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INTRODUCTION

In the midst of a highly depressed economy, the Port of Duluth-Superior remains a vital center of regional activity linking the Twin Ports to national and international markets. Increases in the volume of cargo handled in the Ports have both direct and indirect economic impacts on the region. Constraints to expanded port activity reduce these impacts, and make Duluth-Superior less competitive with other U.S. ports. Among these constraints is the length of the open shipping season. Duluth-Superior faces seasonal temperature variations which force winter closings due to freezing from mid-December through March in most years. Extending the open shipping season has been argued to be a potentially significant means of increasing the competitive position of the Port, reducing unemployment and stimulating additional economic activity in the region.

The purpose of this paper is to review the case for season extension. We do not propose to repeat previous analyses of season extension in the St. Lawrence Seaway system as a whole. Rather, we have attempted to provide a framework for decision-making relevant to the particular problems of Duluth-Superior and its economy. We have also attemped to avoid projections unsupported by hard data. While this may limit the study, we feel it important to emphasize both the complexity and the difficulty of drawing firm conclusions from present information sources.

First, a generalized model of season extension is presented, based on the risks and benefits of an extended season given both climatic and demand uncertainty. The model is applied to the Port of Duluth-Superior to illustrate the risky decision problem facing policy makers and Port officials. Second, existing documentation and new evidence gathered by the authors is used to assess the likely contribution of season extension to economic development in the Port of Duluth-Superior. A third section presents our conclusions.

I. THE BENEFITS AND RISKS OF SEASON EXTENSION: AN ANALYTICAL APPROACH

Whenever inclement weather interacts with shipping decisions, the benefits of continued commercial operation must be weighed against the accompanying risks of damage or delay. In the Great Lakes and St. Lawrence Seaway system, these risks arise from cold weather and ice formation that blocks shipping into and out of ports along the route. Especially vulnerable are those ports farthest to the North and at greatest distance from international shipping lanes in the Atlantic. Duluth-Superior is such a location, requiring roughly ten days to reach from the mouth of the St. Lawrence through the Welland Canal. For this reason, the Port has traditionally closed in December, reopening again when the ice goes out in the spring.

From the perspective of both ocean and lake shippers, the commercial benefits of offloading and onloading cargo from Great Lakes ports late in the season must be weighed against the risks of suffering ice damage or losing use of the large capital investment of a vessel until the ice goes out. From the perspective of the Port, the commercial activity foregone due to ice formation represents a serious cost which if eliminated will lead to increased demand. Season extension is attractive both because it would spread out capital costs of operating the port facility, and would reduce the inventory costs of shippers. However, assurance must exist that the Port, if declared open, will in fact remain so regardless of weather conditions. Because ship cargoes are contracted many months in advance, the risk associated with ice formation creates an incentive for both shippers and Port authorities to set a season closing date which, at a minimum, allows the ten-day trip to and from the Atlantic to be guaranteed in all but the most extraordinary years.

Modern technology has also enhanced the capacity of the U.S. Coast Guard and Army Corps of Engineers to increase the length of the navigation season. "Bubblers" can retard the rate of formation of harbor ice. Together with improved ice-breaking capacity, this technology has led in recent years to moderate extensions in the mandatory closing date, which in 1983 was set at December 15. In the late 1970's the shipping season on the Upper Lakes was kept open for 12 months on an experimental basis. In 1984, a malfunctioning bridge near Montreal, Quebec, coupled with warm weather, led to record extension in the season, which ended in Duluth with the last departure of an ocean vessel on December 23, compared to the earlier record of December 16, 1979. This experience emphasized the complex interaction between ice conditions due to weather, the level of demand, and the decisions of shippers and Port authorities when to close operations.

This complex problem may be analyzed in terms of a trade-off known to statisticians as false positive and false negative predictions, or Type I and Type II error. Type I statistical error, or a "false positive" prediction, results when a null nypothesis of "no effect" is rejected in favor of an alternative hypothesis when the null hypothesis is in fact true. Type II statistical error, or a "false negative" prediction, results from failure to find evidence against the null hypothesis of "no effect," leading to a prediction that turns out to be false.

Expressed in terms of ice formation in the Port of Duluth-Superior, this relationship arises in the following way. Suppose that it is conjectured by the Port Authority that ice will have no effect on harbor operations until December 30. The alternative hypothesis is that such effect will occur earlier than December 30. Based on the null hypothesis of "no effect," a closing date would be given by backing off ten days, to December 20, or long enough for ships carrying international cargo to get through the Seaway and into the open sea. The alternative hypothesis would lead to an even earlier closing date. In this situation, two types of error are possible. First, the null hypothesis may be rejected in favor of an earlier closing date to assure safety, yet conditions may ultimately indicate that it should have been accepted. A "false positive" relationship will have caused the Port to close early when it should have remained open. The opportunity costs of this action are incurred by the Port in the form of lost revenue from shipments. On the other hand, a decision may be made to leave the Port open until December 20, and conditions may be such that ice arrives earlier than predicted. Here, costs are incurred due to damage to boats, ice clearing, or lost reputation to the Port. A "false negative" error results from accepting the "no effect" hypothesis when it proves to be false.

The probability of Type I error (resulting in too early a closing date) must be weighed against the probability of Type II error (resulting in too late a closing date) whenever a particular date for closing is chosen. The relationship between these variables is expressed below, where Ho represents the null hypothesis of "no effect" and Ha the alternative hypothesis that ice will affect shipping before a given date.

Ho: No ice before December 30

Ha: Ice before December 30

State of the World	Decision: Accept Ho: No ice until December 30	Decision: Reject Ho: Ice before December 30
Ho true: No ice before December 30	Correct decision	Incorrect decision (False positive-Type I error)
Ha true: Ice before December 30	Incorrect decision (False negative-Type II error)	Correct decision

As can be seen, the particular date chosen (here December 30) will determine the relative likelihood of Type I and Type II error. The earlier the date, the lower the likelihood that the no effect hypothesis (Ho) will be accepted and then found to be wrong due to early ice formation. Hence, early closing guards against Type II error and its associated costs. However, such early dates also raise the likelihood that Type I error will result, in which shipping could have continued beyond the closing date but is prevented from doing so. In summary, the later the closing date chosen, the higher the likelihood that the no effect hypothesis will prove false (Ha will prove true), leading to shipping tie-ups and ice clearing expenses. The earlier the closing date chosen, the higher the likelihood that the harbor will be clear and open for shipping but unavailable for use.

This problem may be expressed as a trade-off between risks and benefits (Runge, 1983) of the following form.

Let

A_t = a random variable defining the ice thickness and associated weather conditions in the Duluth harbor at closing date t.

T = a random variable defining the threshold level of ice thickness and associated weather conditions deemed acceptable by shippers.

These variables are assumed continuously distributed with nonzero mean and variance.

$$E(A_t) = \mu_A;\ V(A_t) = \sigma_A$$
$$E(T) = \mu_T;\ V(T) = \sigma_T$$

The term μ_A measures the mean weather and ice conditions at a given date t, such as December 30, while σ_A measures the variance of these conditions from year to year. The mean value μ_T represents the threshold weather and ice conditions acceptable to the average shipper, while σ_T represents the variance resulting from differences in various types of shippers. Russian boats, for example, are known to tolerate difficult ice conditions due to the strength of their hulls, while Asian crews find winter conditions in the Port difficult to tolerate.

It should be noted that σ_A and σ_T represent the two types of uncertainty most important to the Port. These are variations in weather conditions on the date the Port will be closed and differences in shippers' attitudes toward cold and ice. The dilemma facing the Port is: at what date should closing be set so that the weather and ice conditions are most likely to be at or below the threshold of acceptability to the average shipper? The probability that on this date the cold and ice conditions are, in fact, less than the threshold, measures the interaction between the two types of uncertainty, and indicates the net risk facing the Port in choosing a particular closing date t. Denoting this risk by R_t, we have

$$R_t = Pr\ (A_t < T) > 0$$
$$= Pr\ [(A_t - T) < 0] > 0$$

The interval $(A_t - T)$ defines a third random variable, capturing the difference between the weather and ice conditions at a particular date t and the threshold of acceptable conditions to shippers. The probability that this interval is negative is the risk that the weather and ice conditions will be below the threshold acceptable to the average shipper at a given date t. Lowering R_t thus requires choosing a date for closing in which this probability is small. The most obvious way to do this is to move the date up to the point that ice will never be a problem, even in the most extraordinary years. This risk-minimizing strategy is clearly costly, however, since it leads to the loss of revenues that would otherwise be generated by having the port open. On the other hand, increasing the risks by extending the season, while it increases the benefits associated with shipments, raises the costs of keeping the Port open, especially if all but the most intrepid shippers opt out of moving cargo as insurance costs mount. In this sense, the model defines the tradeoffs between risks and benefits of choosing a particular closing date.

This argument may be brought together with the analysis of Type I and Type II error above by recognizing that the null hypothesis of no effect implies that the date chosen is sufficiently early that the threshold will not be crossed. The "no effect" null hypothesis Ho and the alternative hypothesis Ha may therefore be rewritten in terms of $(A_t - T)$.

$$Ho: \quad (A_t - T) \geq 0$$

$$Ha: \quad (A_t - T) < 0$$

If Ho proves true, then the date chosen must have been early enough to avoid the threshold, but if Ha proves true, then the date chosen was not early enough. Since the net risk of choosing a date t is $R_t = Pr\ [(A_t - T) < 0] > 0$, a positive value of R for a given date t can only result if there is some positive probability that Ha is true.

We can summarize the analysis in terms of the basic trade-off between the risks of a particular closing date and the expected benefits and costs of that closing date expressed in terms of shipping revenues, employment effects, and indirect economic effects. A net expected economic benefits function G(A) associated with direct shipping activity and indirect effects is maximized by choosing t, a closing date, subject to the level of risk associated with that date R_t. If $B(A_t)$ are the benefits of shipping up to that date, and $C(A_t)$ are the costs of keeping the Port open through bubbler operation, ice-breaking, etc., then the problem in any year is to choose t so as to maximize the discounted stream of benefits in that year (where r is the annual discount rate, reflecting the opportunity cost of capital) subject to an acceptable level of risk R*. This may be written

$$\underset{t}{\text{Maximize}}\ G(A) = E\left[\frac{\sum B[(A_t) - C(A_t)]}{(1 + r)}\right]$$

subject to:

$$R^* - R(A_t) \geq 0$$

$$A_t \geq 0$$

The constraint $R^* - R(A_t) \geq 0$ implies that $R(A_t) \leq R^*$, where R* is an acceptable level of risk. In words, the risk associated with a closing date t must be less than some "given" level R* set by government policy or, perhaps more significantly, by shipping insurers. This constraint captures the uncertainty that makes the problem more complex than an ordinary benefit-cost calculation in which the marginal benefits of season extension are set equal to marginal costs to derive an "optimal" closing date t. The Lagrangian expression for this constrained optimization problem takes the form

$$L = E\left[\frac{\sum [B(A_t) - C(A_t)]}{(1 + r)}\right] + \lambda[R^* - R(A_t)]$$

Kuhn-Tucker conditions for a maximum are:

(1) $\frac{\partial L}{\partial A_t} \leq 0 \qquad A_t \frac{\partial L}{\partial A_t} = 0$

(2) $\frac{\partial L}{\partial \lambda} \geq 0 \qquad \lambda \frac{\partial L}{\partial \lambda} = 0$

(3) $A_t \geq 0 \qquad \lambda \geq 0$

These conditions can be useful in analyzing the trade-offs between benefits and risks. The first pair are conditions for a maximum level of net benefits to the Port. If the date chosen is such that $\frac{\partial L}{\partial A_t} = 0$ and $A_t > 0$, then an interior maximum is achieved. In this case, an optimal date is chosen by setting the marginal benefits of the closing date equal to marginal costs.

$$MB = MC$$

If risk is a binding constraint, due to government policy or insurance costs, or any other factors leading to recognition that a positive risk exists that ice conditions may surpass the threshold, first order conditions for a maximum take the form

$$\frac{\partial L}{\partial A_t} = MB - MC - \frac{\lambda \partial R_t}{\partial A_t} = 0$$

so that

$$MB - \lambda \frac{\partial R_t}{\partial A_t} = MC$$

Here, an optimal closing date requires that the marginal riskiness of closing date t, $\frac{\partial R_t}{\partial A_t}$, weighted by the shadow value λ attached to this risk, be deducted from marginal benefits before they are set equal to marginal costs. As either the shadow value or the riskiness of a closing date rises, reflected in such factors as insurance costs, this risk factor increases in magnitude, urging earlier closing dates. It is therefore necessary to estimate the riskiness of a given closing date, ex ante, as well as to weight this riskiness according to the value reflected in such factors as insurance rates before an "optimal" closing date can be chosen.

In summary, an analytical description of the risks and benefits of choosing a particular closing date indicate not only the complexity of the decision, but its dependence on a variety of forces largely outside the control of the Port. The two most important forces are weather and the willingness of shippers to make the journey in the face of these conditions during the winter months. This willingness is in turn a function of domestic and international market conditions which are also beyond the control of the Duluth-Superior economy. Because these forces are unpredictable, uncertainty over their values interacts to define the net risk of setting a particular closing date t.

Reducing this risk requires either an earlier closing date, or substantial investment by the Port and the larger Seaway system to remain open in winter. In either case, costs are involved. In the first case, costs will be borne by the private sector dependent on the Port due to foregone shipping activity, as well as by state or federal government transfers to those eligible for unemployment compensation. In the second case, costs will be borne by shippers in the form of private insurance, and by the Coast Guard and Seaway system in the form of maintenance and ice clearing to keep the Port and Seaway open. These are the fundamental trade-offs between risks and potential net benefits of season extension. We now turn to what is known about the factors affecting these risks and benefits.

II. EMPIRICAL EVIDENCE ON SEASON EXTENSION

The generalized risk-benefit model above calls for a variety of empirical data not all of which are strictly quantified, or even quantifiable. While useful in analysis, the model cannot be "solved" to give a precise date for season extension, primarily because it rests on particular attitudes toward risk, and thus the relative weight given to the uncertainties discussed above. We have been able to gather information on a variety of components, however, which allow us to make provisional remarks on season extension in the Port of Duluth/Superior. This information may be divided into three categories: (1) weather conditions and variability; (2) shipping trends by season (time of year); (3) disaggregated economic benefits and costs. After presenting this information, we shall comment on its interpretation and relationship to the issue of risks raised in the first section of the paper.

(1) Weather Conditions and Variability

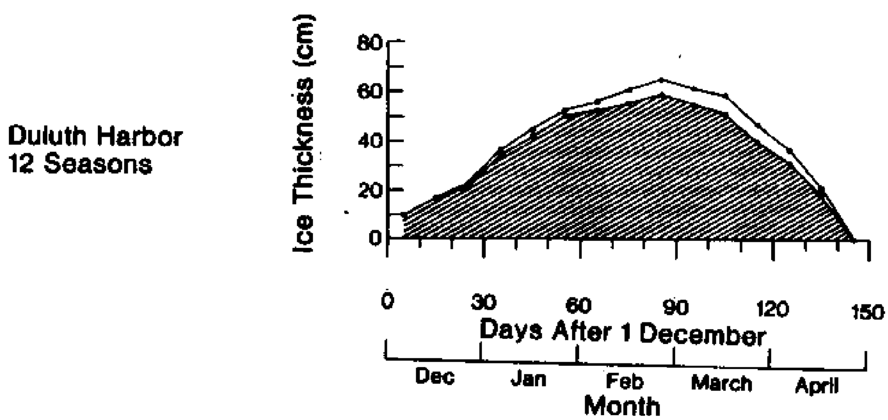
National Oceanic and Atmospheric Administration (NOAA) data on Great Lakes weather conditions (Assel, et.al., 1983) were analyzed to identify the mean and variance of ice cover in Lake Superior and in bays and harbors. Ice charts for 20 winters (1960-1979) and air temperatures over an 80 winter period (1898-1977) were used to estimate the likelihood of inclement weather and ice conditions by various dates. Large differences existed in Lake Superior ice cover in the 20 winters from 1960 to 1979, although maximum ice charts for the last half of December and January show a persistent area of open water in early winter. This open water extends over virtually the entire lake in December, the Eastern half of the lake during January 1-15, and smaller areas in the Eastern lake during January

16-31. There is also a persistent pattern of open water, restricted to the Northeastern quadrant of the lake, in late April during the ice break-up period. Ice cover builds gradually in the late fall and continues all the way through March, during which it begins to decline.

Specific measurement of ice conditions at Duluth-Superior are shown in Figure 1, which compares mean ice thickness at various points in the calendar year. The Duluth Harbor chart describes the amount of clear ice and white ice measured in the Port from 1967-68 to 1976-77 (Assel, et.al., 1983, pp. 13-15). Two traces of ice thickness are shown. The outer curve indicates the mean ice thickness for both clear and white ice (white ice is defined as snow-ice, slush, pancake, brash, and ball ice), while the inner curve indicates the amount of clear ice only. As Figure 1 demonstrates, ice begins to build in Duluth-Superior in December, increasing its rate of accumulation in late December and early January.

Variation from season to season is, however, substantial. Figure 2 shows maximum, minimum and normal ice concentration distributions for Lake Superior for nine half-month periods from December 16-31 (D2) to April 16-30 (A2) (Assel, et.al., 1983, p. 23). The range from minimum to maximum ice cover clearly suggests the high variance in seasonal ice cover from year to year, underscoring the difficulty of making season closing decisions on the basis of "normal" conditions. This variance increases from December into January, so that in a given year, the lake may be open, closed, or partially open in mid-January. This tendency is shown by Figure 2 in map reproductions (Assel, et. al., 1983, pp. 26, 28) for extremes in ice cover for January 1-15 and January 16-31 from 1960-1979. In contrast to the maxima and minima, the "normal" ice cover clearly fails to reflect

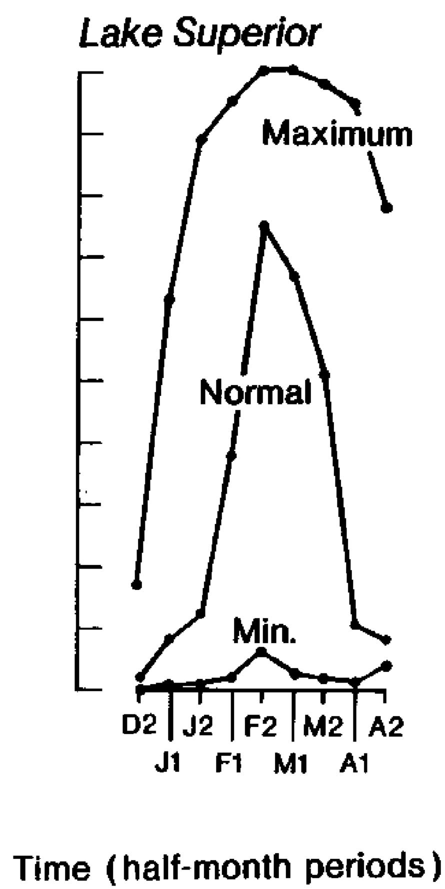
FIGURE 1. Mean ice thickness vs. time for the period of record at Duluth-Harbor.

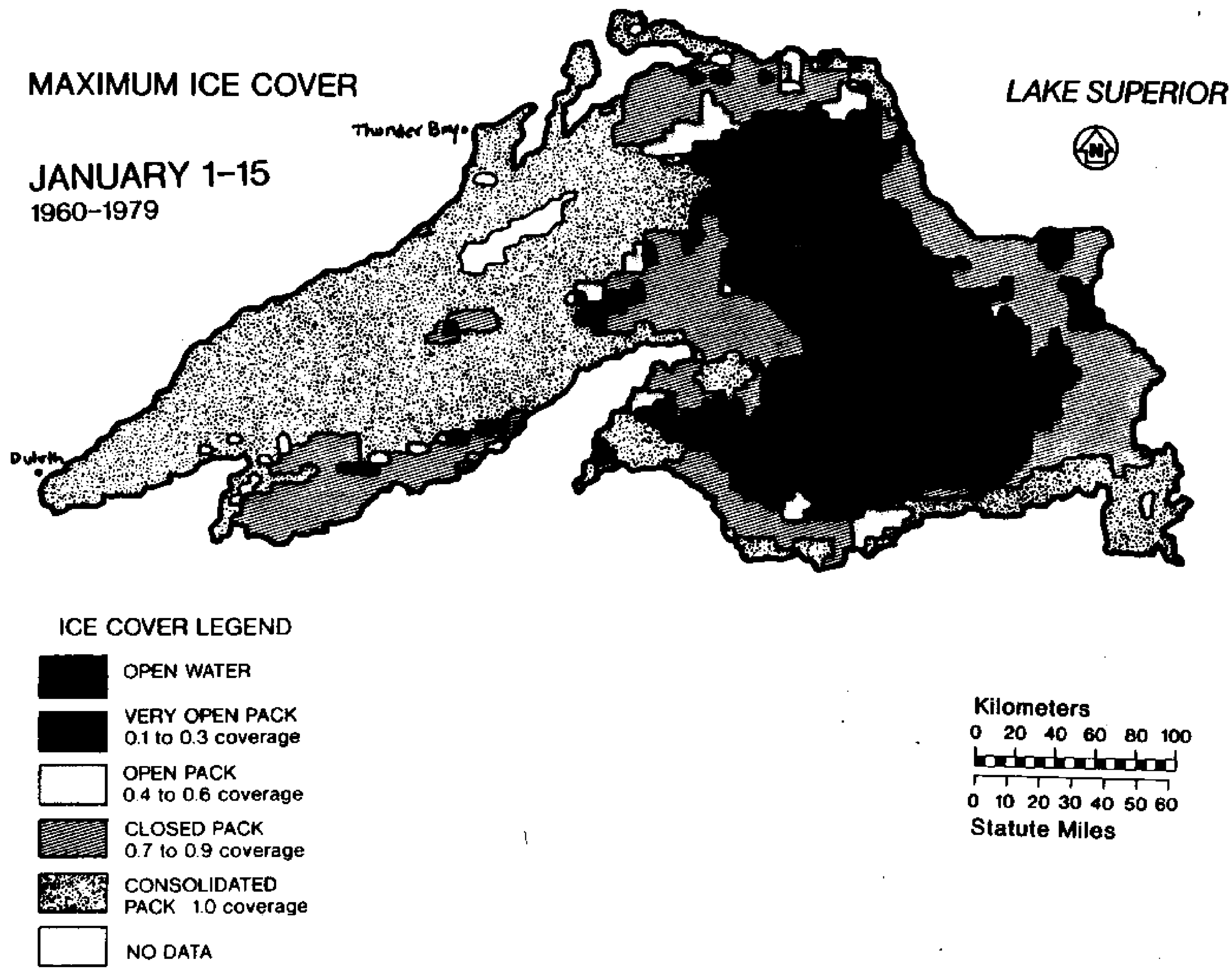


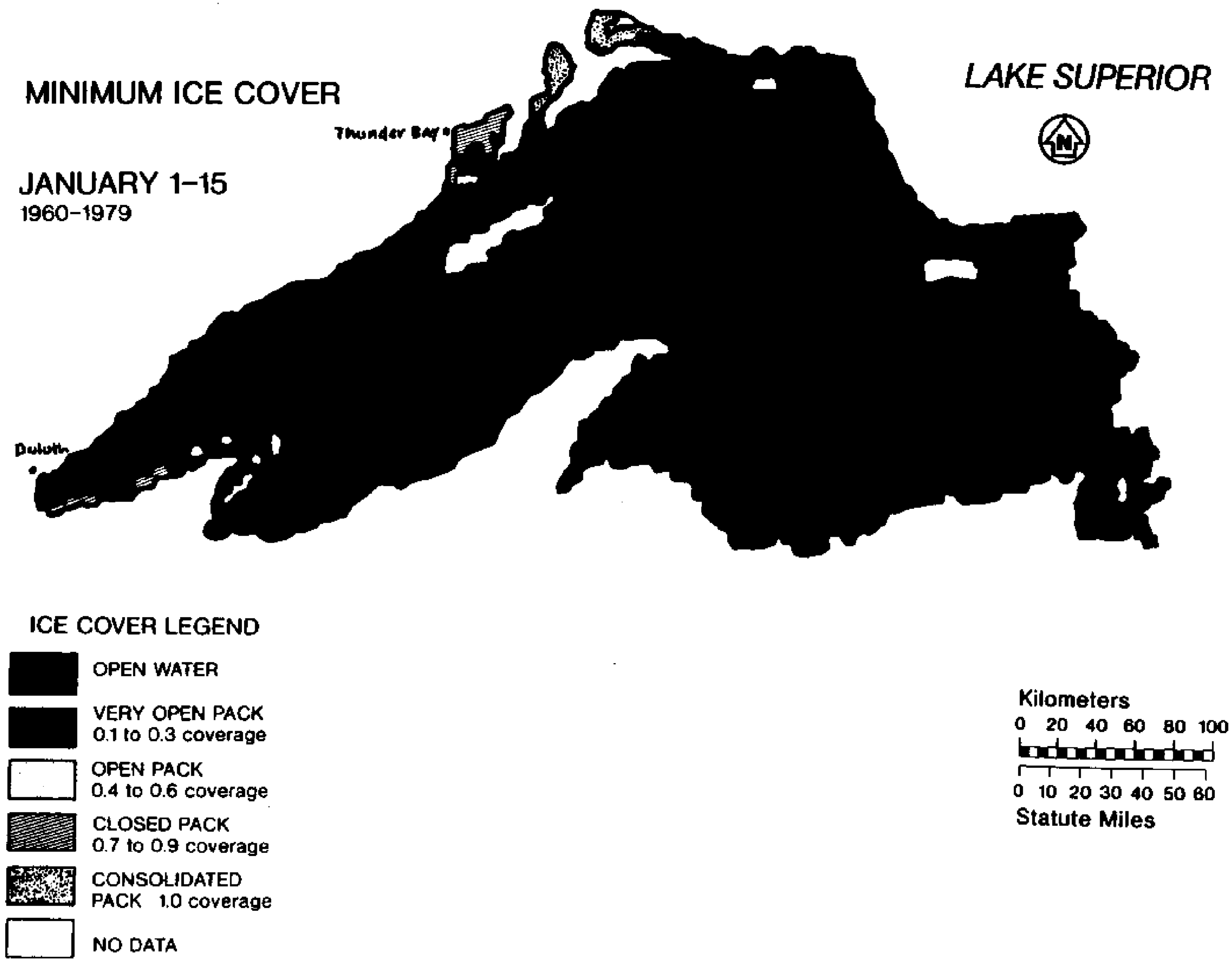
SOURCE: Great Lakes Ice Atlas, NOAA, 1983, p. 15.

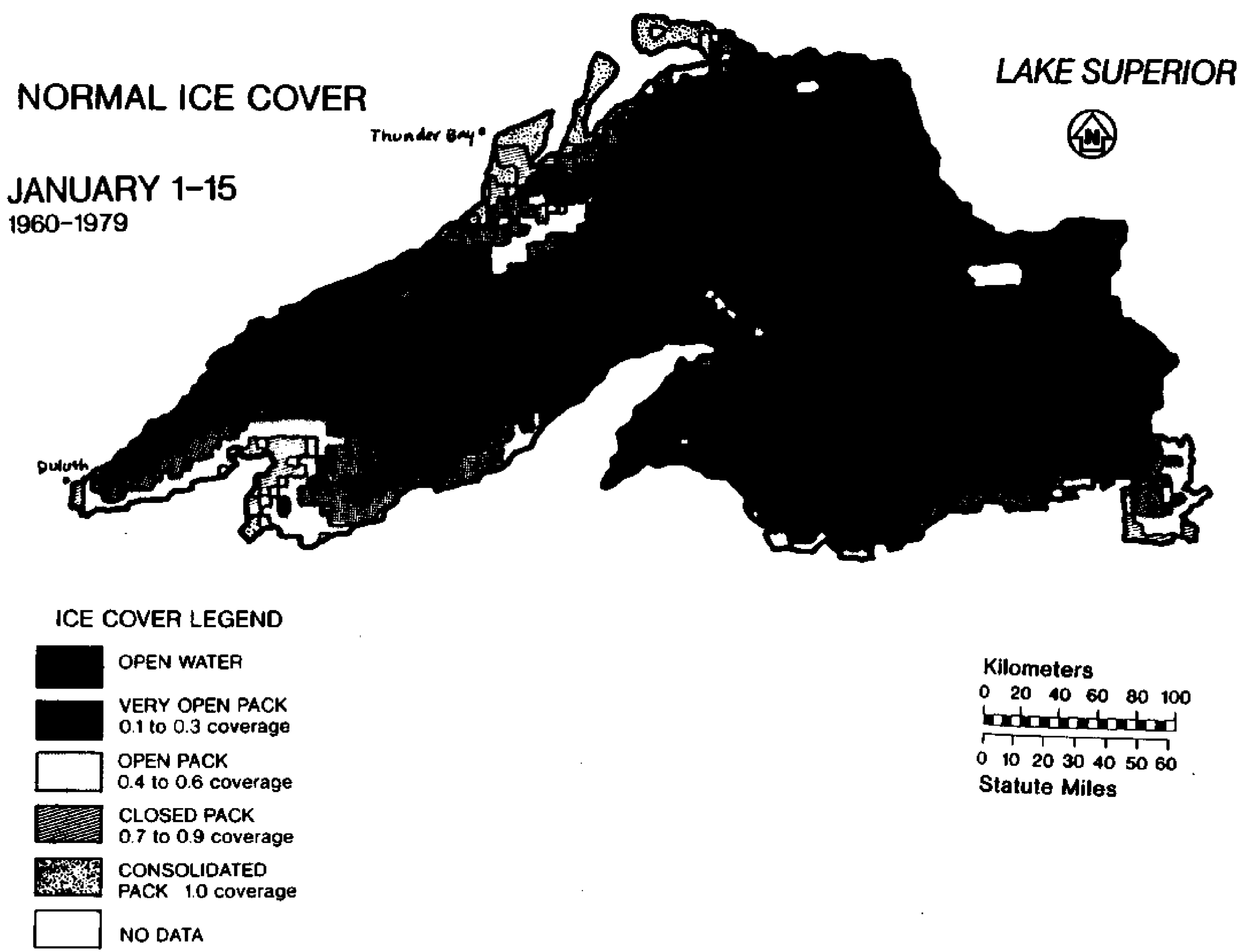
FIGURE 2. Ice chart for maximum, minimum, and normal ice concentration distribution patterns for Lake Superior for the nine half-month periods starting December 16-31 (D2) and ending April 16-30 (A2).

The half-month ice cover statistics are shown in graphical form and are arranged in descending order of normal percent ice cover below.




MAXIMUM ICE COVER
JANUARY 1–15
1960–1979
LAKE SUPERIOR
Thunder Bay
Duluth
ICE COVER LEGEND
OPEN WATER
VERY OPEN PACK 0.1 to 0.3 coverage
OPEN PACK 0.4 to 0.6 coverage
CLOSED PACK 0.7 to 0.9 coverage
CONSOLIDATED PACK 1.0 coverage
NO DATA
Kilometers
0 20 40 60 80 100
0 10 20 30 40 50 60
Statute Miles


MINIMUM ICE COVER
JANUARY 1–15
1960–1979
LAKE SUPERIOR
Thunder Bay
Duluth
ICE COVER LEGEND
OPEN WATER
VERY OPEN PACK
0.1 to 0.3 coverage
OPEN PACK
0.4 to 0.6 coverage
CLOSED PACK
0.7 to 0.9 coverage
CONSOLIDATED
PACK 1.0 coverage
NO DATA
Kilometers
0 20 40 60 80 100
0 10 20 30 40 50 60
Statute Miles


NORMAL ICE COVER
JANUARY 1-15
1960-1979
LAKE SUPERIOR
Thunder Bay
Duluth
ICE COVER LEGEND
OPEN WATER
VERY OPEN PACK
0.1 to 0.3 coverage
OPEN PACK
0.4 to 0.6 coverage
CLOSED PACK
0.7 to 0.9 coverage
CONSOLIDATED
PACK 1.0 coverage
NO DATA
Kilometers
0 20 40 60 80 100
0 10 20 30 40 50 60
Statute Miles

this wide variation. As noted above, variance in ice conditions at a given date t, represented in our model by σ_A, is an important source of risk in setting a closing date.

Turning from ice cover to more general data on weather severity, data have been collected on freezing degree-days (FDD), defined as the difference between 0° Centigrade and the average of the daily maximum and daily minimum temperatures. If, for example, average temperature on a given day is -4° C, 4 FDD's are accumulated for the day, and if it is 4° C, 4 FDD's are subtracted for the day. A summation of FDD's is started in the fall and continued until April. The maximum FDD accumulation usually occurs in March. Early accumulation of FDD's is evidence of winter severity. The cumulative frequency distribution of FDD's gives evidence of this severity. Based on data from 1898-1977 (Assel, et.al., 1983, p. 17), the climatology of seasonal FDD's is illustrated in Figure 3, which again shows the considerable variation in temperatures in relation to mean values from year to year during the 80-winter period. Variations are, however, more pronounced later in winter, during February and March, than in December and January when season extension would be most likely.

More important to the analysis of season extension is the subseasonal or monthly variation in temperature. Table 1 shows the 80-winter mean accumulated FDD's for 1898-1977 for 5 locations on Lake Superior. With the exception of Thunder Bay, Ontario, Duluth shows the earliest accumulation of FDD's on Lake Superior. Deviations from this mean are reported in Table 2. Downward deviations correlate closely with ice formation. As in the case of ice cover, a highly variable pattern from year to year exists.

The general picture emerging from this data is one of considerable variation in cold and ice conditions from year to year, increasing the

FIGURE 3. Eighty-winter mean and four-winter extremes of lake-averaged freezing degree-days for Lake Superior.

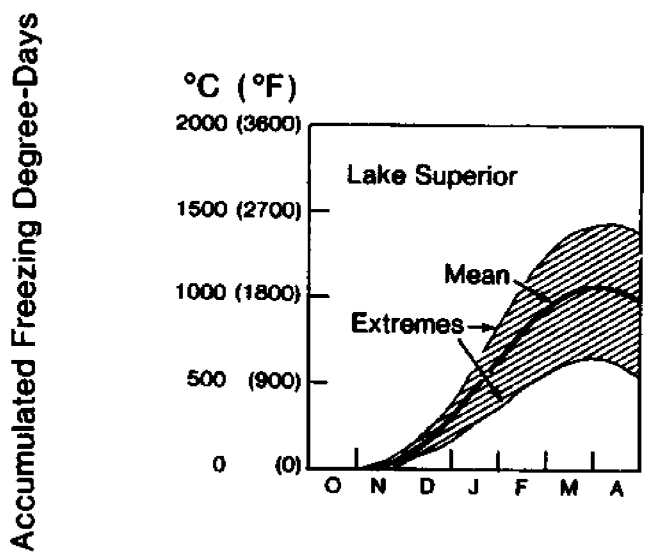


TABLE 1. Mean semimonthly freezing degree-day accumulations for the 80-winter period, 1898-1977, for Lake Superior.

Lake location	October 1	October 2	November 1	November 2	December 1	December 2	January 1	January 2	February 1	February 2	March 1	March 2	April 1	April 2
Lake Superior														
Thunder Bay, Ont......	0	3	25	69	138	183	203	237	208	148	120	67	- 2	-62
Houghton, MI..........	0	1	11	36	82	117	134	163	155	118	94	45	-17	-80
Duluth, MN............	0	3	22	65	129	170	188	214	184	129	96	44	-24	-80
Marquette, MI.........	0	0	7	29	70	100	117	142	133	96	73	27	-27	-80
Sault Ste. Marie, MI..	0	0	8	32	82	121	138	170	165	123	98	48	-14	-79

Oct. 1 = October 1-15 Nov. 2 = November 16-30 Jan. 1 = January 1-15 Feb. 2 = February 15-28 Apr. 1 = April 1-15
Oct. 2 = October 16-31 Dec. 1 = December 1-15 Jan. 2 = January 16-31 Mar. 1 = March 1-15 Apr. 2 = April 16-30
Nov. 1 = November 1-15 Dec. 2 = December 16-31 Feb. 1 = February 1-14 Mar. 2 = March 16-31

SOURCE: Assel, et al., 1983

TABLE 2. Deviation of 1960-1977 mean of semimonthly freezing degree-day accumulations from the long-term mean (1898-1977) for Lake Superior.

Lake location	October 1	October 2	November 1	November 2	December 1	December 2	January 1	January 2	February 1	February 2	March 1	March 2	April 1	April 2
Lake Superior														
Thunder Bay, Ont......	-0.1	1.8	-2.0	- 4.9	- 2.8	-18.3	-29.0	- 8.6	- 3.6	-13.8	4.6	- 7.1	2.6	4.4
Houghton, MI..........	0	0.9	-2.8	- 2.0	- 5.8	-13.6	-21.9	- 7.5	0.4	- 6.3	5.4	-11.0	-10.4	-5.1
Duluth, MN............	0	1.9	-2.5	- 0.9	- 4.7	-15.9	-32.9	-15.5	0.6	- 5.3	4.4	-10.5	- 5.1	0
Marquette, MI.........	0	-0.3	-5.9	-10.7	-10.7	-25.8	-41.8	-21.9	-13.5	-16.6	-6.0	-18.9	-14.9	-0.3
Sault Ste. Marie, MI..	0	0	-1.1	3.4	3.4	-17.3	-18.7	- 1.6	-1.1	0.5	9.7	- 5.2	- 5.3	6.9

Oct. 1 = October 1-15
Oct. 2 = October 16-31
Nov. 1 = November 1-15
Nov. 2 = November 16-30
Dec. 1 = December 1-15
Dec. 2 = December 16-31
Jan. 1 = January 1-15
Jan. 2 = January 16-31
Feb. 1 = February 1-14
Feb. 2 = February 15-28
Mar. 1 = March 1-15
Mar. 2 = March 16-31
Apr. 1 = April 1-15
Apr. 2 = April 16-30

SOURCE: Assel, et al., 1983

overall uncertainty associated with a fixed season closing date. What is more, when the more recent period 1960-1977 is compared with the long term 1898-1977 mean, FDD's appear to have increased (Assel, et. al., 1983). This suggests a trend toward earlier, colder winters in the more recent period, as suggested by Table 2. Overall, these data suggest that substantial variability in potential season length will probably continue. Whether the movement toward colder winters is part of a longer term trend is too complex an issue to be addressed in this analysis. The 1960-1977 period would suggest that mean values for cold and ice conditions, represented by μ_A in the model above, are generally becoming colder earlier in the season. However, the high variability from year to year, represented by σ_A, reinforces the riskiness of any fixed closing date.

(2) <u>Shipping Trends by Season</u>

In addition to uncertainty over cold and ice conditions, a second area of uncertainty concerns the average level of demand for commodities moving through the Great Lakes from year to year. Existing estimates of future demand depend on behavioral assumptions and a variety of guesses as to the increases in demand due to season extension. Earlier studies (Schenker, et. al., 1972, and U.S. Army Corps of Engineers, 1979) acknowledge these uncertainties, even given the data provided by the test period of open navigation on the Upper Lakes.

Using data from 1979-1984, we can estimate the average impact of alternative lengths of season extension on recent levels of tonnage, and calculate the approximate economic effects on those parts of the Duluth-Superior economy most directly affected by shipping activity. To do so, however, it is important to examine recent trends in shipping activity in the Port. Table 3 shows total waterborne commerce over the period 1979-1984, indicating a decrease in cargo tonnage (of 44 percent) from 1979-1983, with some recovery in 1984. This decrease arose in large part from secular decline in the taconite ore industry and from economic recession, together with reduced grain exports, especially corn shipments. These forces were reinforced by government actions, together with general increases in the value of the dollar over the period. The Carter grain embargo, in particular, led to substantial declines in Soviet October purchases for December lifting of corn, which provides an important share of late season Port activity. Such October purchases are a significant share of total grain handled, reflecting the bimodal distribution of port activity in the spring and fall of the year. Seasonal concentration of shipping activity is important to estimates of the impact of season extension. Volumes of grain handled by Duluth-Superior elevators in 1982, for example, as reported to the Minneapolis Grain Exchange, show high levels of activity with peaks in April or May and mid-October, a drop in mid-summer (prior to grain harvests) and total cessation in winter. Soviet purchases alone declined from 884,611 metric tons in 1979 (the year prior to both the embargo and the beginning of the rise in the dollar) to 15,210 metric tons in 1981 (by 98 percent). In 1983, the resumption of Soviet shipping still led to only 122,755 metric tons of October purchases.

In 1984, increases in exports to the Soviet Union, coupled with the effects of improved domestic economic activity, were joined by warm weather. This relatively favorable combination of circumstances increased total metric tonnage to 32,500,000. While this recovery can be attributed in part to the extended 1984 season, it may be largely the result of unpre-

TABLE 3. Number of Vessels and Cargo in Metric Tons--
Port of Duluth/Superior, 1979-1984.

	1979	1980	1981	1982	1983	1984	6-Year Average
Number of Vessels	2,164	1,829	1,728	1,137	1,195	1,285	1,556
Cargo Tonnage	43,813	37,853	36,407	25,620	28,824	32,500	34,170
Tons per Vessel	20.24	20.69	21.06	22.53	24.12	25.29	21.96

SOURCE: Port Authority of Duluth

dictable shifts in both weather and shipping demand. Hence, it would be an error to interpret 1984 as an indicator of the impacts of season extension in general. In any given year, these impacts may be greater, or less, than observed in 1984.

A general decline in activity is also reflected in the number of vessels calling at the Port from 1979-1984. Oceangoing vessels declined from 370 in 1979 to 249 in 1984 (down 33 percent); and all ships declined from 2,164 in 1979 to 1,285 in 1984 (down 41 percent). Oceangoing vessels as a percentage of total shipping declined from 17 percent of all vessels in 1979 to 15 percent in 1981, but increased to 19 percent of the much smaller number of vessels in 1984. The number of ships declined proportionately more than tonnage because the average ship size increased. This was more dramatic for lake vessels than ocean vessels because older, smaller lake vessels, which have higher operating costs per ton, have been taken out of service as demand has declined. Despite the improvement in 1984, this trend reinforces the tonnage data.

Shipping activity appears to be headed generally downward at the Port. This may be due to the risk aversion of shippers, but could also be due to national and international competition for low cost commodities or increased competition from other trade routes. For example, low barge rates in recent years have presented strong competition for several lake ports, including Duluth-Superior. The causes of the decline in shipping activity could be based on risk, cost, or both.

(3) Economic Costs and Benefits

These trends are, of course, a major reason why calls for season extension continue. Most of these calls are predicated on claims concerning the impact of such extensions on the local economy. To date, estimates of the impact of Port activity on the economy of Duluth have been largely based on a 1976 study by J.F.P. (Jeno F. Palucci) and Associates in a Port Authority of Duluth mimeo, undated. The value added calculations performed in that study were originally based on 1972-1974 data and have since been updated. The value added calculations were combined with estimates of a "multiplier effect" of 2.57 times direct income to determine overall impacts. We were unable to determine how value-added calculations were arrived at in the 1976 study, and can therefore neither endorse nor criticize its results. Multiplier effects, while difficult to test empirically, are deserving of further study in light of secular trends in industry and commerce since 1970.

Perhaps the best available current information indicating the direct impact of Port activity on the local economy is provided by longshoremens' unions, notably the I.L.A. Marine Association Welfare Fund. Data on total hours worked by longshoremen from 1979-1984 in both the Port of Duluth and Superior are broken down by cargo, grain handling, cleaning and fitting. Table 4 indicates that total longshoreman hours worked declined in the Twin Ports from 207,700 to 152,568 (26 percent) from 1979 to 1984. The distribution of hours worked indicates slight increases in cargo handlings with substantial decreases in grain handling. Grain handling hours in Duluth fell by 11 percent, 18 percent, 4 percent, 25 percent and 10 percent respectively in each year from 1979-80 to 1983-84, or an average decline of 13.6 percent over the five year period. In Superior, yearly percentage declines in grain handling were 9 percent in 1979-80, 8 percent in 1980-81, 31 percent in 1981-82, an increase of 10 percent in 1982-83 and a decline of 13.8 percent in 1983-84, or an average decline of 10.4 percent.

TABLE 4. Total Hours Worked: Cargo, Grain, Cleaning and Fitting -- Duluth and Superior Longshoremen, 1979-1984.

	1979	1980	1981	1982	1983	1984
Duluth						
Cargo	62,620.50	47,514.25	60,907.75	63,030.25	68,586.50	67,405.25
Grain	47,811.50	42,599.50	35,012.00	33,676.50	25,174.50	22,569.50
Cleaning and Fitting	282.50	357.00	190.00	498.75	0	0
TOTAL	110,714.25	90,471.75	96,109.75	97,207.00	93,761.00	89,974.75
Superior						
Cargo	0	1,552.00	6,918.25	5,826.00	0	9,586.25
Grain	95,948.50	87,464.50	80,464.50	55,595.00	61,538.50	53,007.00
Cleaning and Fitting	1,043.00	1,243.00	32.00	0	0	0
TOTAL	96,991.50	90,259.50	87,414.75	61,421.00	61,538.50	62,593.25
Duluth-Superior						
TOTAL	207,705.75	180,731.25	183,524.50	158,628.00	155,299.50	152,568.00

SOURCE: Duluth-Superior I.L.A. Marine Association Welfare Fund, Duluth, Minnesota

One reason for this decline was the reduction in overall commerce discussed above. However, inspection of grain handling facilities in the Port also suggests a strong trend toward increasing substitution of capital for labor. One grain elevator, while newer than many others, employs only 21 or 22 men to load grain on board ships. All but a handful work as sweepers to keep dust levels down. Actual loading can be accomplished by three or four men assisted by computer-operated loading machinery. This technology may be expected to characterize future bulk cargo loading facilities in the Port, if DuluthSuperior is to remain competitive.

According to the I.L.A. Marine Association Welfare Fund, longshoremen straight time pay was $15.08 per hour in 1984 and overtime pay was $22.50 per hour. Since approximately 45 percent of all hours worked are overtime due to the seasonal concentration of loading, the direct economic effects of Port activity included $2.8 million in wage income for longshoremen alone. Not all of this wage income will be spent; some will be saved. And of the proportion spent, not all will be spent locally. Although longshoremens' wages in isolation clearly understate the direct effects of Port activity, they are firmly grounded in existing data and involve no imputations or guesstimates.

Longshoremens' hours can be used as a proxy to estimate the relative impact of season extension on Port employment, or at least on its most immediately affected individuals. Since the impact on longshoremen is the most dramatic direct employment effect of season extension, studying this impact will provide insight into other, less obvious effects. Table 5 shows tons of cargo per hour and hours worked per vessel by longshoremen from 1979-1984. Tons of cargo per hour worked fell from 1979 to 1983 while

TABLE 5. Tons Per Hour and Per Vessel, 1979-1984.

	1979	1980	1981	1982	1983	1984	6-Year Average
Longshoreman Hours (in thousands)	207.7	180.7	183.5	158.6	155.3	152.6	173.1
Cargo Tons (in thousands)	43,813	37,853	36,407	25,620	28,824	32,500	34,170
Tons/Hour	210	209	198	162	186	213	197
Vessels	2,164	1,829	1,728	1,137	1,195	1,285	1,556
Hours/Vessel	96	99	106	139	130	119	111

hours worked per vessel rose, reflecting an overall trend toward fewer vessels and less cargo for the established work force. In 1984 there was an increase in tons of cargo per hour to 213, and a decline in hours per vessel to 119. Tons of cargo per vessel has increased over the period, reflecting larger vessels. If the six year average of 197 tons of cargo loaded per longshoreman hour from 1979-84 is used as a base, then the increase in hours worked due to season extension can be determined assuming that the average cargo movement for the year would characterize the extended season. Similarly, if the average of 111 longshoreman hours per vessel over the period is taken as a baseline, then increases in vessels due to season extension can be used to calculate approximate increases in hours of longshoreman employment. In effect, these impacts consider the potential direct employment effect of season extension. Impacts on the larger economy depend on assumptions that longshoremen represent a fixed percentage of this economy.

Table 6 shows the results of these computations for one, two, four and eight week season extensions. Using the six year average of 111 longshoreman hours per vessel and 1984 wage levels, each additional ship calling during the extension would lead to increases in direct wage income of $921 per week at standard time and $1,125 at 45 percent overtime for a total of $2,045. The first row of Table 6 shows the additional longshoreman wages if 42 ships per week (the 6 year average) called during the extended period. The wage increase is approximately $86,000 per week.

Although additional benefits would undoubtedly accrue to other parts of the local economy, data and linkage to larger input-output models are not currently available. This analysis assumes that the demand for Port

TABLE 6. Season Extension Increase in Annual Longshoremen's Wage Bill.[1]

Number of Additional Vessels	Length of Extension			
	1 week	2 weeks	4 weeks	8 weeks
42 ships/week @ 111 hrs. per ship [2]	85,890	171,780	343,560	687,120
21 ships/week @ 111 hrs. per ship [2]	42,945	85,890	171,780	343,560
10 ships/week @ 111 hrs. per ship [2]	20,450	40,900	81,800	163,600
42 ships/week @ 130 hrs. per ship [3]	100,170	200,340	400,680	801,360
21 ships/week @ 130 hrs. per ship [3]	50,085	100,170	200,340	400,680
10 ships/week @ 130 hrs. per ship [3]	23,850	47,700	95,400	190,800

[1] Computed from a 37-week base season using 1984 wages with 45 percent.

[2] Cost per vessel, $2,045

[3] Cost per vessel, $2,385

facilities during the extended season would be the same as the average demand during the regular season. It is also assumed that this is "new" demand and is not the result of a substitution of shipping during the lengthened season in lieu of stockpiling.

The next row of Table 6 shows the impact of additional demand per week equal to one-half of the six year average. The wage increase at that level is $43,000 per week. If the demand is only one-fourth that of an average week or 10 ships, the longshoremen's wage impact would be approximately $20,000 per week.

The third and fourth rows of table 6 show the wage increase if the average longshoreman hours per vessel is 130 hours as it was in 1983. This is 17 percent more than the 6 year average. In that case, the longshoreman wage bill per ship would be $2,385 and the added wages per week of extension would be $100,170. If only half the number of ships called, the additional wages would be $50,085 and if the added demand was one-fourth that of an average week, the additional longshoreman wages would be approximately $24,000 per week.

It should be noted that to get an increase in overseas shipping, the St. Lawrence Seaway shipping season would also have to be extended in phase with that of Duluth/Superior. Results are also based on the further significant assumption that longshoremen are willing to work additional hours during the extended season. Union contracts require that benefits such as health insurance are earned by each union member after working a given number of hours each year. Working conditions during severe weather once the annual number of hours is reached, may lead to a reduced willingness to work additional hours. This point was stressed to the authors in interviews with longshoremen representatives.

III. CONCLUSIONS

Although this study must be considered preliminary, its findings suggest that in and of itself, season extension would contribute only marginally to increased economic activity in the Port of Duluth-Superior. In the first section of the paper, the complexity of setting a date for an extended season was demonstrated. As later and later dates are chosen, the risk that shippers will refuse to navigate the Seaway increases along with the costs of keeping the system open. Yet it is clear that too early a closing date can lead to lost revenues in the Port. These risks vary from year to year, making the choice of a single date for closing problematic. The foregone benefits of too early a closing date, when weighted against the costs and risks of later closings, suggest that flexibility should be retained whenever possible, so that season extensions can be undertaken whenever high demand coincides with warm winter weather.

Attempts to guarantee seasons extensions longer than a few weeks, however, will result in substantial costs. These costs have been well-documented (Army Corps of Engineers, 1979). It is our view, however, that insufficient attention has been given to the variability in such costs. Whether benefits exceed costs of season extension will depend on both the weather and shipper demand during the year in question, making the entire issue one of decision making under uncertainty. Uncertainty surrounds both weather and shipping demand conditions in a given year.

When empirical evidence on weather conditions and shipping demand is evaluated more closely, the importance of this variability on a year-to-year basis is reinforced. The risk that weather conditions will exceed the threshold deemed tolerable by most shippers increases as later dates are chosen, lowering the marginal benefits of season extension. This risk is attributable to the considerable deviation from "normal" winter weather from year to year. Data from the last 20 years suggest larger accumulations of freezing degree days (FDD's) early in the season. Data on shipping volume through the Port suggests less variability but declining volume with a modest recovery in 1984. This is due largely to the dependence of the port on taconite shipments.

When the direct economic effects of season extension on longshoremens' wages are examined, the result of one or two week extensions is not large in relation to overall wage income. Although effects on other sectors would no doubt occur, data on those direct effects is lacking, and attempts to impute indirect and/or multiplier effects are unverifiable at this time. The modest impact of season extension on those most directly affected should also be tempered by a recognition that longshoremen may not choose to work the additional weeks, because of weather conditions and/or favorable union contract arrangements.

In the final analysis, we conclude that season extension can, in certain years, increase employment and economic activity in the Port. Flexibility in setting the closing date should be maintained to take advantage of high demand years and favorable weather conditions. However, without a much broader program of economic development activities, as well as federal and international actions leading to increased shipping demand, season extension will not substantially improve the condition of the local and regional economy.

Bibliography

Assel, R.A., Quinn, F.H., Leshkevich, G.A. and Bolsenga, S.J. Great Lakes Ice Atlas, Great Lakes Environmental Research Laboratory. Ann Arbor, MI. July 1983.

Runge, C.F. "Risk Assessment and Environmental Benefits Analysis," Natural Resources Journal, Vol. 23, July 1983, pp. 683-696.

Schenker, E., Bunamo, M. and Smith, D.B. Extending the St. Lawrence Seaway Navigation System: A Cost-Benefit Approach, WIS-SG-72,209, The University Wisconsin Sea Grant Program. Jan. 1972.

U.S. Army Corps of Engineers. Final Survey Study for Great Lakes and St. Lawrence Seaway Season Extension. V01. I-V, Detroit District. Aug. 1979.