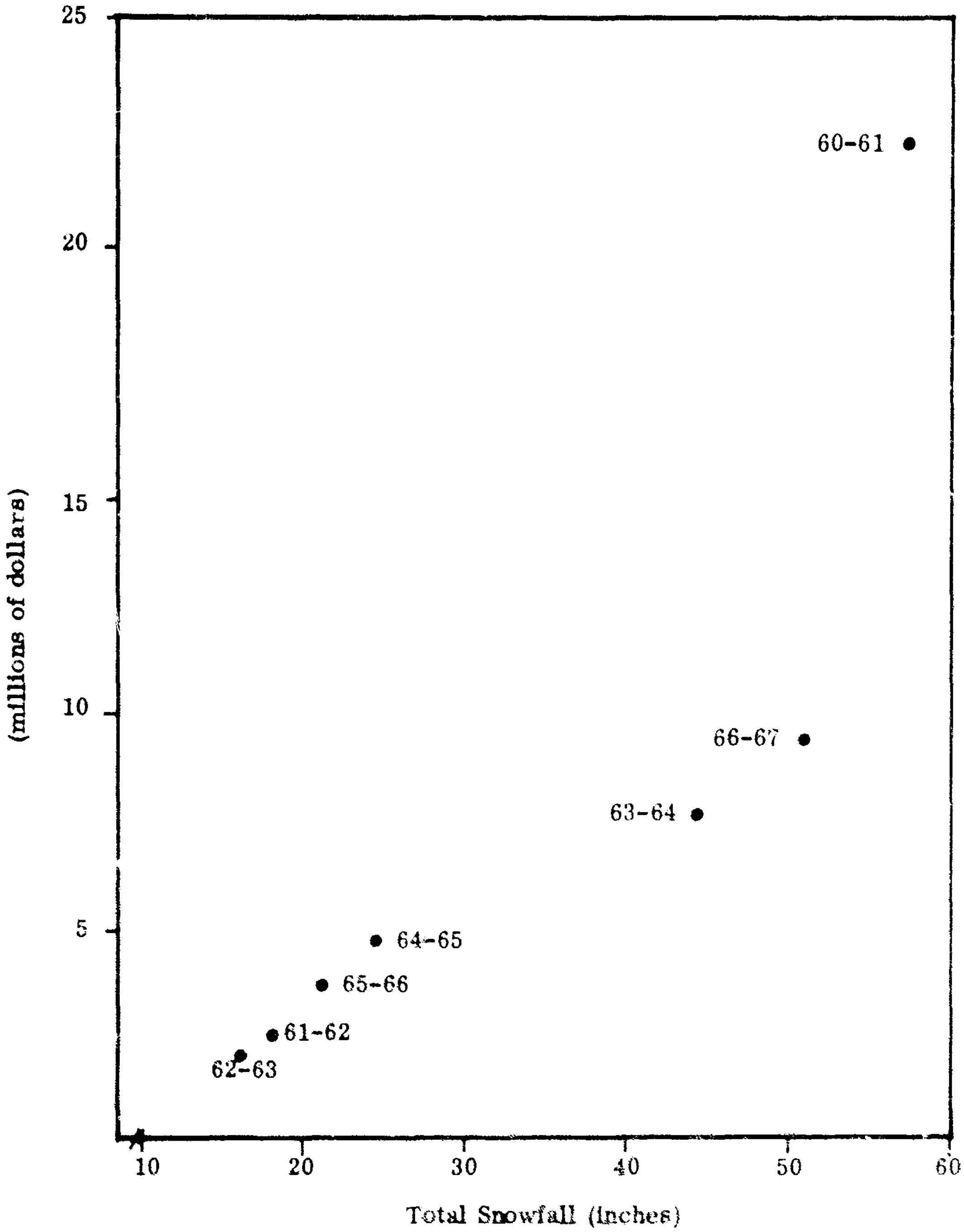

Figure C-2: TOTAL EXPENDITURES FOR SNOW CONTROL OPERATIONS, N.Y., N.Y., SEVEN YEARS (actual dollars) intensity of its snowfall. For city i, this can be represented as

$$B_i \quad f(P_i, L_i, E_i, H_i, S_i, N_i)$$

where

B_i = benefit for city i

P_i = population, city i

L_i = land area, city i

E_i = total annual expenditure, city i

H_i = annual highway expenditure, city i

S_i = mean annual snowfall, city i

N_i = mean number of days with snowfall > 1.0 inch

If it is assumed that the benefits for each city of a given group of cities is governed the same relationship, then the total benefits for this group is represented by the summation

$$BT = \sum_{\text{all } i} f(P_i, L_i, E_i, H_i, S_i, N_i).$$

City i's relationship to the total can be expressed as a percentage in the form

$$BP_i = (B_i/BT)\ 100\%$$

A number of functional forms were tried for the B_i relationship, combining the various measures of city size and snow intensity in simple ways. The B_i's for the list of 75 cities were calculated, and BP_i's for a few cities were examined. These are reported in Table C-2 for Washington, Philadelphia, and New York.

It must be emphasized that the B_i function and the resulting BT are proxies for the costs of snow control, snow related traffic accidents, and traffic delays due to snow. These actual costs are replaced with a function of variables that

Table C-2

PROPORTIONS OF 75 CITY TOTAL FOR 3 SELECTED CITIES, RESULTING FROM TRIAL FUNCTIONAL FORMS

Functional Form B_i =	Washington, D. C. (percent)	Philadelphia, Pa. (percent)	New York, N. Y. (percent)
$k\,P_i\,S_i$	1.195	3.42	19.35
$k\,P_i\,N_i$	1.075	3.38	17.54
$k\,P_i\,S_i\,N_i$	.469	1.59	12.02
$k\,P_i\,L_i\,S_i$	.592	3.59	47.19
$k\,P_i\,L_i\,S_i\,N_i$	.295	2.14	37.55
$k\,L_i\,S_i$	.869	2.01	6.79
$k\,L_i\,N_i$	.774	1.96	6.09
$k\,E_i\,H_i\,S_i$	1.812	.73	87.85
$k\,E_i\,H_i\,N_i$	1.780	.79	86.92
$k\,E_i\,S_i$	2.625	2.55	37.98
$k\,H_i\,S_i$	4.630	2.10	24.60
$k\,H_i\,N_i$	4.190	2.10	22.60
$k\,P_i^{5}\,S_i$	1.020	1.80	5.18
$k\,(P_i\,S_i\,N_i)^{5}$	.967	1.79	4.93
$k\,P_i\,S_i^{5}$	1.675	4.57	21.50
$k\,P_i\,N_i^{5}$	1.590	4.56	20.50
$k\,P_i^{62}\,S_i$	1.106	2.19	7.40

Table C-2 Continued

Data Values	Washington, D. C.	Philadelphia, Pa.	New York, N. Y.
P_i: population (thousands)	764.	2,002.5	7,782.
L_i: land area (sq. mi.)	61.	129.	300.
E_i: municipal expend. ($1000)	370.	328.	3,359.
H_i: highway expend. ($1000)	47.7	19.8	160.4
S_i: mean annual snowfall (inches)	18.7	20.4	29.7
N_i: mean annual no. of days with snowfall > 1.0 in.	5.	6.	8.

are more readily available. We will assume that the benefits attainable for different areas will be proportional to the snow-related costs, so that the function selected can be used to relate the benefits found for Washington, D. C., to the national total.

In looking for a scaling factor, we want the function from which it is derived to give "reasonable" results, in terms of the relation between an individual city's cost and the total, and among the cities. The trial functional forms give widely varying estimates of Washington's contribution to the 75 city total. ranging from .295 percent to 4.63 percent. New York's contribution ranges up to 87.85 percent, and these extremes seem unreasonable. In addition, five of the trial forms produce estimates in which Philadelphia's costs are smaller than those of Washington. Some of these presumed anomalies seem to be explained by the fact that the data for municipal expenditures and highway expenditures are for one specific year and therefore could induce fluctuations that are avoided by using population or land area figures. Some of the functional forms seem to over-stress the differences in city size and, in one case, result in estimated proportions for Washington and New York of .295 percent and 37.55 percent, respectively.

We looked for a solution that fit in with our preference for a middle ground among these extremes and also fit in with the few data points available to us. The one chosen was of the form

$$B_i = kP_i^a S_i.$$

A value of the exponent a was derived by taking the cases of New York and Washington and assuming that the benefits for each would be proportional to an average value of their snow fighting expenditures. In the 1960 to 1967 period, Washington's snow expenditures averaged $1.18 million per year,[1] while comparable expenditures for New York averaged $7.89 million.[2] Equating the ratio of these

1. Official Snow Removal Reports, District of Columbia.

2. J. T. Lennon, "Cost Analysis of Snow and Ice Control Operations," APWA Yearbook (1967).

expenditures to the ratios of the functions of population and snowfall allows us to solve for $a = .62$. The use of this form, as shown in Table C-2, gives results that are in line with our intuitive feel for the situation. It indicates that Washington's share of the potential benefits for these 75 cities would be 1.106 percent,

It is instructive to look at the cumulative effect of this benefit generating function as it is applied to the list of 75 cities. Figure C-3 illustrates the way in which the function $BT = \sum kP_i^{.62}S_i$ responds to adding cities to the list, largest first. The horizontal axis represents cumulative population (in thousands) of all cities considered, and the vertical axis represents the resulting value of BT (for $k = 1$). The first point represents the value of BT for New York alone, the second represents the combined effect of New York and Chicago, while the last point represents the effect of all 75 cities, including Utica, the last and smallest. The 1.106 percent figure for Washington is the result of dividing its B_i by the BT at the last point:

$$B_i/BT = 1{,}145.5/103{,}982 = 1.106\%$$

To review what we have done, a relationship between potential benefits for Washington and for a group of the 75 largest cities with significant snowfall was derived. Our experience with the District of Columbia information guided us in the selection of a relationship that makes intuitive sense and fits with our limited data. We will now extend this work to the other metropolitan areas not represented in the list of 75 central cities. This includes all the non-central metropolitan areas.

ADJUSTMENT TO INCLUDE OTHER CENTRAL CITIES

An estimate of the first group is obtained by examining the list of the 130 central cities that reported populations greater than 100,000 in the 1960 census. Of the 50.7 million persons in this group, 34.15 million (67.4 percent) lived in cities that receive more than 10 inches of snow annually. In 1960, a total of 58.3 million people lived in central cities, so that 7.4 million resided in cities smaller than the 100,000 minimum in our sample. If the 67.4 percent factor applies to this group

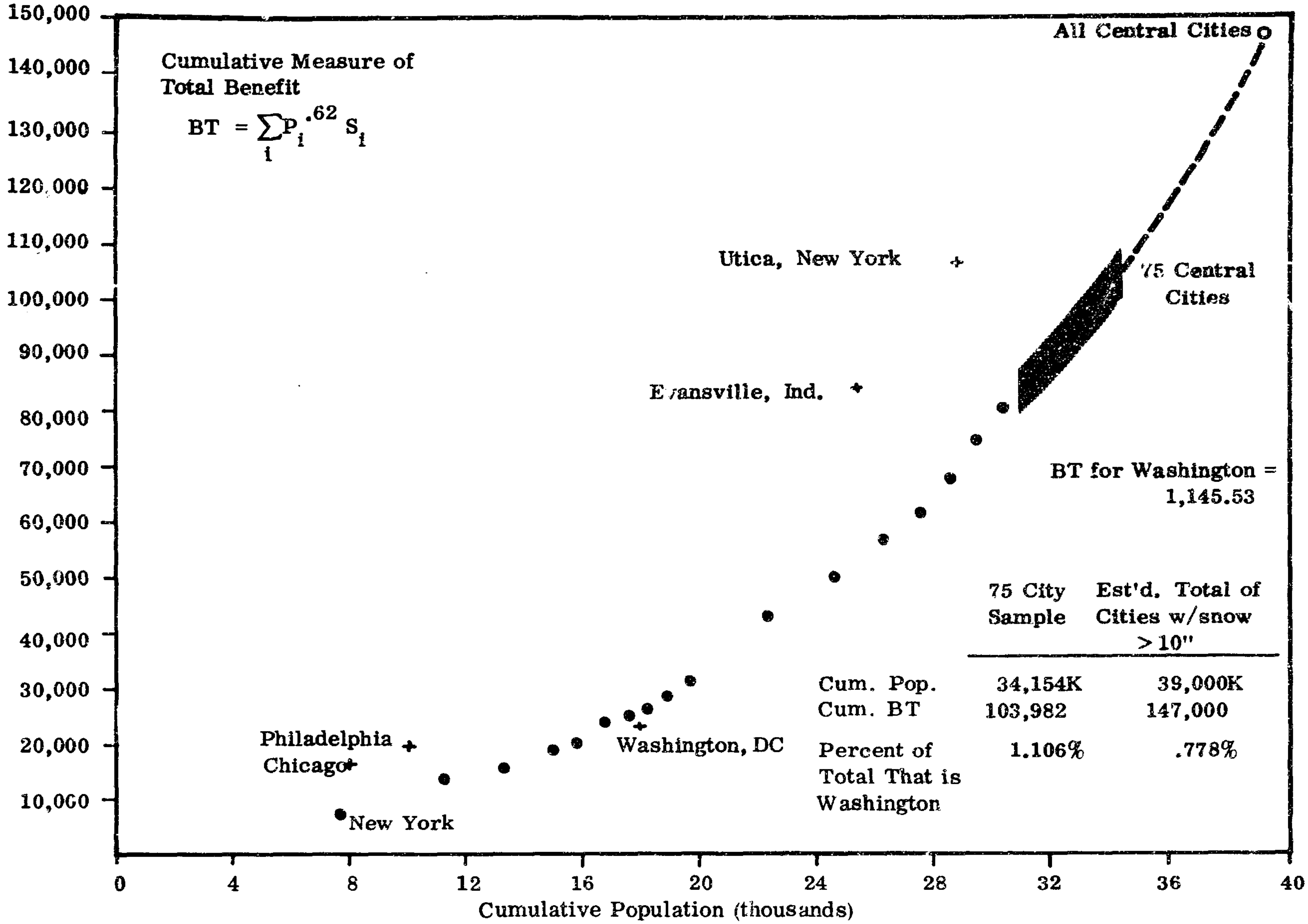

Figure C-3: RELATIONSHIP BETWEEN CUMULATIVE BENEFITS FOR CENTRAL CITIES AND CUMULATIVE POPULATION as well as to the 75 city group, then the total population of central city dwellers of concern to us would be 34.15 + (.674)(7.4) = 39.11 million. Extrapolating the relationship shown in Figure C-3 to this cumulative population yields a BT of 147,000.

Thus, we conclude that the benefits found for Washington would be .778 percent (1,145.5/147,000) of the benefits for all central cities. To scale District of Columbia benefits to total central city benefits, we apply a factor of 128.7.

Inclusion of Suburban Areas

The other areas of concern for benefits related to improved prediction of snowstorms are the suburban fringes surrounding the city centers. In 1960, 63.0 percent lived in the metropolitan areas listed as SMSAs. Of these 133 million people, 54.5 million lived outside the central cities, which compares with 58.3 million central city residents. Thus, this represents a great target for potential benefits.

For the purpose of this study, the suburban areas were assumed to be similar to small central cities in terms of the expected benefit response to improved forecasting. The same mechanisms of cost incurrence (removal operations, accidents, and delays) exist, and the suburban areas resemble many of the smaller central cities in their characteristics of land use and population density.

It was reasoned that if two areas had comparable population densities and comparable amounts of land devoted to streets, they would be comparable in their incurrence of costs due to snowstorms. Therefore, a change in predictive ability would have similar effects on reducing overall costs for the two areas.

Among a group of eight central cities, we found that the proportions of land area devoted to streets is a generally increasing function with population density. (See Table C-3 and Figure C-4.) Information was available for three metropolitan areas, relating population and land use to the distance from the center of the city, represented by a set of generally concentric rings. Table C-4 displays the street area percentage and population density by ring for the Chicago, Pittsburgh, and Baltimore SMSAs. The approximate division between the central city and the

Table C-3

POPULATION LAND USE CHARACTERISTICS FOR EIGHT CENTRAL CITIES

City	Population (1000)	Population Density (1000/sq. mi.)	Percent Land Used for Streets
New York	7,782	26.0	34.6
Chicago	3,550	16.0	25.9
Washington, D. C.	764	12.4	27.8
Detroit	1,670	12.1	30.8
Pittsburgh	604	11.0	25.0
Minneapolis-St. Paul	796	7.5	29.1
Chattanooga	130	3.6	23.9
Tucson	213	3.0	28.3

Source: The Economic Feasibility of Decentralized Metropolitan Regions, H. R. Woltman, et al., PRC, Los Angeles, October 1965.

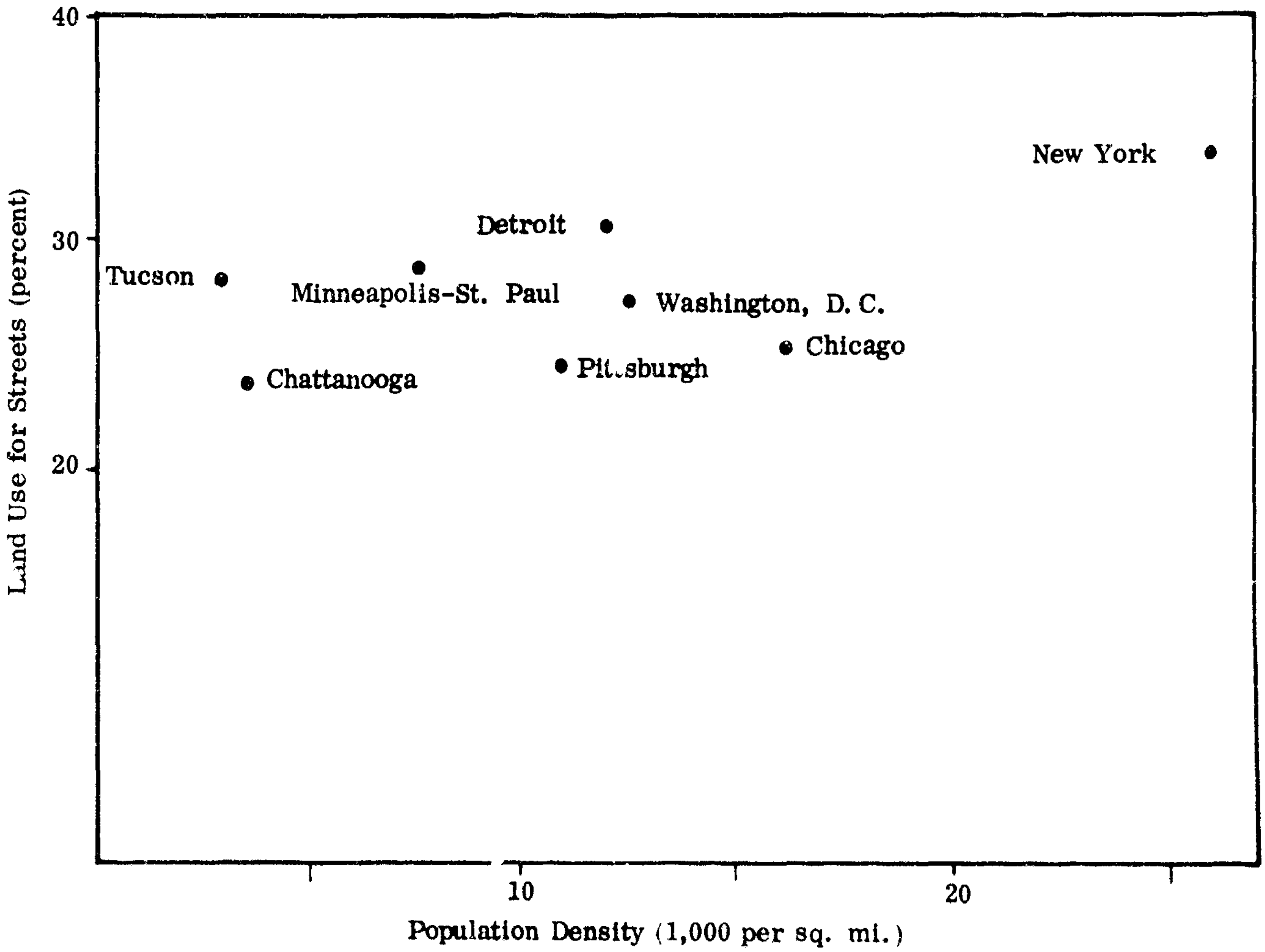

Figure C-4: LAND USE FOR STREETS RELATED TO POPULATION DENSITY--EIGHT CENTRAL CITIES

Table C-4

RELATIVE STREET AREA AND POPULATION DENSITIES FOR REGIONS AROUND CITY CENTERS

City	Ring No.	Percent Land Devoted to Streets	Pop. Density in Ring (1000/sq. mi.)	Pop. Density Central City	Pop. Density Suburbs
Chicago	0	35.8	5.3		
	1	36.1	29.1		
	2	30.4	30.5	16.0	
	3	31.9	26.7		
	4	31.6	18.1		
	5	32.3	9.3		
	6	30.0	5.6		5.3
	7	36.6	4.1		
	Total	32.8	11.7		
Pittsburgh	0	41.5	6.0		
	1	34.4	20.7	11.0	
	2	30.3	18.6		
	3	29.3	16.0		
	4	26.7	11.9		
	5	27.7	8.3		
	6	27.0	6.2		7.7
	7	30.5	4.5		
	Total	28.2	9.25		
Baltimore	0	38.6	4.6		
	1	31.4	28.4	12.0	
	2	26.8	15.5		
	3	19.2	7.3		
	4	16.0	4.1		4.2
	5	17.0	2.6		
	Total	18.7	6.55		

Source: The Economic Feasibility of Decentralized Metropolitan Regions, H. R. Woltman, et al., PRC, Los Angeles, October 1965.

surrounding suburbs is indicated by the heavy line, and the population density for those two segments of the SMSA is also shown. Figure C-5 shows the relationship between population density and relative street area graphically.

For each of these three metropolitan areas, both population density and the fraction of land devoted to streets declines from the central city to the suburbs, with a slight increase in street area at the outer ring. The levels of density and street area in the suburbs are comparable, however, with those in the smaller of the central cities listed in Table C-3. Of the 25 smallest cities in our sample of 75 with significant snowfall, all but two have population densities in the range of the suburbs shown in Figure C-5. These cities range in size from 100,410 people (Utica) to 141,543 (Evansville, Indiana) and vary in snowfall from 11.9 inches to 97.5 inches.

Our conclusion is that these cities represent the physical and climatological characteristics of the suburban areas reasonably well. We shall assume that the benefits per capita accruing the suburbs will be similar to those in the central cities with a population of 100,000 to 142,000. Referring back to Figure C-3, the slope of the curve in the vicinity of these cities gives us a measure of this rate of benefit incurrence, RBT. This has a value of 6.78 BT per 1000 persons.

PROJECTING TO 1985 ACTIVITY LEVELS

A comparison between 1960 and 1968 populations[1] shows a net increase of 20.5 million persons in metropolitan areas, all of which occurred outside the central cities. We assume that this trend will continue into the 1985 time period. Thus, the population for central cities for 1960 will be assumed to apply for 1985 as well.

Projections of total U.S. population for 1985 range from 241.7 million to 274.7 million, averaging 258.5 million. This is an increase of 58.7 million from

1. U.S. Department of Commerce, Bureau of the Census, Pocket Data Book--USA 1969.

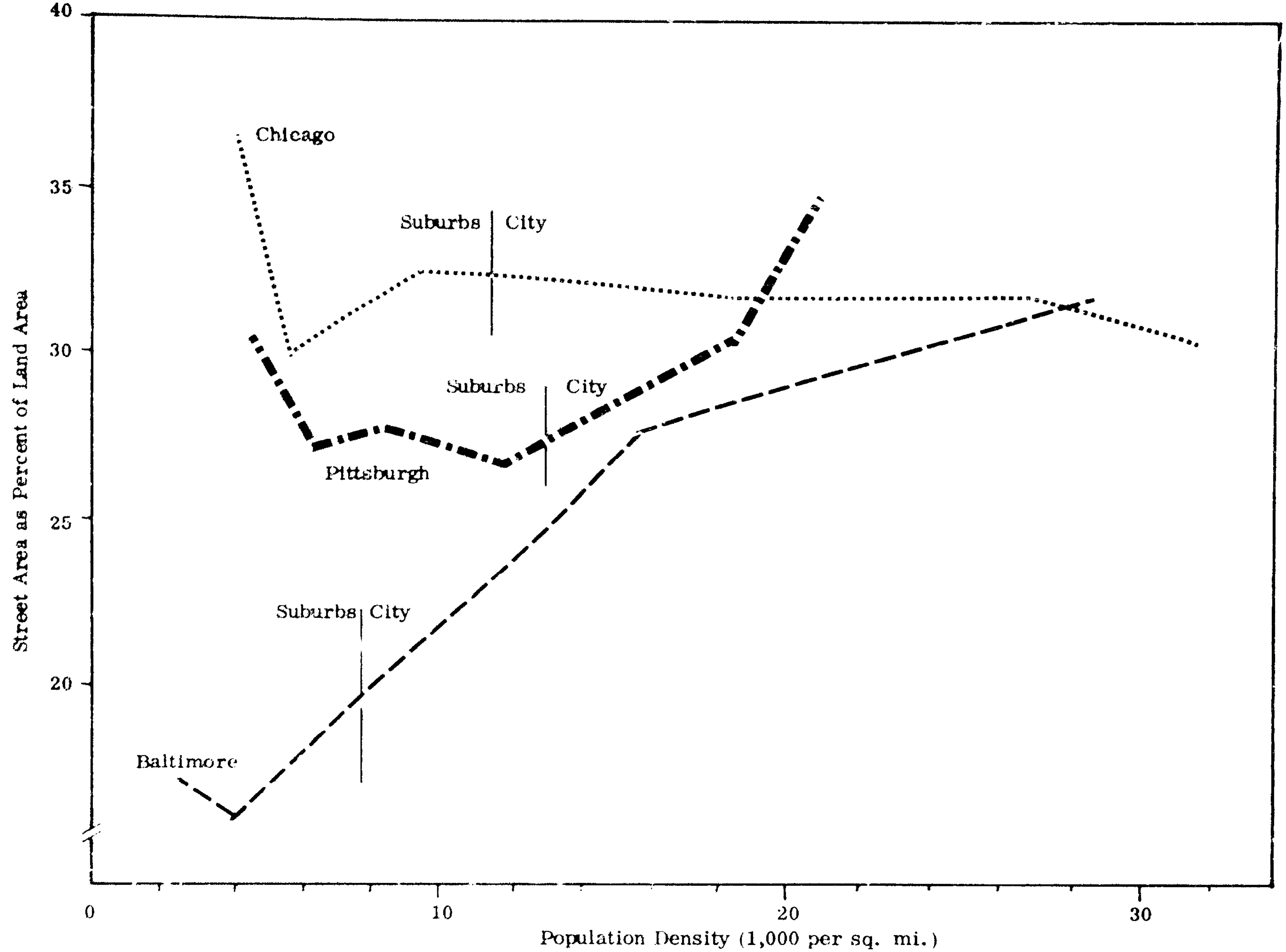

Figure C-5: STREET AREA RELATED TO POPULATION DENSITY

1968. Seventy percent of the total U.S population growth from 1960 to 1968 was in suburban areas. If this relationship holds into the future, there will be a net increase of 41.0 million persons in the suburbs from 1968 to 1985, bringing the total to 109.8 million. If 67.4 percent of this population lives in regions with significant snowfall (as is true with central city inhabitants), then 74.0 million people will be affected. Multiplying this figure by the rate of benefit incurrence found above yields

$$BT_{suburbs} = (6.78)(74{,}000K)$$
$$= 501{,}000$$

The value of B_i for Washington is 0.206 percent of the BT for the suburbs in 1985. The scaling factor is 486 (=1/.206 percent).

ADJUSTING FOR OPERATING TECHNOLOGICAL CHANGES

It can be expected that the benefits from improved forecasting in 1985 will be relatively less than at present for cities of comparable size. The reasons for this stem from the changes that are likely to occur in transportation operations and from technological innovations in fighting snowstorms and reducing their costs.

We would anticipate some decrease in street level traffic as more cities take action to combat urban congestion. Some cities, such as Washington, will have new underground rapid transit systems to relieve some of the burden on the city streets. There will also be an effect on traffic in the surrounding suburbs served by these systems and extensions of existing rapid transit systems. Other innovations such as "fringe parking" at rapid terminals will become more widespread and consequently reduce the volume of traffic. Such a reduction will make the total cost target smaller, thus reducing the potential benefits.

Technological advances have occurred over the previous few decades to lower the cost of fighting snow. These include the widespread use of salt on streets, the development of more efficient machinery for snow control, and the use of heated pavements on bridges, hills, etc. Operations have been made more efficient by the use of radio controlled equipment and as more serious thought has been put into organizing and controlling the snow control function. There has been considerable pressure for making automobiles safer, and there continues to be pressure for reducing the cost of accidents, in terms of personal injury and mechanical damage. While it is not possible to predict what improvements will come in the next 15 years, it is very likely that some changes will occur. These changes can only contribute to lowering the potential for benefits due to improved weather forecasting.

A subjective estimate of the reduction in potential benefits is that 28 percent per decade is entirely feasible. Thus, benefits calculated for 1985 will be reduced by 35 percent to account for the changes in operations and technology between 1968 and 1985.

BENEFIT COMPUTATION--NATIONAL, 1985

Table 10 of Chapter 7 summarizes the derivation of the scaling factors for projecting the benefits found for Washington, D. C., to a national scope in the 1985 time period. The annual benefits for the three levels of improvement for the District of Columbia are shown in 1968 dollars. The resulting expected national benefits are then shown in the right-hand column.

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NATIONAL DATA BUOY PROJECT OFFICE

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