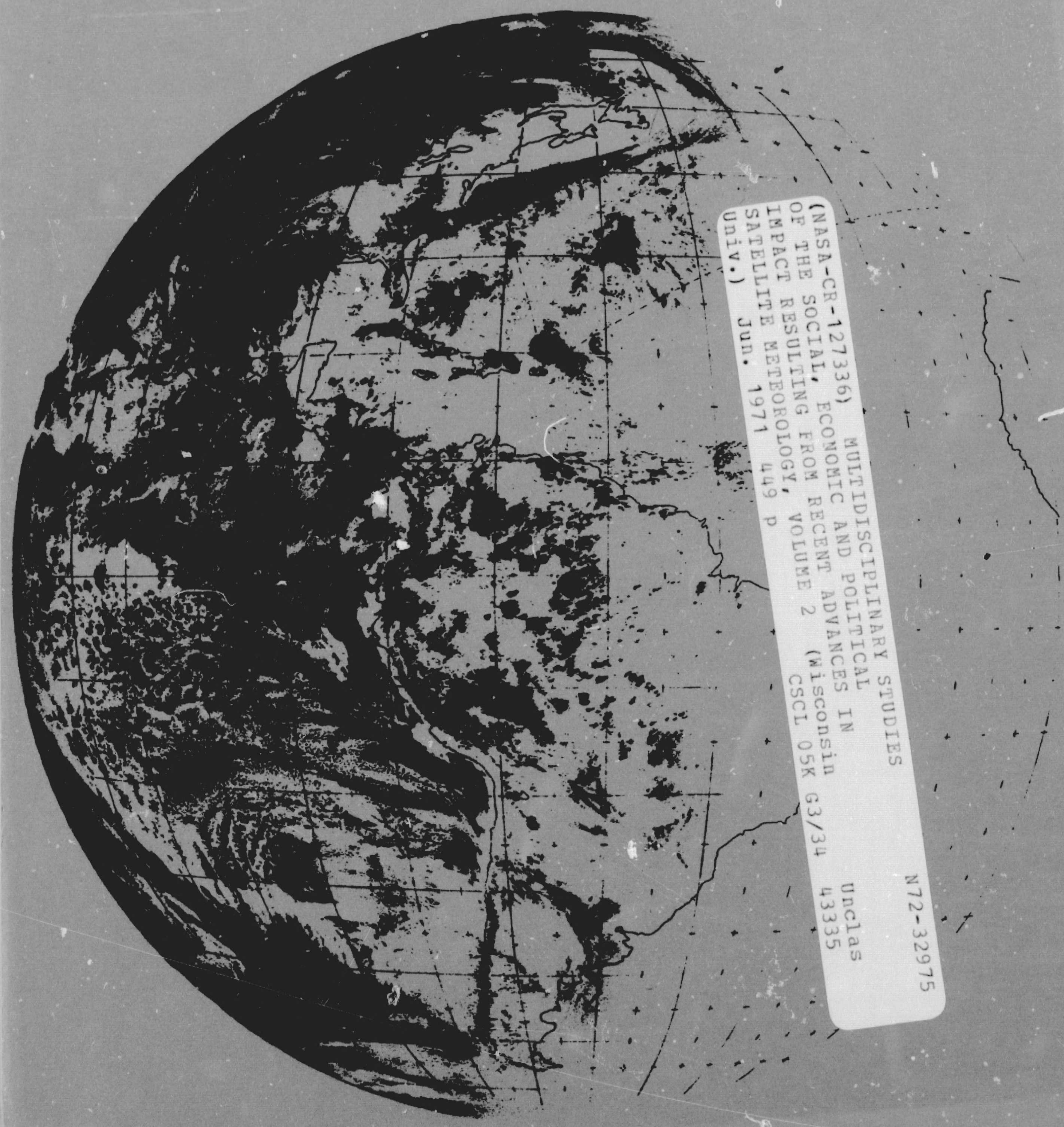
multidisciplinary studies of the social, economic, and political impact resulting from recent advances in satellite meteorology

an interim report
volume two

space science and engineering center
the university of wisconsin
madison, wisconsin



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MULTIDISCIPLINARY STUDIES OF THE SOCIAL, ECONOMIC AND POLITICAL IMPACT RESULTING FROM RECENT ADVANCES IN SATELLITE METEOROLOGY

Interim Report on

NGL 50-002-114

Volume II

The research in this document has been supported by the National Aeronautics and Space Administration

June 1971

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PREFACE

The multidisciplinary studies undertaken under this NASA grant explore and evaluate the impact of the meteorological satellite and the concomitant impact of the data derived from it on various user groups. As expected, the primary impact related to those who would use satellite data for weather prediction and related purposes. A secondary impact was in the area of international concerns where GARP and other international meteorological activities were affected and international law was developed. A tertiary impact was exemplified by satellite photographs utilized in advertisements and related materials. However, this impact has not as yet been treated in detail given the scope of our research. The determination and analysis of these impacts are extremely significant in that this data will help guide the development of NASA meteorological satellite systems in the future. The case studies, supporting studies, and independent studies all emphasize the potential of the meteorological satellite, and from these findings it can be seen that there is a wide scope for continued research approached from the perspective of the user.

We wish to thank Nancy Bauch, Linda Mangum, Sandra Noe, Patricia Luetgert, and Harold Oxley for their help in the preparation of this report.

Additional thanks go to Professor Bruce Lusignan who was responsible for initial organization of the interdisciplinary team approach, and to

Miss Justine Dakin who served as project coordinator and was responsible for following up the initial participant contacts and preparing work assignments. A further note of thanks goes to Mr. Tom Haig for his participation in the review process on the project.

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MULTIDISCIPLINARY STUDIES OF THE SOCIAL, ECONOMIC AND POLITICAL IMPACT RESULTING FROM RECENT ADVANCES IN SATELLITE METEOROLOGY

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THE NATURE AND IMPACT OF THE BENEFITS OF IMPROVED SATELLITE WEATHER FORECASTS ON AGRICULTURE

Kenneth R. Smith and Frederick H. Boness*

To determine the economic value of improved weather information is a problem with several dimensions. Consider a situation where all producers have fully adjusted to present circumstances. The producer of corn, for example, has decided upon the optimal number of acres to plant, the optimal operations during the growing season and the optimal harvesting strategy. We can, if you will, describe his annual activities and identify those points on the activity cycle that are particularly sensitive to weather. Assume that the initial circumstances to which everyone is fully adjusted involve an absence of weather information. Thus, while the production of various products is sensitive to weather, there are no possibilities for reorganizing the activity cycle to mitigate the effect of "bad" weather or take advantage of "good" weather. Now imagine that circumstances change so that the producer has available accurate weather forecasts. What we wish to do is trace the effects of these forecasts on the decisions of the producer and the subsequent effect of the producer's reaction on the supplies of the product, the market price and the allocation of resources.

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In the first instance, we might expect the producer's reaction to be an increase in the supply of the product that is forthcoming at the established price. We could then identify a benefit to the producer in that while his costs have supposedly been unaffected (it is, of course, possible that in order to facilitate the reorganization that results in an increase in supply, the producer must incur some additional cost; in this case the net benefit would be reduced), the increased supply will result in larger revenues. Of course, the producer's reaction could have other effects than increases in supply (such as reduced production costs). In part one of this introduction, we examine in more detail the nature and significance of the producer's reaction to better weather information.

However, the adjustment process does not stop there. If all producers are in the same situation there will be an increase in total aggregate supply. Given that consumers were originally obtaining all they wanted at the current market price, this will result in an excess supply which in turn will cause the market price to fall. Thus, the producer will not retain all of the benefit identified in part one. Finally, after the new market price has been determined and producers have adjusted their production to this new market price, the production of corn may be more or less attractive than in the original situation given the present allocation of resources (land) to the various crops. If this is the case there will be a further adjustment with either more land or less land used to produce corn. We must take into account the effect of this final adjustment on the distribution of the original benefit. The last two issues outlined above are considered in part two of this introduction.

I

In this section we shall indicate the nature of the benefits resulting from the producer's reaction to better weather information, indicate how these benefits arise, and finally, describe the methodology used to determine their magnitude.

The benefit most frequently identified in the various case studies is an increase in supply. Supply increases are likely to occur for two reasons. First, in many instances it is felt that the producer could prevent losses which presently occur because he lacks knowledge of forthcoming bad weather. For example, crops such as tree fruits and cranberries are often destroyed by frost. If the producer has time to prepare for the freezing weather, these could be saved by heating or irrigating. Time is also required to start up heating (or for that matter air conditioning) operations for greenhouses. Major crop losses may occur at harvest time if fields must be abandoned because excessive rain prevents the men and machines from getting into the field, or because high temperatures cause the crop to go to maturity faster than it can be harvested. These losses could be prevented with weather forecasts by altering the harvest schedule.

Second, supply may increase as a result of improvements in the effectiveness of certain operations which increase the yield. It is suggested that corn producers may increase yields substantially by employing supplemental irrigation during periods that are predicted to be excessively dry. Also, applying fertilizer when the weather is most appropriate may have some effect on yield (although it is likely to be marginal).

Another type of benefit which the case studies identify is a reduction in the costs of production. The major effect of the forecast is to reduce uncertainty about the future. As a result, the producer can reorganize portions of the production process. The studies which dealt with crops where large labor crews had to be mobilized on a seasonal basis indicated that accurate weather forecasts would facilitate the more efficient allocation and scheduling of this labor. Where migrant labor is brought in it was felt that their arrival might better be timed so that no potential planting or harvesting days would be missed, while at the same time the laborers would not arrive early and have to be paid when there was no work. Another example, which is noted in several case studies, is the possibility of saving the cost of a fungicide or insecticide spray when the producer knows the weather is not conducive to the development of the disease. He currently sprays because he is uncertain of the weather and cannot take a chance on the disease developing.

The final type of benefit identified in the case studies is an improvement in the quality of the crop. This could result, for example, because the producer is able to harvest at the optimal time. The studies on hay and corn indicate that such a benefit could occur. However, the effect of an improvement in quality is frequently equivalent to a change in quantity. For crops which are graded, the effects are likely to be changes in the quantities of the various grades. It may be that with the weather information there will be a greater supply of high-grade crop and (perhaps) smaller supplies of the lower grades. Even for nongraded crops it may be that the quality effect manifests itself as a change in quantity. The hay study, for example, indicates that improving the quality of hay will affect the supply of milk.

Having described the nature and basis of the benefits which are expected to result from accurate weather forecasts, let us turn to a discussion of the methodology used to quantify these benefits. Basically, the quantitative aspect of the case study involves a re-examination of those points of the production process where it is felt benefits might occur. However, the perspective is quite different. For those points of the production process where it was felt an increase in supply would result it was necessary to determine (by using records, by talking with producers, or by some alternative method) the present size of the loss which results from the lack of weather forecasts. Similarly, where a saving in production costs is anticipated, it is necessary to estimate the frequency and size of the saving.

The results obtained in this way provide the investigator with an idea of the maximum benefit that can be achieved when accurate weather forecasts are available. In addition, they indicate where in the production process the benefits are likely to be the greatest; this is important for if it is not possible to derive quantitative estimates of all the potential benefits, at least the investigator will know if he is dealing with the most significant elements.

Of course it is not likely that all of the benefits identified by considering current costs and losses can be achieved. There will exist reasons why a producer may not be able to or may not want to utilize the weather forecast, and in these cases the potential benefit will not be realized. The job of the investigator is to consider the reasons why the full benefit will not be realized and estimate the percentage which will be.

There are basically three reasons why the full benefit may not be realized. First, it may be the case that a producer for some reason is unable or unwilling to respond to the forecast. For instance, in the example cited earlier the harvest could be speeded up to prevent a loss only if additional workers and machinery were available. Similarly, in cases where heating is the expected response to the weather report, it is necessary to consider if the resources (fuel, smudge pots, men to put them out) will be available when they are required. Several case studies indicate a potential benefit from being better able to enter into certain types of contractual arrangements (e.g., ordering seeds, timing arrival of migrant labor). But if these arrangements do not allow the producer to make changes within the anticipated two-weeks forecasting period then the potential benefit will not be realized. All of these examples illustrate situations where because of insufficient flexibility the producer is unable to respond to the weather information.

There are also situations where the producer will be unwilling to respond. In deciding whether or not to utilize the weather forecast the additional costs that are incurred must be deducted from the expected benefit. If the costs are greater than this benefit it will not be rational to respond to the weather forecast. This situation is illustrated in the economic study of corn. The report indicates that the cost of irrigation equipment will probably be greater tnan the additional profits which the producer can expect to make by increasing his yield. A producer may also choose not to use the weather information if the expected benefits are relatively small and the costs resulting from an inaccurate forecast are great. This situation may involve the frequently identified example of saving the cost of an insecticide or fungicide spray. The cost of such a spray is small compared to total production costs, whereas the cost of an inaccurate weather forecast may be the loss of the entire crop to disease or pests. Thus it is highly possible that the producer may prefer to incur the small cost regularly to prevent an infrequent but large loss.

A second reason why the full benefit might not occur results not from the inflexibility of the producer, but rather from the severity of the weather. The hay model indicates that if weather is so bad that the producer is unable to cut and dry his hay within a two-week period following the optimal cutting date then for practical purposes the crop is useless and there is nothing the farmer can do about it. The same situation develops when a hard freeze occurs. Heating and irrigation are only effective when the temperature is near freezing; if it should fall several degrees below freezing these methods will not save the crop. The investigator must determine the frequency with which these types of weather phenomena occur so that the resulting unpreventable losses can be deducted from the maximum potential benefit.

The third consideration which the investigators must take into account is the effectiveness of the producer's response, when he is able and willing to act on the weather information. For example, where the forecast permits him to prevent losses (say by heating or speeding up the harvest) which he would otherwise incur, the investigator must ask, can the entire loss or only a portion of it be prevented? The lettuce study indicates that even if the producer is aware of approaching heavy rains and takes steps to reduce standing water in the field, he will probably be able to save only about 35% of the losses that would have occurred without the weather forecast. The problem of determining a producer's effectiveness is also illustrated in the hay study. Suppose the producer cuts his hay and then, for the next three days, it rains. The nutritional value of the hay declines from 70% to 35%. Now with weather forecasts let us suppose that the producer knew that after the three days of rain the weather would be good and he would be able to cut and dry his hay satisfactorily at that time. One might be tempted to conclude that weather forecasts would improve the nutritional value of the hay by 35%. However, this would not be correct, because the uncut hay loses value as it stands in the field. Hence, when the farmer is able to cut the hay on the fourth day its value may be only 66% and the effect of his response is an improvement in the quality of the hay by 31% rather than 35%.

Let us conclude this part of the paper with some comments about the relationship between the methodology outlined above and the case studies which follow. First, we should note that no single case study has been as thorough and complete as the methdology might imply (although taken as a whole they have been at least as complete). There are good reasons for this. In many instances there simply do not exist data on the magnitude of current losses and costs directly caused by weather; thus it has been necessary for the investigators either to develop data from models (as in the hay study) or collect information through discussions with producers (as in the corn and lettuce studies). As a result the investigators were encouraged to concentrate on those aspects of the production process and those benefits which appeared a priori to be of greatest significance.

Second, our discussion of the methodology above has not adequately indicated the degree of subjectivity which has entered into the case studies. In considering the effectiveness or flexibility of the producer's response, for example, it is simply not possible to know with certainty how effective or flexible the producer will be. The investigators have had to make their "best guesses" about the effectiveness or flexibility. In fact, this has been a major reason for having the case studies conducted by individuals whose areas of specialization include the crops which they investigated.

Finally, we should point out that not all case studies have pursued the investigation to the same extent. This has been by design. After the initial study in which potential benefits were identified, but no attempt was made to quantify them, it could be seen that there were many similarities in the types of benefits which were expected to occur. It was therefore felt that it would be possible to make generalizations about the quantitative magnitude of the benefits without necessarily investigating at the quantitative level all crops studied.[1]

II

In part one we indicated the nature of the benefits which the case studies identified and examined how the magnitude of these benefits was determined. In this part we shall consider how market interactions might distribute these benefits between various groups and also what might be the long-run reallocations of resources.

One type of market interaction is illustrated by the case study on floriculture. This case study concludes that the "overall effect of more accurate short- and long-range weather predictions would be a more steady flow of flowers throughout the year with a stabilization of prices and a better chance for adequate profits." To the extent that losses are prevented because of weather forecasts, it is certainly true that the flow of flowers will be more steady and prices more stable. However, in some instances, as we noted earlier, it is not possible to prevent the loss even with the knowledge that the weather is going to be unfavorable. In such a case market interactions will not stabilize consumer prices but will distribute the profits one way when weather information is available and another way when information is not available. Presently, a retailer (or wholesaler) places his order with a

[1]The nature and significance of these generalizations will be discussed in a later study concerned primarily with integrating the economic findings of all areas of the project.

supplier. If unfavorable weather forces the supplier to default on this order the retailer is simply left without flowers. At the same time, since the supply has been reduced, the price to consumers will rise. This means that retailers whose orders were filled are making large profits while those whose orders were not filled are making none. The larger profits occur only to those retailers with flowers and not to their suppliers because the flowers were bought at a lower price when it was thought there would be an adequate supply. On the other hand, if weather forecasts enable the defaulting suppliers to notify their customers in advance that their orders cannot be filled, these retailers could seek out those suppliers whose flowers were not affected by unfavorable weather. The result would be a higher wholesale price of flowers. Those wholesalers whose supply of flowers was not affected by the weather would receive this higher price, and all retailers could obtain part of the limited supply of flowers. The price to consumers would be the same as in the case without weather information because the supply is the same, but now there are no retailers receiving large profits; all retailers are receiving a normal profit. This type of market interaction will be most likely to occur for those crops where unfavorable weather forces suppliers to default on orders, that is, highly perishable crops such as lettuce and floriculture which must be ordered a week or more in advance.

A second type of market adjustment deals with the consequences of an increase in the supply of the crop. This is important because it appears that much of the effect of improved weather forecasting will be an increase in supply. When the supply of any product is increased, the normal market reaction is for the price to fall. The net impact on the farmer will depend on how big a price reaction is required to re-equate the increased supply with market demand. The answer to this question depends upon the elasticity or the price flexibility of demand.

Price flexibility is the percentage change in the price of a commodity associated with an isolated 1% increase in the quantity sold. While individuals make quantity decisions based on given prices, market supplies of many agricultural products are fixed in the short run and prices must bear the adjustment burden. Consequently, the amounts by which market prices change in response to output changes between production periods is the important factor. We may consider the flexibility of price either at the retail level or at the farm level; depending upon how the price spread is determined, these flexibilities may or may not be equal. Briefly, it can be shown that if the spreads are a constant percentage of the retail price, the flexibilities of retail and farm prices will be equal. If the spreads are absolute amounts of dollars and cents, prices would be more flexible at the farm than at retail. This is important. If the price flexibility F is less than minus one (minus because price increases are associated with quantity decreases), then a 1% increase in quantity will necessitate a price decrease of more than 1%. This results in a fall in the net revenue available to the farmer; he is worse off than he was before the better weather information increased the quantity of this product.[2] Some examples of price flexibilities for various products are given in Table 1.

The effect of quantity increases on the producer also depends on the length of time period considered. As people's incomes and the number of people increase over time, the demands for most commodities also increase. However, increased consumer incomes do not necessarily mean the farmer is better off. If output were constant, higher incomes would mean higher retail prices. The fact that higher incomes generally result from higher wages may well mean that the margin the processor requires to cover costs increases and the farm price remains constant. Thus, higher quantities would have, on the farmer, the effect described above, even if incomes were increasing simultaneously.

The question of the market adjustment to supply is also dependent upon other factors which the above discussion has assumed constant. For example, if a crop is controlled by a price support program or quota system the adjustments of these programs to the increased supply are likely to be quite significant in determining how the producer will be affected.

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[2] To see this, consider the following where R is net revenue, p is price and q is quantity:

$$R = pq$$

Totally differentiating

$$\frac{dR}{dq} = [q\frac{dp}{dq} + p]$$

$$= p[1 + \frac{q}{p}\frac{dp}{dq}]$$

$$= p[1 + F]$$

where F is the price flexibility. If F is less than minus one, revenue falls as quantity increases.

Table 1

Price Flexibilities for Various Agricultural Products

Product	At Retail[1]	At Farm[1]	At Farm[2]	At Farm[3]
Potatoes	-2.57	-5.28	-2.14	
Sweetpotatoes	- .76	-1.15		
Tomatoes	- .85	-1.03	- .215	
Grapefruit	- .82	-2.06		
Lettuce			- .387	
Peas				
fresh			- .35	
canned			- .10	
Apples	- .81	-1.43		
fresh				-1.3
canned				-1.7
other				-2.1

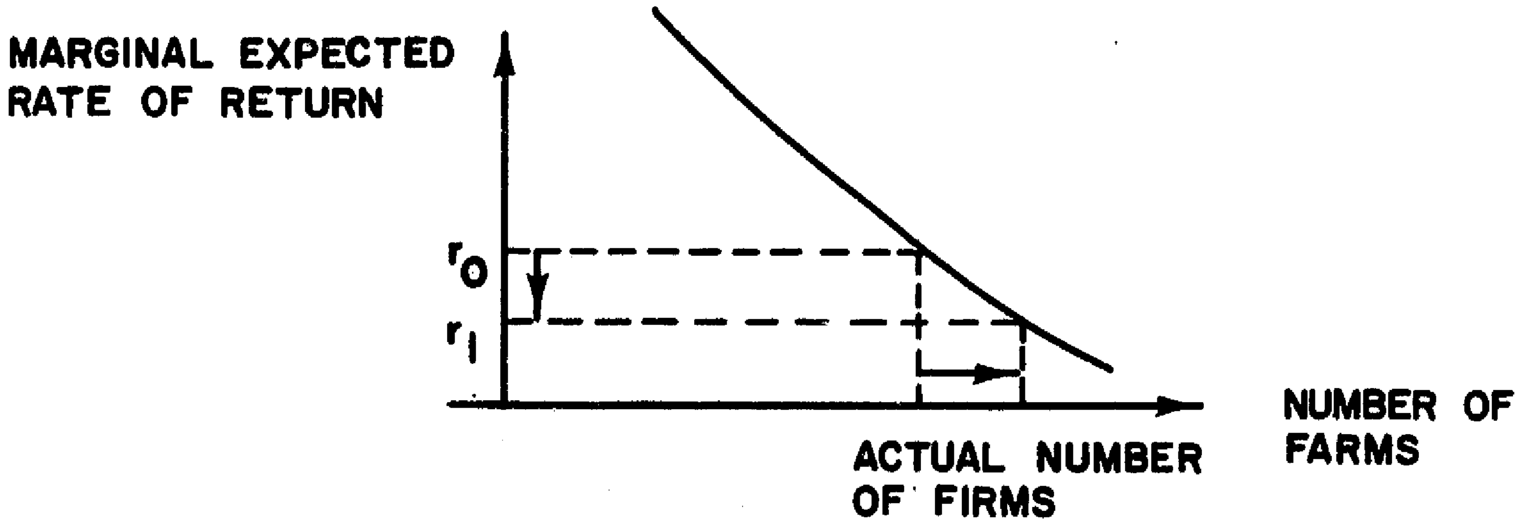
[1]Waugh, F. V., "Demand and Price Analysis: Some Examples from Agriculture," USDA Technical Bulletin 1316 (1964), pp. 19-20.

[2]Shuffert, D. M., "The Demand and Price Structure for Selected Vegetables," USDA Technical Bulletin 1105 (1954), p. 22.

[3]Bartto, Lynn M., "Effects of Apply Supply Management Programs in N. Y. State," New York, Cornell University, Agriculture Economics Research, No. 62.

Another assumption implicit in our discussion of supply increases has been that the crop is ungraded or else that the increases have been such as to leave the share of the total crop for each grade unaffected. In fact, as we have already indicated, we expect quality improvements resulting from better weather forecasts to change these shares (specifically, to increase the share of better grades and reduce the share of poorer grades). The effect of a change in the quality mix may be separated from the effect of a general increase in supply by examining the effect that changes in the mix have on total revenue, given a fixed total supply. In this case we must deal with a separate price flexibility for each grade. It is, of course, necessary to determine whether the price function for each grade can be defined in terms of supply of that grade only or whether it is also necessary to take account of cross effects (that is, interactions from other grades). Assuming for the moment that such cross effects can be ignored, the change in total revenue will be positive when quality increases (that is, the quality mix is upgraded) if the ratio $\frac{P_A}{P_B}$ is less than the ratio of $\frac{1 - |F_B|}{1 - |F_A|}$ where F_A, the price flexibility of demand for Grade A, is assumed to be greater than one. If this condition is not satisfied the change in total revenue will be negative. If the cross effects are included the relationship becomes more complex.

We have also assumed that the change in supply is affected only by producers who are already producing the product. In fact, supply may also increase because new producers enter the market. This could result in the following way: At any point in time there are farms earning different rates of profit either because they are being operated at different levels of efficiency or because their quality of inputs (such as land) differ. Furthermore, the rate of profit earned by a farm is not certain but rather varies randomly from one period to the next as a result of variations in output, price, etc. For some given amount of uncertainty we can draw a schedule relating the number of farms to the marginal expected (or average) rate of return ($MERR_0$):



As we increase the number of farms we are adding farms with a lower level of efficiency or lower quality of inputs. Thus, the expected rate of return on each additional farm is smaller. There is some minimum expected rate of return r_0 necessary to keep the farm in production and it is this rate in conjunction with the schedule that determines the actual number of farms N_0 and as a result the amount of output. It is quite likely that this minimum expected rate of return depends upon the amount of uncertainty and that the lower the amount of uncertainty the lower the expected rate of return required to induce farms into production. If the variance of output (and price) is reduced by better weather information, even if the average rate of return schedule is unaffected, we might expect the minimum expected rate of return will fall to r_1 and the number of farms and thus supply will increase. Alternatively, it may be the case that weather information increases the average return on all farms. That is, the schedule in Figure 1 shifts upwards (to $MERR_1$) and the number of farms making greater than the minimum expected return r_0 increases. This also leads to an increase in supply.

The initial increase in supply is basically a short-run consequence of the improved weather forecasting. Whether the supply will remain higher in the long run also depends on the size of the reduction in production costs identified by the case studies and the shifts in resource allocation which are a consequence of this reduction. In the simple case where supply expands and net revenue declines, we expect that the marginal producers will operate at a loss and in the long run leave the industry. Alternatively, these resources will be shifted into the production of other crops. However, if the increased supply is accompanied by reduced costs of production the marginal producers may still be able to make sufficient profits; in fact, if costs decline significantly relative to the decline in revenues new producers may actually enter the market, thus increasing supply even further. This represents a shift in the allocation of resources from that which would have existed in the absence of the weather forecasts.

Resources would also be reallocated if it became relatively more profitable to produce in a particular geographical area. Such a situation may occur in the production of lettuce in eastern states. For lettuce produced in the eastern part of the country, predicting supply is difficult because of the weather. However, if better weather knowledge enables better predictions, so that eastern producers are able to enter the seven-day market to a greater extent than presently, the effect may be less reliance on western suppliers (whose lettuce is more expensive because of transportation costs). We would thus expect lettuce production in eastern states to increase and the demand for western lettuce to decline (other things being equal).

A reallocation of resources similar to this might also occur amongst different crops produced within the same region. It is usually true that a producer has the opportunity to produce a variety of alternative crops on his land. His particular choice will depend on what his land is best suited for given the methods of production available for each type of crop and also his expectation of the price of that crop. Now if long-term weather forecasts cause differential changes in the costs of production or if the changes in supply affect the relative prices of the different crops, it may become profitable for the farmer to produce a crop other than the one he had been producing. We should note that if many producers make this type of adjustment supplies would be affected.

The conclusions we can draw from our analysis of market interactions and resource reallocation are not nearly as specific and definite as would be desired. However, we can make some general statements about the benefits resulting from improved weather forecasts. The fact that resources can be utilized more efficiently means that there will be a net social benefit. While the quantitative studies indicate that this benefit will be significant, they have not considered its distribution among various groups in the economy. When we estimate the benefit to the individual producer, assuming that all other things are unchanged, we conclude that the benefit will accrue to that individual producer. However, if all producers are utilizing the weather information within a competitive framework the benefit may be transferred to the consumer. In fact, under certain conditions the result may be a situation in which the producer is worse off with the weather forecasts than without them; however, while he loses others will gain. In such a situation we face the difficult problem of comparing the gains of some with the losses of others.

A CASE STUDY TO DETERMINE THE NATURE OF THE IMPACT ON HORTICULTURAL CROPS RESULTING FROM RECENT ADVANCES IN SATELLITE METEOROLOGY

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N. A. Meier*

The purpose of this study was to determine the nature of the economic impact that more accurate and longer range weather predictions would have on the producers and processors of horticultural crops. All aspects of horticulture are discussed, including landscape plants, fruits, flowers, and vegetables. The crops discussed are the following: fresh vegetables—lettuce and potatoes; processing vegetables—tomatoes, snap beans and cucumbers; fruits—cranberries and apples; ornamental crops—woody trees and shrubs and cut flowers. The weather conditions influencing each crop at different stages of development have been outlined, along with the measures that would be taken to avoid losses if accurate weather predictions were available. Information was gathered through meetings with staff members of several universities and with growers and processors who are directly involved with the production and marketing of the crops.

The four weather parameters found to be of most importance to horticulturalists are: temperature, moisture, wind and cloudiness. The important factors

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of temperature are level, fluctuations, duration, and exact timing of changes. The aspects of moisture that are important are timing, amount expected and in what form, and the duration of the wet or dry condition. Predictions of the time and the velocity of winds are very important. The important aspects of cloudiness are the time of arrival and departure, and the intensity of the cloud cover. The most significant uses of the type of weather information that could be obtained by satellites are in the scheduling of the use of labor and machines, protection against natural hazard, and determining the most efficient use of pesticides, including estimating the progression of a disease or insect population. Overall, with better weather prediction we would expect greater efficiency of operation, stabilization of supplies and prices to the consumer.

I. Introduction

Weather information is and will continue to be of major concern in the production of horticultural crops due to the extreme perishability of many crops and because the potential yield and quality of certain crops is largely dependent upon the weather. Weather information is one of the ingredients in the mix from which operating decisions are drawn that affect two important aspects of the horticulture industry: efficiency of operation and stabilization of production. The purpose of this case study was to determine the nature of the economic impact which would result if more accurate and longer range weather predictions were made available to the producers and processors of horticultural crops.

Throughout the country, growers monitor the available sources of weather information from radio, television, newspapers, and nature itself to develop the best possible analysis of present and future conditions. The need by horticultural industries for precise weather information has been recognized by ESSA. At the present time, special forecasting programs for fruit crops are being provided by the ESSA during critical frost periods in Florida, Wisconsin, California, Oregon, and Washington, and extensive general forecasting programs have been established in several states throughout the country.

To meet the objectives of this study, the growing and marketing operations for selected horticultural crops were studied to identify and discuss those operations that were influenced by certain weather phenomena at critical times in the growing cycle. Information was obtained both from university staff members of several institutions who have special knowledge of particular crops, and from growers and processors who are directly involved with the production and marketing of the specific crops. The individual meetings were informal to encourage a free exchange of thoughts and ideas.

The crops selected for discussion were: lettuce and potatoes—fresh vegetables; tomatoes, snap beans, cucumbers—processing vegetables; cranberries, apples—fruit crops; woody shrubs and cut flowers—ornamental crops. The crops were selected on the basis of one or both of the following criteria; their value to the economy of the U. S. and their particular uniqueness of being especially dependent upon certain weather parameters.

II. Ornamental Horticulture

The esthetic use of plants is a unique feature of horticulture, distinguishing it from other agricultural activities. In the United States ornamental horticulture is undergoing a renaissance brought about by an increased standard of living coincidental with the development of suburban living. Also contributing to the expansion of the industry is the national request for beautification of our highways, parks, schools, recreational areas, and industrial sites. There are two major areas in ornamental horticulture—(1) floriculture which pertains to the production of herbaceous flowering plants; and (2) woody ornamental culture which refers to the production of woody plants including trees, shrubs, and vines. Improved weather predictions concerning day-to-day conditions and regarding long range conditions are needed in floriculture because of the high value and high perishability of the many species involved. Such predictions are needed in woody ornamental culture due to the high seasonality of the work.

Most nurserymen are dependent upon the weather during all seasons of the year for the production of their crop which has a national value of $300 million. The discussion of crop production in nurseries will proceed from spring through winter. The management at the McKay Nursery Company of Waterloo, Wisconsin was the source for most of the information about landscape plants. The nursery, which is the largest in Wisconsin with over 700 acres of landscape plants, sells to wholesalers, retailers, and directly to the public through its own landscape architects and salesmen. Most nurseries in the northern part of the United States experience a six to eight week peak production period in the spring in which up to 75% of the gross volume of business is transacted. This occurs because most woody ornamentals are transplanted in the spring before the onset of leaf-bud expansion so that they will have the best chance of establishment and continued survival. Plants set out in late summer and fall have less well established root systems and thus are more susceptible to dessication and death during the winter. In addition to the sale of plants during this spring period some transplanting, weeding and application of pesticides to the rest of the stock has to be performed. Accurate long range weather predictions of ten days to two weeks would be of tremendous benefit in two main areas during this peak production period. The first is the determination of the labor procurement needs and the second is the estimation of when to stop taking sales orders.

The labor force used by many nurseries is obtained from Texas and the individuals must be informed by the middle of March when to come up North. Usually April 1st is set as the arrival date but the exact date is dictated by soil conditions, i.e. thawing and dryness of the soil to permit digging. Often in the past, the labor arrival has not coincided with the optimum time for starting field work and the workers either could have started earlier or the workers had to sit idle for several days. The latter is especially undesirable from the employer's viewpoint because he usually has to supply the employees with some minimum funds for sustenance which are not equal to a working wage and the employees are not content at the very start. Furthermore, if the two-week prediction in mid-March shows that there will be a late spring, then the nurserymen would likely ask for more laborers.

May 15 usually marks the end of the peak season for nurserymen. Most growers have a several-weeks backlog in orders by mid-April and they need to know how many fair weather workdays there will be between then and approximately May 15 in order to know if they can take any more orders. At present they look at previous years' weather records to get an estimate of an average number of good days remaining. With a longer range prediction they would have a more accurate estimate.

Accurate short and long range predictions for freezing temperatures are also greatly needed in the spring so tender plant parts can be protected. For example, new growth of spruce and fir seedlings is susceptible to late spring frosts. Most nurseries are equipped to protect these seedlings with solid set irrigation but a forewarning of at least one day is needed to allow sufficient time to check the equipment before the frost. For another example, bare roots are damaged if exposed to freezing temperatures. The handling of bare rooted stocks must be postponed until warmer weather arrives or arrangements have to be made to protect the roots by such means as balling, which is digging balls of soil along with the roots of the plant which are then wrapped in burlap. Or, management could change to regularly dig balled and burlapped plant materials.

More accurate short and long range rain predictions would also be of benefit for scheduling work during the peak spring period. One example is a nursery that has certain orders to fill by a certain date but is block digging and plans to fill later orders. If it received a long range prediction for rain that would prevent their filling the later orders they could change from block digging to digging to fill the specific orders before the rain. Another example is a nursery that has carefully selected a particular field where it wants to plant out its most valuable shade tree whips. It is preferable to have the soil prepared just before planting to get maximum weed control while maintaining good soil structure. Prediction of a rain would allow them to stop tilling and plant trees on all land that had been tilled. On the other hand, predictions of dry periods and hot dry winds would probably result in certain stocks being left in storage until more favorable weather arrives. Five years ago the McKay Nursery lost their entire inventory of new arborvitae because they set it out in late May just at the beginning of a dry period. They had no means to irrigate the plantings. This year they have very few arborvitae to sell because of it. These are just a few of the many specific ways in which weather predictions can be an aid to the nurseryman during the spring.

Many nurseries do not have enough work after the spring rush to keep the large labor crews. Long range weather predictions are needed by the management so they can tell the crew chiefs approximately when the work will be completed so these leaders can make arrangements for their crews to work in some other area. This little help to the crews may mean that a nurseryman can expect the same crew back the following year. However, the nurseries will need occasional help throughout the summer for weeding. Often this labor can be obtained from neighboring farms or vegetable processing plants. Good weather predictions could be used so arrangements are made to avoid procurement of labor over a rainy day. Other than for scheduling labor for these short periods, weather predictions would not be needed in the summer except to help control a few pests. Wind predictions for spraying may be of benefit as would predicting for conditions conducive to the buildup of certain insects diseases so that precautions could be taken to avoid damaging infestations.

In fall, activity in nurseries increases and scheduling of work is again important and dependent upon weather. Many species are grafted onto hardier rootstocks, and this is most easily done in storage in the winter. The plants for grafting must be dug in the fall. Also, many woody ornamental plants that will be sold the following spring as bare rooted material are dug the preceding fall and stored. The problem arises from the fact that the trees should be left in the field as late as possible so they will have natural leafdrop. Defoliation can be completed in storage but the process is costly and can increase losses during storage. Accurate day-to-day frost predictions would be an aid in determining when early, temporary frost will leave the ground and normal digging can resume, and when to have the workers available. Long range predictions would be of particular importance to indicate when the ground will freeze and not thaw again, and how many working days are left until then. Often nurserymen will work overtime several weeks in a row to get the fall work completed and then have some good weather left. Had the good weather been predicted, the extra expense of paying overtime could have been avoided and the employees would have been happier with a few more weekends off.

Winter weather predictions are important to many nurseries for primarily two reasons. First, most of the large trees are transplanted at this time. In early winter the prospective tree sites and the soil around the trees in the nursery have to be insulated against freezing. If a heavy snow were predicted, however, the insulating may not have to be done. During the winter the holes are dug one or two days in advance of the actual transplanting and the trees are loosened at the nursery. If very cold weather, say 0°F., were predicted, only as many holes would be dug and trees loosened as could be completely transplanted before the cold. An open hole and loosened tree would freeze solid with low temperatures and completion of the job would possibly have to wait until spring. When transplanting large trees, it is also important to know whether or not the surface of the soil or turf is thawed, and whether it may become thawed later in the day. Plywood sheets can be taken along to prevent damage by machinery to a thawed lawn. This becomes increasingly important in early spring. The second area where winter weather predictions, especially long range ones, are of interest to nurserymen is planning of sales trips. A large number of sales are made in the months of January and February, two months with numerous snow storms and icy highways that can upset travel plans. With accurate predictions, salesmen can set up meetings with much more assurance of fulfilling appointments with wholesale distributors and other large volume buyers.

For a table summary of woody ornamental culture, see Table 1.

III. Floriculture

Floriculture, the other major area in ornamental horticulture, is also very dependent upon weather. The industry can be divided into two main areas. One area includes flowers grown for sale for planting into gardens, termed bedding plants, and the other includes those materials grown for sale as cut flowers, potted flowers, and other potted plants.

Most of the sales of bedding plants are sold on a retail level by garden centers. Other supplies carried by these centers are vegetable transplants, seeds, bulbs, fertilizers, gardening equipment, and so forth. Weather predictions of one or two weeks could be used by these centers for predicting when they will need to hire additional personnel to serve the influx of customers on the fair weather weekends. These merchants could also more wisely plan their open houses and specials so they will fall on those favorable weekends when people will most be thinking about the needs of their yards. These centers could use the predictions to provide better customer service by being able to tell the customers when it is safe to set out their plants and avoid the frosts.

The cut flower potted plant industry is nationwide and the flowers and plants in any one floral shop are probably from sources across the nation. One large source of flowers and plants is greenhouses, and several plant growing problems could be partially overcome with more accurate short and long range weather predictions. Light is very important to bring plants to flower at the right period before specific holidays, with the ten-day period immediately before the holidays being especially important in greenhouse production. Two possibilities exist to overcome an extended cloudy condition if one could be predicted. One is to increase the head to speed flowering, but this results in a decline in quality. The other alternative is to supply supplemental lighting thereby keeping up the quality, but this is costly. However, with accurate predictions for cloudy weather, the chance of lower quality or the probability of a higher cost would be undertaken rather than have a crop bloom after the holiday. By missing one or two major sales periods, a greenhouse grower may lose a market completely to the competition. High light intensities are especially necessary for crops as roses, lilies, and poinsettia for flowering and development.

Just as it is necessary to raise the temperature in greenhouses for flower growth, particularly in winter, it is also necessary to lower the temperature at times, especially in summer. For example, one large midwestern grower and wholesaler air conditions two acres of roses from June 15 to September using the airflow over wet pad system. But in 1968 they lost 30,000 to 40,000 roses of a 100,000 rose crop for Mother's Day in May because they bloomed too early. They had three days of temperatures 85°F and higher a short time before the holiday that forced the bloom and they did not have their air conditioner in operation. If the high temperatures had been forecast a week prior, they would have had enough time to install their cooling system and prevent the loss.

Predictions for frosts and sudden drops in temperature in the fall are important to growers that have crops still in the field. Azaleas, hydrangeas, and Christmas cherries need to be out of doors as late in the fall as possible because they need the short days and cool nights for maximum quality plants. As an example, one grower lost his entire azalea crop in 1965 when the temperature dropped from 80°F to 38°F in one day. Since then he grows the entire crop under glass which is considerably more expensive. However, with accurate ten-day predictions he would grow them out of doors once again because he would have time to move them indoors before frosts. Gladiola bulb growers could make good use of predictions for good drying conditions in the fall. The bulbs are best left in the field a day or two after digging to allow them to dry so they will keep better.

Many of the cut flowers and potted plants for the retail trade must be obtained from other parts of the country. Accurate short and long range weather predictions would be of tremendous help both to the grower and to the buyer. For example, one large Milwaukee wholesaler annually buys over 500,000

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carnations from one grower in Colorado. In 1967 this western grower could fill only a portion of the order due to extensive frost damage suffered one night. If the grower had sufficient notice he could have supplied heat because the flowers were already under plastic. Or, if the buyer had some forewarning, he could have quickly tried to pick up some carnations from growers in different areas thereby assuring himself of an adequate supply. Ten days to two weeks is sufficient time for the buyer to change his orders. Some California growers have as much trouble with excessive rain as with frost and the predictions of such natural hazards would again allow the buyer to shift his orders to other unaffected areas so that he will have a steady supply of flowers for his retail customers.

Accurate weather predictions would be an aid in performing all production activities for flowers grown out of doors. The main aid to the growers in the large cut flower region in Florida would be the prediction of hurricanes and near freezing and freezing temperatures. One of the main crops there is chrysanthemums which could be harvested earlier than normal or protected by plastic or foam similar to that used on tomatoes. There is also the correct planning of a spray schedule that combats the numerous diseases and insects which cause considerable damage under certain weather conditions. A more detailed explanation of how a spray schedule can be made more effective and efficient will follow later in this paper. Another aspect that Florida growers must consider is the degree of protection for the flowers during transportation to the market. They must determine how well to insulate the individual cartons of flowers and whether to use the more costly insulated and heated trailers. Accurate predictions of the weather in the various regions the trucks will pass through as well as predictions of the weather at the time and place of arrival are important. At present, all shipments in the winter are given the maximum amount of protection but many times the precautions are unnecessary. Another plan could be to delay the shipment for a day or two if more favorable weather is predicted. Winter shipments of cut flowers from California and Colorado are made mostly by air freight and the general weather at the point of destination usually determines the amount of insulation in the individual cartons. Here also, all shipments in winter are well insulated because weather predictions have not been accurate enough and the airlines do not always take proper precautions against freezing once the shipment arrives. Through the use of more accurate weather predictions money could be saved on insulating costs.

The overall effect of more accurate short and long range weather predictions would be a more steady flow of flowers throughout the year with a stabilization of prices and a better chance for adequate profits for the grower, wholesaler, and retailer through greater efficiency in operations.

For a table summary of floriculture, see Table 2.

IV. Fruits

The production of fruits for fresh and processed use is also an expanding industry. As people become more affluent, they spend more of their food budget on fruits, especially on fresh fruits. The per-capita consumption of fresh fruits is the highest it has ever been. For the purposes of this report, the fruits will be divided into two groups and discussed. The first will be the small fruits, referring to those fruits borne on plants close to the ground such as strawberries, raspberries, cranberries, and grapes. Of these, cranberries will be discussed because they are particularly subject to severe damage by unfavorable weather in their growing sites. The second group is tree fruits, which are borne on trees and include such crops as apples, citrus, cherries, and peaches. This report will emphasize apples, one of the major fruit crops of the country, and a crop for which special forecasting information has been provided for many years.

Cranberries are a high value per acre crop with a 1967 national average value of over $1000 per acre, a crop values at $21.9 million from 21,120 acres. Wisconsin supplies one-third of the cranberries for the country. The crop will be followed through a normal year's sequence of events, with particular attention paid to those aspects influenced directly by weather and to which weather predictions would be most beneficial.

Cranberry bogs are flooded during the winter to prevent dessication of the plants. Spring removal of the floodwater should be timed so that there will be no hard freezes afterward. However, if the temperatures rise and warm the water, the bogs must be drained to avoid oxygen deficiency around the plants. Accurate two-week weather predictions would aid in determining when flood waters should be removed or replaced if a severe freeze is imminent.

New plantings are made in the spring. Pieces of stem are inserted partially into the ground. For the best survival the humidity needs to be high to reduce transpiration (water loss) until the cuttings root. Weather predictions would be useful here to schedule plantings before rains or, if no rain was forecast, the grower would set his overhead irrigation system up. On the other hand, plantings before heavy rains should be avoided since the excessive water may damage the new plantings.

The most serious threat to cranberry production is the late spring growing season frosts and freezes which kill buds, new growth, blossoms, and berries. In the cranberry bogs, frosts may occur every month of the year. On the average, frost protection is required twenty times from May 1 to June 30, when the plant and flower are most susceptible, and several more times from August 15 to November 1 as the fruit is maturing.

Frosts in cranberry fields are a serious hazard because cranberries are grown in low-lying marshy areas that encourage the accumulation of cold air on clear, cold nights. The damage from frost is prevented by flooding the bogs with water to provide a covering of water at the base of the plants. The water acts as an effective conductor of heat from the water itself and the soil to increase the temperature of the microclimate around the vines and prevent damage. Flooding of a bog takes from five to eight hours since all primary and secondary ditches need to be filled. To further complicate matters, the bog must be drained every day when bright sunny days prevail to prevent damage to the plants from the lack of oxygen in the water. Thus, more accurate short term frost predictions are needed to prevent unnecessary flooding of the bogs. With some growers, more accurate long range predictions are needed to determine when to divert water from the Wisconsin River to the ditches surrounding the bogs. The growers are charged for the water by the owners of the hydroelectric and storage dams on the river. Sprinkler irrigation is also used as a method of frost protection on 70% of the Wisconsin cranberry acreage. The principle involved in this frost protection is that the change in state from water to ice results in the release of energy, the latent heat of fusion. Consequently, its temperatures do not drop below 20°F.; the formation of ice, or the occurrence of a white frost actually protects vegetation from the freezing air temperatures. Protection by sprinkler irrigation requires far less water and less labor input than does the flooding procedure.

At present a special weather forecaster is employed in Wisconsin to make temperature predictions for cranberries with forecasts made at noon and at 6:00 P.M. If there is any change after 6:00 P.M., key growers are telephoned. The one problem with the system is that there is a four-to six-hour lag in the forecasts.

Accurate hail predictions could be used by cranberry growers because they can flood their bogs for good protection. Hail is especially damaging to developing buds and flowers. However, a grower stated that he could not afford to flood unless there was at least a predicted 80% chance of hail three to five hours in advance because there is too much damage to the plants in the flooding. Currently it is not possible to make such accurate predictions.

Cranberries flower from June 25 to July 15, and are pollinated on warm, sunny days when pollen is readily shed. Many days do not have such ideal conditions for pollination and therefore hives of bees are commonly moved into the bogs to increase pollination. Accurate weather predictions would be a definite aid to growers for notification of the bee keepers to tell them when and how many hives are needed. Any one flower is only open for a limited period so a delay in getting bees could result in a loss of a percentage of the total yield potential.

The application of pesticides could also be altered according to the weather predictions. Fertilizer applications are often made by airplane and the best time to apply would be just before a light rain which would wash the material off the foliage and into the ground. It is also desirable to avoid applying such chemicals before an extended dry spell where the chemicals would not be active. In contrast to this, insecticides and fungicides should not be applied before any rain because rain would wash the chemicals from the foliage where they are needed to be effective. Two important insect pests of cranberries are the cranberry fruitworm which bores into the fruit and the cranberry fire worm which feeds on the foliage, and on the fruit in the second brood. The adults of these insects are moths which, on warm nights, fly and lay eggs which hatch ten to fourteen days later. Control includes trying to eradicate the adult during its flight and also the young just after hatching. Predictions of the night temperatures would allow growers time to get prepared ant to spray at a time when the most moths are in the air. The growers could also predict when the eggs would be hatching and could plan treatments to control the young effectively.

Cranberries, being a cool season crop, will be restricted in growth when air temperatures around the vines rise to near 100°F. Sprinkler and flood irrigation lower the temperature through evaporation. Accurate predictions of such high temperatures would allow the grower to irrigate his crop ahead thereby lessening the possibility of heat stress. Predictions of rainfall could enable the growers to avoid costly irrigations.

Weather predictions would also be of benefit in the fall at harvest time. The longer the fruit is left on the plant, the better the color and development and in some cases the keeping ability. The fresh and processed markets place a premium on these qualities. Therefore, it may be desirable for the grower to delay the harvest. Accurate two-week weather predictions would allow the grower to adjust his harvest schedule, slowing down and allowing the crop to improve in quality or speeding up and finishing before the hard freezes arrive.

In mid-December, growers gradually build a layer of ice on their bogs. The ice acts somewhat as insulation but more important, it slows dessication of the plants. One problem that arose in Wisconsin in 1968 was that heavy snows fell before the protective ice sheet was laid down preventing the growers from forming sufficient ice and some damage to the beds resulted. With an accurate weather prediction, the bogs could have been flooded ahead of the snow so the snow would have melted in the water. The marshes could then have been drained and the layers of ice properly laid down when cold weather arrived. The prediction of prolonged very cold weather is important so the bogs can be iced over just before the very cold weather.

Apples are a major fruit in the U. S. with a production of 119 million bushels or 5,403 million pounds in 1968. In 1967, the 120 million bushel crop had a value of $304 million.

One of the major natural hazards to apples, where accurate weather predictions would be of benefit, is freezing temperatures just before and during blossoming. The tender buds and blossoms and very young fruit are easily killed or damaged at temperatures a few degrees below 32°F. A most common means of frost protection is heating pots spaced throughout the orchard. Protection below 28°F is common and under the proper conditions crops are saved with the temperatures in the low twenties. Experience shows that the fires must be well distributed in the orchard, a minimum of about forty per acre and a maximum of about 150 depending upon the predicted temperature. A few hours warning of frosts is desired for help must be obtained to light the heaters and instruct the people when to arrive for firing. The heaters must be started before the freezing temperatures are reached, but can be stopped if there is a sudden change toward warming. Thus growers are constantly monitoring weather information during cold nights to determine both when to start firing and when to cease firing. They would utilize precise information at fifteen-minute intervals. Three- to four-day predictions of freezing temperatures are also of considerable value, especially if frosts are forecast for several days in a row. Both fuel and personnel to light the fires must be on hand. An extended cold period causes problems to the suppliers of fuel for storage supplies may not be adequate. The apple growers in Washington and Oregon utilize both minimum temperature forecasts and dew point temperature forecasts because the amount of heating required is a result of the minimum temperature and dryness of the air. Dew point temperatures of 10°F to 20°F are particularly difficult to protect against. Some growers indicated a desire for temperature information forecasts for thirty feet and sixty feet above the surface during the freezing evenings in order that the height of temperature inversions could be determined. With warm air aloft, less heating would be required.

During the winter months, rapid temperature decreases to below -5° F cause serious injury to trunks and limbs of fruit trees in Washington and Oregon. Slow decreases in temperature over a week-or two-week period are rarely damaging because the trees "harden off." The sudden temperature changes are sometimes damaging to apples but the most frequent damage is to peach fruit buds. Accurate three-to five-day forecasts of these changes would permit growers to ready burners for raising the temperature in the orchards.

Apples are completely dependent upon insect pollination and honey bees are the primary pollinators. Weather predictions for temperature, rain, and wind during the season of pollination would be of the same benefits as those mentioned for cranberries.

Fruit thinning is another operation where weather has a direct effect and the prediction of weather would result in greater efficiency. Most apple varieties need to be thinned in order to obtain a commercially acceptable size. Presently, thinning is accomplished through the use of chemicals sprayed on the trees five to twenty days after blossom petals fall. Uniform coverage throughout the tree is very important so the wind needs to be as calm as possible. Also, the ideal temperature for the application is 70°F. At higher temperatures more of the fruit thinning chemical is absorbed and the rate of application must be reduced. At temperatures below 70°F, too little of the fruit thinner is absorbed and the rate of application must be increased. Also, the rate of application is dependent upon the occurrence of rain at one and two days following application and therefore, the rate of application is adjusted accordingly to the predicted possibility of future rain. Thus, forecasts of wind speeds, temperatures and rainfall are needed for fruit thinning operations.

The prediction of winds is becoming increasingly important for all pesticide spraying in orchards as more and more growers are turning to ultra-low volume spraying. With this method of spraying the amount of water mixed with the pesticide is much reduced. Adequate coverage is maintained by breaking the spray into very small droplets that are less apt to run off the foliage and the fruit. However, the maximum wind velocity allowed is ten m. p. h. for sprays and four m. p. h. for concentrate dusts. Accurate predictions for the different periods of the day are needed.

Apple trees, their foliage, and their fruit are attacked by several serious pests. One of the diseases is apple scab, which reduces the photosynthetic surface of the leaves as well as causing blemishes on mature fruit. Initial inoculum is almost always present at the beginning of the season for the scab fungus overwinters in fallen leaves. Spores are discharged when conditions are cool and moist. Rainy periods are necessary for infection as the apple leaves must be wet and dews usually do not provide enough water. Predictions for rainy and cool weather, especially as the foliage is coming out, would allow orchardmen to put on a protective coating of the proper fungicide. Currently, such protective sprays are applied regularly throughout the spring, but several of these applications could be avoided while maintaining adequate control of the disease. Apple scab forecasts are made in Great Britain and, with better predictions, could be made here.

The codling moth is the most serious insect pest of apples, causing most of the wormy fruit which is so familiar to everyone. Its control is closely linked to specific weather patterns. In most sections of the country, three to four sprays applied at ten-to fourteen-day intervals are recommended for control of the first brood larvae. The applications should begin ten to fourteen days after petal fall. With accurate weather predictions the adults might also be controlled because the moths are active mainly on warm nights. A spray just prior to, or on such nights would be effective

Semidormant sprays, applied for insect and disease control in early spring, are not effective if the temperature drops below 20°F within forty-eight hours after application. Thus, two-day temperature forecasts are utilized with this spraying operation.

Dr. Stanley Hoyt, of the Tree Fruit Research Center at Wenatchee, Washington, is developing an integrated insect control program that has already saved Washington apple and pear growers several million dollars in reduced chemical and application costs by advising the growers of the exact time when particular insects are present in large enough numbers to do economic damage. The crux of the program is the blending of biological and chemical control such that the natural predators are protected whenever possible. The grower must know what chemical materials to use, what materials to avoid, and when to spray in order to conserve the pest's predators. The weather usually determines the status of the pest in relation to its predator and when the pests will become economically destructive. Accurate weather predictions will put real teeth into the program and would enhance the possibility of using the program nationwide on many crops besides fruit.

Prediction of high winds at harvest time would benefit the grower in two main ways. First, it would enable him to make a concerted drive to pick those varieties that are easily bruised, that swing and hit against branches or other apples and those varieties that drop from the trees easily. Secondly, it would enable him to apply hormonal sprays to prevent natural abscission on those apples that he would not be able to pick and would likely drop in the wind. The application of the preharvest hormonal sprays is a common practice on certain varieties, particularly Red Delicious, but it could be more effectively timed and used only when necessary on other varieties. Winds of fifteen m.p.h. and more cause apple dropping.

See Table 3 for a summary of fruits.

V. Fresh Vegetables

Wisconsin is the source of several fresh vegetables and the procedures involved in the production of these crops in the state are similar to those of most other vegetable-growing areas. Of the fresh vegetables, potatoes and lettuce are among the most valuable in the country with values of $600 million and $200 million, respectively, and so they will be discussed in detail.

Potatoes in Wisconsin are grown primarily with irrigation as they are in many potato-growing areas. Overhead irrigation systems are the primary source of water to the crop. Even though the soil is quite sandy and very well drained, accurate rain predictions are very important to the scheduling of field operations. At planting time, if rains are predicted, growers may go to two ten-hour shifts instead of one twelve-hour shift before the rains. Also, once it does rain, if good weather is predicted for several days, the grower may stay off the wet field an extra half-day waiting for better field conditions. Occasionally, the soil is dry at planting and the field is irrigated just before planting. With accurate rain predictions, decisions to irrigate or not could be made with more justification. Occasionally in late spring the soil becomes very dry and hard. At this time the grower may wait a day or two for a predicted rain before plowing, or, if no rain is predicted, he will irrigate before plowing.

The timing of the irrigations during the growing season is especially critical. It is most desirable to keep the plants growing at an optimum rate with as little stress as possible for maximum yield of No. 1 potatoes. Many of the irrigation systems used have a single moveable line. That is, the line moves across or around the field irrigating as it moves. Most of the fields are large with a single line irrigating up to 160 acres. This means that the systems must be started at least two days before the plants come under a moisture stress because it takes two days for the sprinkler to cover all areas of the field. With the older equipment, this time can be as long as four or five days before the system makes a complete revolution. If a good rain were predicted, the grower would not have irrigated this crop because it is costly to run the equipment not only from the point of fuel used and water costs, but also each pass with the system does some damage to the crop. Also, there have been several cases of excessive nitrogen-leaching from too much water. Furthermore, the grower would like to be able to stop his system in a position so that it does not interfere with other field operations such as cultivating and spraying. Many systems cannot be moved without irrigating because they depend on water pressure to supply the energy that propels the system. The extra water would cause excessive leaching as well as bog down the equipment. A rain prediction would allow the system to be stopped without a chance of the crop coming under a moisture stress.

A particular need for weather predictions is in planning disease control programs. Late blight of potatoes, Phytophthora infestans, is one of the most epidemic diseases of this crop, for it has terrific "explosive" and destructive power when weather is favorable, causing severe defoliation of the plant. There exists sufficient initial inoculum in most potato producing areas to start an epidemic. Epidemics are very likely to start after two or more weeks of wet weather. They develop most quickly when cool, wet nights alternate with warm, moist days, because the optimum temperature for germination of spores is approximately 54°F, and that for growth and sporulation is 72°F to 76°F. The incubation period is about two and one-half days at the optimum temperature and there is general agreement that the disease is checked abruptly at 79°F to 80°F with dry weather. The critical factors for epidemic development, then, are abundant moisture and temperatures alternating between cool and warm.

It has been found that there exists a cumulative effect under favorable conditions that can be used to predict blight activity. Nineteen hours of 90% relative humidity at 60°F to 77°F has resulted in moderate to heavy late blight infections whereas twelve hours under the same conditions resulted in only a light infection. As potatoes have a fairly long growing period and are susceptible during the entire vegetative period, there is danger of epidemics wherever and whenever weather is favorable. At the present, growers commonly spray on seven-to ten-day intervals but reduce this to five-day intervals when conditions are conducive to blight spread. The biggest problem has been getting out the forecast of blight conditions early enough. With improved weather predictions, the blight conditions could be determined sooner and with more reliability so that the information could be forwarded to the grower before the disease becomes epidemic in proportions. This may result in fewer sprays being required.

The prediction of winds and rains would permit more efficient pesticide applications. The wind cannot be above ten m. p. h. for good spraying from airplanes. Also it is most desirable to let the spray materials set on the foliage for six to eight hours before a rain so they will have time to become fixed and less likely to be washed off.

Rain predictions are also important at harvest time. Many of the early potatoes are packaged and shipped right from the farmer's packing sheds. If rain were predicted, the harvesting crews could dig ahead so the packing crews would not have to stop. Harvesting ahead is not desirable from a quality standpoint because the skins of new potatoes are easily bruised and do not keep well. With the accurate rain prediction the grower would sacrifice the loss in quality to keep the packaging crews working. In late fall the important weather factor is severe freezing before completion of harvesting of the late potatoes. The late potatoes are mostly stored, so they should remain in the ground as long as possible to develop tough skins. Most harvesting operations continue seven days a week, until the crop is in. Often towards the end of the season a day or two off on a fair weather day is appreciated by the labor. However, the grower will not stop for fear of freezing weather. With precise predictions, harvesting time could be known so that a day could be taken off when there was sufficient warm weather expected so that the crop could be all harvested. And conversely, if predictions were for hard freezes that would reach the tubers, the grower could harvest as much of his crop as possible even if it meant hiring additional workers.

For successful lettuce operations, it is necessary to have a steady supply at harvest; therefore, the plantings are staggered in the spring and early summer to provide a continuous harvest. Conditions for rapid and uniform emergence are most desirable to insure the steady supply. The prediction of quick storms or sudden heat is very important to the planting schedule. Moisture is kept fairly constant in the organic soils by the raising and lowering of the water table through extensive ditch systems. Several lettuce growers use overhead irrigation to insure uniform emergence but if there were a more accurate prediction for rain they would not irrigate for fear that the rain on the near saturated soil would reduce emergence of the seeds. If high winds were predicted growers would irrigate to moisten the surface of the soil to keep it from blowing and damaging the seedlings.

In May and June the first major insect pest arrives—leaf hoppers. They are the carriers of a virus causing aster yellows and migrate into the state each spring and summer, bringing infestations of the disease with them. If aster yellows appears early in a lettuce planting, no heads will develop. In some areas, such as in Wisconsin, Michigan, and New York, this is potentially the most destructive disease of lettuce. Dr. Keith Chapman of the Entomology

Department at the University of Wisconsin has been following the movements of the leaf hoppers for several years and provides the growers of Wisconsin with an approximate date of arrival so they can be prepared to spray for control. He has found that the insects originate in the Ozarks and the grain areas of Arkansas and Missouri. They will move in any air above 60°F as fast as that air air moves and in the direction that it moves. In one case leaf hoppers moved from northern Missouri to northern Wisconsin in only two days. Currently, Dr. Chapman leads a team of entomologists south along the Mississippi River in mid-April. When the team reaches the first hoppers, it turns west and cuts across the mass of leaf hoppers taking samples to ascertain the numbers and to test for virulence. The prediction of wind patterns would be of particular benefit when estimating where the masses of leaf hoppers will move and how fast. Occasionally June wind patterns appear for a few days in mid-April to May and this is sufficient time to bring in large numbers of leaf hoppers. Leaf hopper control provides the only control measure against infection and spread of the virus causing aster yellows.

Among the fungal diseases of lettuce is downy mildew which can become serious in damp, cloudy weather. One grower applies a fungicide with every spray but insists that if damp, cloudy weather were more accurately predicted, he would put on a higher rate, or if warm, dry, sunny weather were predicted he would apply a lower rate or none at all. The result would be more efficient use of the fungicide.

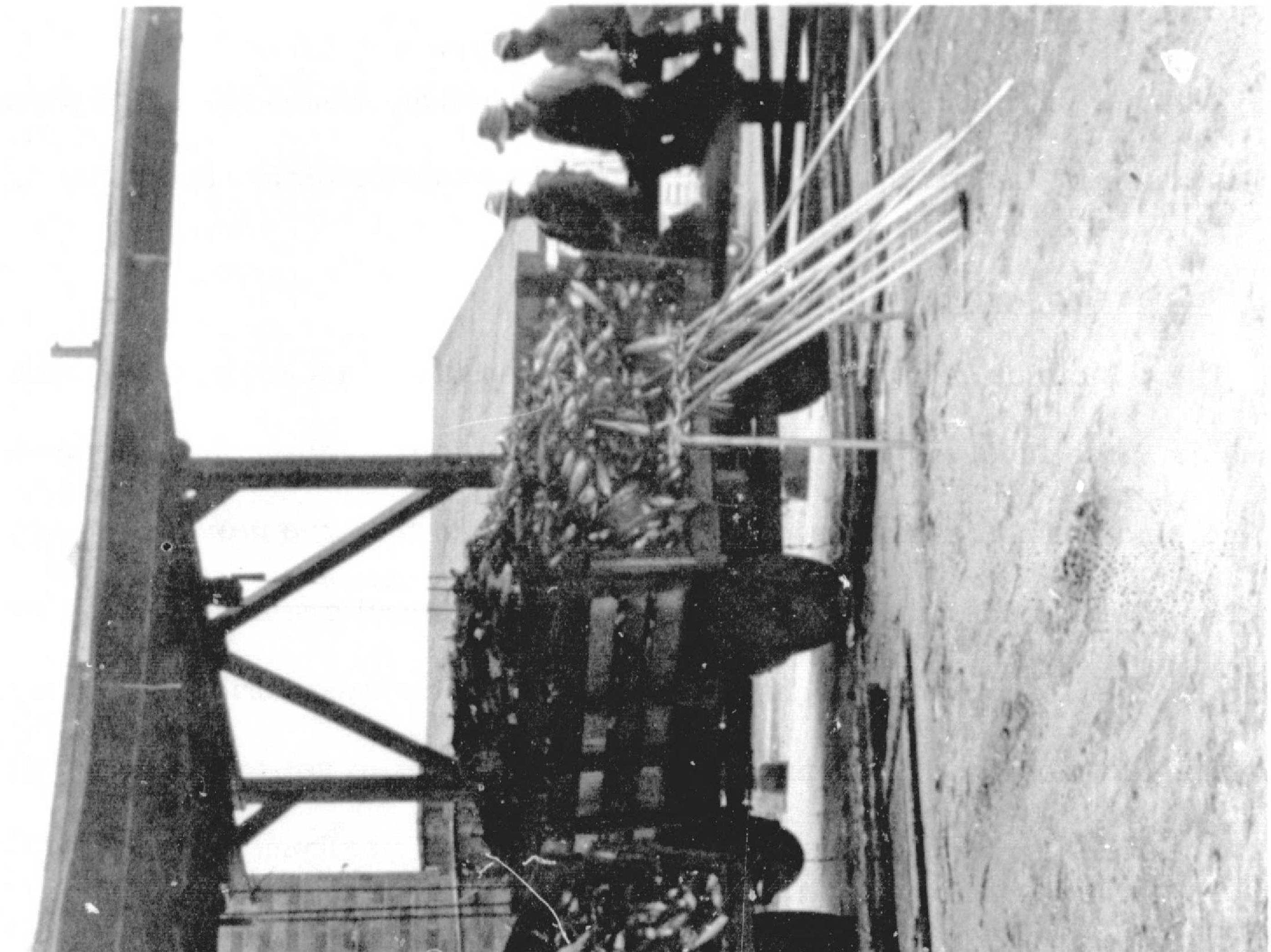
The prediction of wind velocity would be an aid in determining the spray schedule for both ground and airplane application methods for reasons of preventing excessive spray drift. In addition, soil in lettuce heads which causes lower quality is caused by high winds and dry soil. Predictions of these high winds would allow the grower time to moisten the soil surface. Wind direction and speed is helpful to know in setting up overhead irrigation equipment when just moistening the soil surface. Irrigation lines could be set further apart taking advantage of the wind. With a thirty m. p. h. wind, laterals that are usually set ninety feet apart could be set 180 feet apart, thereby doubling the area covered.

Accurate short- and long-range weather predictions have numerous applications during the harvest of the lettuce crop. The single most important area in which accurate weather forecasts of from one to two weeks would be beneficial to eastern U. S. lettuce growers is in predicting sales. Presently, the eastern growers book only a small amount for the seven-day advance sales that are competitive with lettuce from California and 80% of the lettuce is booked only a day or two, at the most, in advance of harvest. Accurate long-range temperature and rainfall forecasts would enable the growers to estimate yields and date of harvest of a field more precisely. This would allow them to be more competitive with California sales and make a greater share of their bookings a week in advance. Accurate short term predictions of freezes and/or rain would enable fields to be harvested ahead of the unfavorable weather so previously-made bookings could be filled. At the same time the growers keep an eye on the market because if they can wait an extra day with the price holding up they usually get 10% to 20% more production. There are gray areas in every operation and the more accurate and longer range weather predictions would help separate the gray areas into black and white areas.

Weather predictions, both short- and long-range, would be very important tools to use in the production of most of our fresh vegetables. See Table 4.

VI. Processing Vegetables

The principles involved in processing vegetable crops are generally the same as those involved in the processing of all crops. Much of the concern is for meeting the processing requirements rather than the crop growing requirements. The major requirement is efficient scheduling of operations. The vegetable processing industry is characterized by a harvesting period that is relatively short, seldom exceeding four months. In order to get the maximum use of the facilities, processing plants need to be run a maximum of hours per day, seven days per week, continuously for the four months. The processing firm has to be concerned with scheduling the arrival of the laborers for the plant. This is usually a mixture of local labor plus considerable numbers of migrant labor. The timing of this migrant labor's arrival is significant to the processor and to the laborer. At present, the processor has to use an educated guess and usually has the workers arrive several days early just in case the weather changes and the crop is early. Most processors provide the food for the workers at this time and some provide a guaranteed minimum wage. This is costly to the processor. This usually is discouraging to the employees as well because they have nothing to do for several days. With more accurate long range weather predictions, the processor could more accurately assess when the crop will be mature and schedule the arrival of the labor closer to the time when they would



be needed. Necessary to efficient operations is the arrival of all supplies on time. In the spring the planting must be done on a precise schedule so the crop will mature at the right time. The field crews must have the necessary fertilizers, chemicals, machinery, and seed available to them. Seed shipment delays occasionally stop the planting. Most processors order seed shipments as late in spring as possible so they will not have to store it. However, in 1964, the Mississippi River was flooded leaving only a few railroad bridges usable, and this resulted in a backup on the west bank of railroad cars carrying seed shipments east. If the wet weather causing the flood had been predicted far enough in advance, most of the seed could have been shipped prior to the natural disaster. Among the materials that must be available at harvest time are the finished product containers. For example, can manufacturers closely watch the progress of a crop so they can have the right number of cans prepared for a particular crop at the time that crop is ready for harvest and not have a large surplus when the processing is completed?

Many vegetable crops have relatively narrow peak quality ranges and may become overmature in one to three days. Also, once harvested, many of the crops must be processed within a few hours or the quality will drop below acceptable standards. To provide a more steady flow of produce into the factory, the management could certainly use more accurate, longer range weather predictions. With one-week to ten-day weather prediction, management would have a much better idea of what order in which to harvest fields, and could plan for more convenient movement of harvesting machines from one area of production to another. Also, "glut" production periods could be predicted, and all the harvesting and processing operations could be speeded up in advance. All companies said that they would much prefer to harvest part of a crop on the immature side and take the lower yields because the quality would be high. Once a company gets behind in harvesting, it often has to skip over whole fields of a crop because they are overmature, and then it usually starts in the schedule at a point where the crop will be only marginally acceptable. Another aspect of weather predictions during the harvest season is the prediction of yields and quality which the sales people use as a tool in determining whether they will have an excess or a shortage of a particular product. They can buy or sell to other processing companies to make up any differences between production and their sales quotas. A processor must protect his own label's shelf space in grocery stores especially when entering new markets. Also, there exists the possibility of selling some of the raw product to other processors if yields are predicted to be above factory capacity or arrangements could be made to move the produce to other processing plants owned by the same company. The overall result would be a stabilizing of the market.

Fall and winter shipping of canned goods is dependent upon the weather also. First, the management should match the warehouse temperature to the expected temperature of the area being shipped to, especially when shipping into warmer temperatures. If the cans are cooler than the surrounding air they will "sweat" which results in loosened labels, enhancement of rust, and generally an appearance less appealing to the customers. Secondly, there is the problem of whether or not to get insulated railroad cars, which are more expensive. The above-mentioned weather-dependent decisions are common to all processors to some degree.

Three specific crops were chosen for discussion: tomatoes, snap beans, and cucumbers. The tomato is one of the most popular vegetables as well as one of the most important. It ranks next to the potato in total farm value in the United States and heads the list in value among the perishable vegetables. The 1968 processing crop was valued at $281 million with almost seven million tons harvested and the fresh market crop was valued at $231.5 million dollars for almost one million tons. The acreage and production of tomatoes grown for processing are much greater than those grown for market in the fresh condition. Several climatic factors affect tomato production. The tomato plant is a warm plant and requires a relatively long season to produce profitable yields. It is tender and will not withstand a hard freeze. High humidity with high temperature favors the development of foliage diseases. On the other hand, hot, drying winds often result in the dropping of the blossoms. These facts affect the production operations in different parts of the country in slightly different ways.

Depending on the length of the growing season, tomatoes are either direct seeded or transplanted. In western regions and especially in California, most tomatoes are direct seeded due to the longer growing season. In the midwest and east, tomatoes had been almost entirely transplanted for many years to help extend the shorter growing season although there is some increase in direct seeding for the advent of mechanical harvesting has necessitated placing greater emphasis on uniformity of maturity which is more easily attained through direct seeding. The success of direct seeding is very dependent upon adequate soil temperatures. A soil temperature of 55°F or more is needed for fast vigorous germination and emergence. At soil temperatures of 50° F and below, germination may be delayed a week or two and the seedlings are much less vigorous, leaving them more susceptible to damping off soil diseases and less competitive with weeds. The prediction of such cool temperatures could aid growers in determining when to seed their crops and when to make successive plantings to spread out the harvest season. If heavy rains were predicted, a planting might be delayed until after the rain because of the formation of soil crusts from such rains. The inability of tomato seedlings to penetrate soil crust is a major drawback to direct seeding in the eastern United States. On the other hand, a seeding may be made just before a gentle rain so fast germination would be enhanced. Ten-day to two-week predictions for temperatures and rainfall would be required because this is the amount of time required for germination and emergence of tomatoes under ideal conditions.

A certain amount of transplanting to establish tomato fields will undoubtedly be continued in the eastern United States to get early harvest. Most transplants are grown in the southern states of Georgia, Mississippi, and some in Tennessee. This brings the problem of correlating the growth and digging of the seedlings with the transplanting operations in the North. The southern plant growers have to seed early, yet avoid frosts in order that they can supply the early plants with consistent reliability for the field plantings in the more northern states. The southern plant growers could make good use of accurate weather predictions in scheduling their plantings. They could also watch the predictions for the areas they ship to, to learn if they need to slow the growth of the plants. A technique has been developed that enables the southern growers to retard a particular planting for up to a week without reducing its vigor. The technique is to clip out the growing point when the seedlings are at a certain height. Vigorous new growth arises from axillary buds further down the plant. The best yields of ripe tomatoes are made from young, vigorously growing transplants. Predictions of weather for from one to two weeks would be needed to use the method effectively. Also, the plant growers would pull and hold plants if they knew there was to be an extended period when it would be too wet to pull plants. Plants can be kept in excellent condition for up to ten days with cold storage.

The risk of frost to early transplanted tomatoes could be greatly reduced through accurate long-range weather predictions. Presently, most processors set out an early planting knowing that they will get a crop from it only every other year. With two-week prediction for frosts they could save themselves the time and expense of making the early planting. Recently, a frost protection machine has come into use that sprays a protective foam over the plants lasting twenty-four hours. It has proved effective against temperatures down to the mid to upper twenties. Accurate predictions would enable the processor or grower to determine when to apply the protective foam.

Once past the freezing periods during the establishment of the tomato plants, the growers and processors must overcome the numerous diseases that can beset the developing plants. Early blight and gray leaf spot, two foliage diseases, are brought on by warm rainy weather and are a considerable threat to tomato growers in the eastern United States. Also, late blight is one of the most destructive and widespread of all plant diseases often destroying entire crops of tomatoes and potatoes in a week of cool, rainy weather as described in the discussion of potatoes. Anthracnose disease is very serious in many tomato growing sections of the United States. It is especially serious on tomatoes grown for processing because of the loss resulting from rotting of the ripe fruit and from the very high mold count in the processed product. Development of the disease is most rapid in warm, damp weather with optimum temperature of about 80°F. More effective and efficient use of disease-control chemicals could be attained through the use of accurate predictions for the various weather conditions that enhance the development and spread of particular diseases. One spray application before the particular weather conditions is as effective as several sprays after to control the spread of the diseases.

The harvesting of tomatoes for processing is undergoing some changes with the advent of mechanical harvesters. In the eastern U. S. the harvesting is reduced. However, with the accurate prediction of a rainy period, machines may be operated at night with a second crew or plans could be made to move machines to areas that expect to have less rain. This would result in greater efficiency and a more uniform supply of produce into the processing plant.

Snap beans are another crop of significance in the vegetable processing industry. In 1968, 626,800 tons were harvested from 266,110 acres with a value of $62.6 million. There are several periods during the growth of beans that are affected by the weather and where some action can be initiated by the grower to overcome detrimental weather conditions. Discussion of the crop will go from planting to harvest. During planting, soil temperature and moisture are important. Soil temperatures of 50°F and below will often result in poor seed germination and uneven emergence. Also, extremely wet soil will result in cracked cotyledons and damage to some of the embryos, causing weak seedlings which are slower emerging and more susceptible to damping off. With accurate weather predictions, growers could avoid planting just before extended cool, wet weather. A considerable number of acres of snap beans are planted on irrigated sandy soils. In this situation most growers find it desirable to plant right after plowing and most preferably just after a rain in order to save an irrigation. In certain areas, farmers are able to double crop their land by planting beans later in summer after a first crop such as peas has been harvested. The growers would wait a few days if they knew a rain were imminent, especially if they were not able to irrigate to moisten the soil before seeding.

Snap beans are especially susceptible to several bacterial blights that develop most rapidly under certain weather conditions. Common blight is favored by relatively high air temperatures, while halo blight thrives under relatively cool conditions. These diseases can do considerable damage to the foliage but the largest economic loss is from damage to the pods which makes the beans unfit for processing. If the pods become infected with either disease when they are young, they will curve excessively due to the death of the tissue in the diseased area. A processing plant can handle only a very small percentage of such curved pods because they need to be removed by hand. A higher percentage results in a significant decrease in plant efficiency and decreased total capacity. A certain degree of blight control can be attained through the application of copper sprays before the conditions arrive that are conducive to disease spread. These sprays need to be on at least six hours in order to be fixed to the surface to prevent washing off. Therefore, the sprays need to be applied at least six hours before any predicted rain. High winds are necessary for the diseases to become an epidemic, for the winds carry the spores to new plants and the soil and debris carried in the wind will damage the plant surfaces making entry of bacteria much easier. Prediction of high winds may enable the grower to irrigate so the surface of the soil will be moist and less apt to become airborne.

Downy mildew is another disease that can become a serious epidemic under continuous high moisture conditions. The most extensive development is on the pod, where from a point of infection the fungus spreads, often covering most of the pod. The pods shrivel, wilt, and gradually die. The best control is to apply a protective spray just before the moist weather condition will occur. Such timely sprays, as mentioned before, always save the producers money by efficient use of materials and labor.

The weather is also very important during the bloom period. Snap beans will drop their blooms and very small beans under hot and dry conditions to the extent that a whole first bloom may be lost. This will throw off the harvesting schedule in the fall and bunch up the plantings. With accurate predictions of such weather conditions there are certain operations a grower should, if possible, perform and others he should not. First, he should irrigate so the plants will not be under a water stress and with certain sprinkler irrigation systems the air temperature can be lowered five to ten degrees. Second, he should avoid cultivation because most bean roots thereby increase the moisture stress. Third, he should avoid doing any spraying, because most sprays cause some dropping of flowers and the hot dry weather would compound the problem.

More accurate weather predictions can also be successfully used during the harvest of snap beans. All bush snap beans for processing are mechanically harvested but the operation is much less efficient in wet weather because the leaves and trash are not easily separated from the beans. If wet weather were forecast most processors would want beans to be picked on the immature side rather than wait until after the rain and have to process overmature beans. Also, frost predictions are important in fall since extra hours would be scheduled to harvest as much produce as possible even if it may be immature. However, an accurate frost prediction would be required before many immature fields would be harvested because of the increased cost of harvesting.

Another processing crop that is especially dependent on the weather is cucumbers for pickling. The 1968 crop grown on 144, 320 acres was worth $51. 1 million. Cucumbers require a soil temperature of at least 60°F to germinate quickly and uniformly. For early crops this factor must be considered and any help from long range temperature predictions would be beneficial. Modern production technology includes the use of herbicides for weed control in cucumbers. These chemicals have a requirement of water soon after application to be effective. Accurate weather predictions would have use in determining when to apply the chemical and whether an irrigation would be necessary immediately following application. Another major problem is determining when to move the bee hives in for insect pollination to insure fruit set. It is difficult to schedule the date for moving bee hives into the field because flowering can be delayed significantly by cool temperatures. A few days of cool temperatures will cause cucumbers to cease developing and remain inactive for several days after the return to warm temperatures. Accurate long-range forecasts are needed to estimate how long it will take the cucumbers to resume normal development. If bee hives are set out before bloom, the bees will start working some other crop and will not return to the cucumbers until the other crop is completely worked over. Wind predictions are also needed so that duff of insecticides applied to adjoining crop fields would not move into cucumber fields in which bees are working and kill the bees.

Diseases are a hazard to cucumbers during the entire growth period of this crop. Angular leaf spot, which reduces total leaf surface and provides entrance for bacterial soft rot on the fruit, occurs in the field in most humid and semi-humid regions. The disease can be controlled by keeping the plants growing vigorously. Accurate weather predictions are needed to determine when a water stress will occur so the crop can be irrigated before it becomes deficient in water and slowed in growth. There are several foliage diseases of cucumber that are controlled by the application of the proper chemicals just before unfavorable weather occurs.

Very important to the harvesting of cucumbers, especially with the advent of mechanical harvesters, is the prediction of the total yield and the time of maturity. The maturity of cucumbers is very temperature-dependent and the prediction of the temperature for from several days to a week in advance would allow for much better scheduling of the harvesting operations.

VIII. Summary

I have discussed the following weather parameters in relation to how they affect the production and postharvest activities of various horticultural crops: temperature, moisture, wind, and cloudiness and have indicated that with accurate and timely predictions the effects of the adverse conditions could be minimized.

There are three aspects of temperature predictions that are especially important: the minimum and maximum temperatures; the fluctuation in temperatures, and the duration of particular temperatures. The concern about minimum temperatures is due to the freezing of plants and plant parts, particularly the blossoms and young fruit. The common means of overcoming the frost are through use of overhead sprinkler irrigation, gas oil burning heaters, or by altering the time of planting and harvesting. Of the crops discussed in this report, injury from frost causes economic losses in the production of flowers, cranberries, apples, tomatoes, and beans. Sudden drops in temperature from high to near freezing will cause serious rupturing of cells in sensitive plants such as azaleas and tomato. With short-term predictions, azaleas could be moved indoors and tomatoes could be protected by irrigation. In greenhouses and storage facilities, sudden drops in temperature could be eliminated by turning on the heaters or furnaces before the outside temperature drop occurs. As temperatures rise, so do transpiration rates, causing excessive water loss and dessication of freshly transplanted crops, as tomatoes. Also, high temperatures encourage epidemic infections of certain diseases such as common blight of snap beans. High temperatures enhance the uptake of thinner sprays used in many fruit crops, thereby causing excessive thinning and reducing the yield potential. And last, in greenhouse flower production unexpected high temperatures can cause premature blooming before a major holiday. The timely prediction of high temperatures would allow the grower to alter his transplanting schedule, spray program, or greenhouse ventilating and cooling systems to minimize the losses. Fluctuations in temperature encourage the spread of certain diseases such as late blight of tomato and potato. If the situation were known ahead of time, the rate of application of fungicides could be increased. The duration of a particular temperature condition is important. Several days of fluctuating temperatures with high humidity are necessary for the late blight disease to become epidemic. With long-range prediction, the spray schedule would be altered for better control. Also, some crops such as snap beans and cucumbers mature quickly, especially at high temperatures. The processor can expect a clumping of several plantings with prolonged hot weather and would probably elect to harvest some of the crop on the immature side before the high temperatures occur. And finally, the time of the change in temperature or time of extreme conditions is important, whether it be the time of night to expect the freezing temperature, or the time of day to expect the very high temperatures. The time must be known so any adjustments can be made prior to it. For example, the orchardman will not want to have his burners heating all night when he only needs them on from four to six in the morning.

Moisture, another weather parameter, has four primary areas of interest and concern to horticultural industries: when rain will arrive; the quantity to expect; the period the condition will last; and the interval between rains. When moisture in the form of rain arrives, it is important to the timing of field operations. Fertilizers and most herbicides are best applied just before a light rain to wash the materials into the soil, whereas insecticides and fungicides should not be applied before a rain, otherwise they would be washed from the foliage. Seeding and planting is more successful if followed by a rain to insure that sufficient moisture is present, especially in late spring and summer. To know how much rain is coming is as useful as knowing when it is coming. Heavy rains will cause the run-off or leaching of added chemicals so that they are lost to the plants. Growers would avoid making applications before such heavy rains. Heavy rains will cause excessive crusting on the clay and clay loam soils, and growers would not seed or plant before such rains. Certain diseases such as apple scab need rains or heavy dews for spore germination and plant infection. Prediction of the wet weather would allow time to put on a protective spray. How long the moist period lasts often affects the buildup of diseases as halo blight of beans and apple scab. The grower could plan to make extra sprays by aircraft if he were unable to do so with ground equipment. If extended rainy periods were predicted, apple growers would contract for more bees to pollinate their orchards. The cranberry growers also would order more bees for pollination. The long-range prediction of the interval between rains would determine the amount of irrigating that would be done and whether or not a second crop would be seeded in mid-summer. The significance of moisture is not totally limited to precipitation for in the prediction of damaging frosts, the vapor content of the air is significant and controls the rate and minimum temperature occurring in a particular evening. The usefulness of humidity forecasts is not now recognized by many agriculturalists, but it is utilized by fruit growers and its importance is increasing.

Short- and long-range wind predictions are needed for several reasons. High winds cause the blowing of sandy soil and the high organic matter soils. Blowing soil kills young seedlings and reduces the quality of crops such as lettuce, when the soil gets into the head. It also encourages the spread of certain plant diseases like common blight and halo blight of beans by making minute abrasions in the exterior protective layer of cells allowing the easy entrance of the pathogens. There is no way to control the wind, but there are ways to prevent the soil from blowing if given from two-to three-days' notice. Moisture on the surface will hold the soil particles together and can be applied by irrigation. Winds are also very important to the scheduling of sprays, the prediction of wind speeds in excess of ten m. p. h. is desired to minimize spray drift. For apple harvesting, ten-day predictions would be important in determining when the grower should harvest those varieties that drop and bruise excessively in high winds.

Clouds produce two main effects of interest to horticulturists: one is the reduced rate at which heat is lost beneath them by trapping the long-range radiation emitted by the earth, and the other is the blocking out of sunlight which is especially needed by the greenhouse flower growers to insure good blooms just before the major holidays. The prediction of the time that a cloud cover will arrive over crops that are sensitive to frost injury as cranberries, tomatoes, citrus, and apples will often determine whether additional frost protection measures will need to be taken. The prediction of the duration of the cloudy condition is needed so that greenhouse growers will know if they need to raise the heat or use additional light.

The major advantages that would result from an increase in accuracy and timeliness of weather predictions are: (1) more efficient operations resulting in reduced cost of production, (2) more effective marketing through supply stabilization, resulting in more stable prices, and (3) an increase in potential production. Through the effective use of weather forecasts some losses can be prevented and others can be minimized. However, not all losses from adverse weather conditions can be eliminated.

VIII. Implications

This report has detailed the needs in weather information for a selected number of agricultural crops. Complete and precise weather information is of significance to crop production because the scheduling of most operations is controlled by the weather and because the plant itself grows and responds differently under varied weather conditions. Thus weather information is a necessary factor in the majority of decisions concerning the production and marketing of each crop. Each grower tends to make maximum use of all available weather information to arrive at the best estimate of climatic conditions for the decisions that he has to make. Many growers subscribe to private weather information to obtain more detailed information on specific aspects of the climate that relate directly to their operations. Grower groups are providing funds for specialized weather forecasts and funds for research to determine the influence of certain weather patterns on crop yield and quality.

In the years ahead, the significance of precise weather information will continue to increase as agricultural enterprises become larger and more specialized. The decreasing per-unit profits, as competition becomes keener, will require that managers make the most efficient possible use of weather information to protect the crops and schedule operations so that a satisfactory return is obtained from each crop. Hopefully, improvements in communication will make it possible for individual operators to obtain up-to-the-minute data to meet their specific needs.

Table 1

Weather Information Requirements
Woody Ornamentals

Event	Type of Benefit	Critical Period	Weather Concern	Prediction Interval
*Labor procurement:	Fewer lost work days	Mid-March to April 1	Precipitation: kind, duration; Frost: duration	2 week
*Labor scheduling: digging of stock for sale, planting out young stock	Most efficient use of labor	April, May	Frost: duration; Rain: amount, duration	1 to 5 day
Scheduling labor for weeding	No lost work days	June, July	Rain: amount, duration	3 to 5 day
Pest control: predicting buildup of pests	Better pest control	June, July	Rain: duration Temperature: amount, duration; Wind: speed	7 to 10 days
Digging stock for following year	Efficient use of labor	Sept. -Nov.	Rain: amount, duration; Frost: duration, time of winter freeze	3 day to 2 week
Transplanting large trees	Increased % of successful transplants, Better customer service	Dec. -March	Snow: amount; Very low temperatures: duration	1 to 5 day

*most significant

Table 2

Weather Information Requirements
Floriculture

Event	Type of Benefit	Critical Period	Weather Concern	Prediction Interval
		GROWER		
Pest control: timing	Improved control:	Growing season	Rain: amount, duration; Temperature: amount, duration; Wind: speed	1 day to 2 week
Protection against natural hazards	Decreased loss to natural hazards	Growing season	Temperature: frosts, very high-duration	1 day to 2 week
Harvest: timing	Increased yields, better quality	Harvest period	Rain: amount, duration; Temperature: frosts, very high; Cloud cover: amount, duration	2 to 5 day
Shipping: insulating shipments	Reduced costs; reduced losses	Harvest season, winter	Temperature: frosts—in areas shipping to and through	3 to 5 day
*Control flowering: greenhouses, 10 days before harvest	Improved quality	All year	Temperature: very high, duration; Cloud cover: amount, duration	1 to 2 week
		CUT FLOWER WHOLESALER		
*Contracting for and buying large volumes of flowers	Adequate steady supply of flowers to meet holiday and other demendo	All year	Temperature:frosts; Rain: excess amounts; (in production areas)	1 to 2 week

Table 2 (continued)

Event	Type of Benefit	Critical Period	Weather Concern	Prediction Interval
		GARDEN SUPPLY RETAILER		
Advertising and planning for specials and sales	Increased sales, better customer service	April, May September	Temperature: Rain: amount, duration	1 to 2 week

*Most significant

Table 3

Weather Information Requirements
Fruits

Event	Type of Benefit	Critical Period	Weather Concern	Prediction Interval
		SMALL FRUITS		
Establishing new beds	Fast starting plants	Spring	Rain: amount; Wind: speed; Temperature	3 to 7 day
*Frost protection: flowers, tender new growth, buds fruits	Consistently good yields	Spring Summer Fall	Temperature: frost time; Cloud cover: time, duration	1 to 3 day
Herbicide application	Better weed control; Prevent pollution	Spring, Summer	Rain: amount; Wind speed, direction	3 day
*Insect and disease control	More effective scheduling and application of pesticides; Prevent pollution	Growing season	Rain: amount, duration; Temperature: duration; Wind: speed, direction	3 to 10 day
Harvest	Improved fruit quality and color	Oct.	Temperature: duration; Rain: amount, duration	1 to 7 day
Winter protection	Greater effectiveness of flooding	Late Nov. - Early Dec.	Temperature: very low, duration	1 to 2 week

*Most significant

Table 3 (continued)

Event	Type of Benefit	Critical Period	Weather Concern	Prediction Interval
		TREE FRUITS		
*Frost protection: flowers, tender new growth	Consis- tently good yields	Spring	Temperature; frost time, duration; Cloud cover: time, duration	Hourly at night; 1 day to 2 week
Pollination: when and how many bee colonies to use	Good pol- lination	Spring	Temperature; Rain: duration; Wind: speed	1 week
Fruit thinning: timing important	Larger fruit	Spring	Temperature: duration; Cloud cover	1 to 5 day
*Disease and in- sect control	More ef- fective con- trol; Prevent pollution	Summer, spring	Rain: amount, duration; Tem- perature: duration; Wind speed	1 to 7 day
*Harvest	Improved quality, increased yields	Fall	Wind: speed	1 to 7 day

*Most significant

Table 4

Weather Information Requirements
Vegetables

Event	Type of Benefit	Critical Period	Weather Concern	Prediction Interval
*Scheduling of plantings	Steady supply of produce at harvest.	Spring.	Rain: amount, duration; Temperature: duration	1 day to 2 week
*Frost protection: seedlings very tender, irrigation	Prevents the loss of a planting	Spring	Temperature: frost; Wind: direction, velocity	1 day to 2 week
Scheduling field operations, labor	Greater efficiency	Growing period	Rain: amount, duration	1 to 5 day
Herbicide application	More effective weed control. Control pollution		Rain: amount; Wind: velocity, direction; Temperature	1 to 3 day
*Irrigating: keep crops growing vigorously	Reduced costs	Growing season	Rain: amount, duration; Wind: velocity, direction	2 to 10 day
*Disease and insect control	Effective control at reduced costs. Control pollution.	Growing season	Rain: duration; Temperature: duration; Wind: velocity, direction	2 to 10 day
*Predicting yield and harvest date	Increased sales, more efficient scheduling of harvest	Summer, Fall	Temperature: duration; Temperature: frosts	1 to 4 day
Harvesting: moval of equipment and crews	Improved yield, quality	Summer, Fall	Rain: amount, duration; Temperature: frosts	1 to 4 day

Table 4 (continued)

Event	Type of Benefit	Critical Period	Weather Concern	Prediction Interval
*Labor procurement: timing very critical	Fewer lost work days	Summer	Rain; Temperature	1 to 2 week
Materials and supplies procurement: never run out	Less lost time	All season	Rain; Temperature	5 to 10 day
Shipping: want no sweating or excess heating	Good quality at market place	Fall, Winter	Temperature: very warm, duration (at area shipping to)	1 week

*Most significant

Table 5

Information Sources

J. W. Apple, Professor, Entomology Department, University of Wisconsin, Madison, Wisconsin.

G. E. Beck, Professor, Horticulture Department, University of Wisconsin, Madison, Wisconsin.

L. M. Berninger, Professor, Horticulture Department, University of Wisconsin, Madison, Wisconsin.

Jack Bloxom, Washington Fruit Produce, Yakima, Washington.

Charles Boon, Superintendent Congdoi Orchards, Yakima, Washington.

Robert Borders, Agricultural Forecaster, U. S. Weather Bureau, Yakima, Wash.

R. Busse, Manager Paramount Farms, Stevens Point, Wisconsin.

R. K. Chapman, Professor, Entomology Department, University of Wisconsin, Madison, Wisconsin.

David Curwin, Professor, University of Wisconsin Experiment Station, Hancock, Wisconsin.

M. N. Dana, Professor, Horticulture Department, University of Wisconsin, Madison, Wisconsin.

Harold Gatzke, lettuce producer, Berlin, Wisconsin.

E. R. Hasselkus, Professor, Horticulture Department, University of Wisconsin, Madison, Wisconsin.

E. Hunkle, Manager, Holten and Hunkle, Co., Brown Deer, Wisconsin.

Stanley Hoyt, Professor, Tree Fruit Research Center, Wenatchee, Washington.

Alan Jones, Agricultural Forecaster, U. S. Weather Bureau, Washington State Tree Research Center, Wenatchee, Washington.

G. C. Klingbeil, Professor, Horticulture Department, University of Wisconsin, Madison, Wisconsin.

Peter Leach, lettuce producer, Berlin, Wisconsin.

W. A. Luce, Former County Agent, Yakima, Washington.

L. E. Mayer, Research Director, Stokely-Van Camp. Inc., Indianapolis, Indiana.

F. E. Moeller, Professor Entomology Department, University of Wisconsin, Madison, Wisconsin.

Table 5 (continued)

Ralph Petranek, Manager, McKay's Nursery, Waterloo, Wisconsin.

E. L. Proebsting, Jr., Professor, Irrigated Agriculture Research and Extension Center, Prosser, Washington.

L. A. Polzak, Research Director, Larson Canning Co., Green Bay, Wisconsin.

P. E. Schultz, Research Director, Libby, McNeil, Libby Co., Janesville, Wisconsin.

Les Sorenson, cranberry consultant, Wisconsin Rapids, Wisconsin.

M. P. Verhultz, Secretary, Wisconsin Canners and Freezers Assoc., Madison, Wisconsin.

Warren Wallace, Agricultural Forecaster, U. S. Weather Bureau, Madison, Wisconsin.

P. H. Williams, Professor, Plant Pathology Department, University of Wisconsin, Madison, Wisconsin.

Selected Weather Forecasting Needs for Horticultural Crops

T. W. Tibbitts
May, 1970

Event	Benefit	Critical Period	Weather Concern	Prediction Intervals	Mode
1. Frost protection of apple tree buds	Prevents fruit bud loss	April and May	Freezing temperatures	3-day	Radio or television - three times a day for general region.
				12-hour	Radio or television - 8 a.m. - for general region.
				15-minute	Radio during critical period (night) for separate 2-mile radius areas.
2. Predicting harvest dates of lettuce crop	Prevent plowing down excess crop	June through September	Temperatures	1, 2, 3, 4, 5-day	Radio or television - three times a day for general region.
3. Scheduling of harvests of lettuce	Insure uniform supply	June through	Occurrence of rains at specific times	2 through 48-hour forecasts	Radio or television at 2-hour intervals during day for general region. Telephone communications from 4 a.m. to 10 p.m. for timing and amount of rain at a specific location.
4. Insecticide or fungicide spraying for any	Prevent unnecessary spraying	Growing season	Presence of winds	1 through 24-hour forecasts	Radio or television at 2-hour intervals accurate to 15-mile radius area.

THE IMPACT OF IMPROVED SATELLITE WEATHER FORECASTING ON LETTUCE PRODUCTION

T. W. Tibbitts*
William Petersen*

Introduction

The purpose of this study was to determine the cost of inadequate weather forecasting to lettuce growers in Wisconsin. The study was undertaken to identify the operations that were affected by various weather conditions and to determine what savings could be made by improved forecasting. It was hoped the study would reveal whether or not the added costs of collecting and communicating better weather data would be justified for lettuce operations in Wisconsin.

Collection of Data and Cost Calculations

The marketing and growing aspects of lettuce production were studied in order to determine where improved weather forecasting could result in savings to the grower. The importance of various weather circumstances in operating decisions and the value of improved forecasting were determined with the cooperation of Gatzke Farms, Inc., Berlin, Wis., Grand Valley Produce,

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Montello, Wis., Mr. Dale Perry, produce salesman with the two farms, Dr. Theodore W. Tibbitts, horticulturist at the University of Wisconsin, Madison, and William Petersen, a student with two summers' experience in the lettuce business. The study considered only those weather conditions which affect operating or marketing decisions and require an advance forecast of two weeks or less.

Losses were calculated using the following information. The size of the farm used was assumed to be 600 acres. The average yield was set at 500 cartons (of two dozen heads) per acre. This figure is higher than the average of 200 cwt per acre given in USDA marketing reports (200 cwt = 450 cartons per acre at 45 lbs. per carton). It was felt that the per-acre yield should be one that represented good management and the use of improved weather information. Production costs used were taken from the costs prepared by the University of California Extension Service and by discussion with Wisconsin lettuce growers. Direct production costs, excluding land rental and supervision costs, were set at $.50 per carton; direct harvesting costs were set at $1.00 per carton; and overhead costs including land rental, equipment and supervision were set at $.50 per carton based on a yield of 550 cartons per acre.

The evaluations made for this report will likely have application to other head lettuce operations on organic soils in the midwest and in the east. This includes about 2,000 acres in Wisconsin, 1,500 acres in Michigan and 5,000 acres in New York, with a total annual value of about $6 million. The losses may be somewhat less in New York due to their nearness to the eastern markets and greater flexibility in marketing alternatives.

It would be very difficult to equate the conclusions drawn from the lettuce operations in Wisconsin to the producing areas of Arizona and California because soil and climatic conditions are so different in the western areas and the losses result from quite different weather events.

The study revealed three categories of weather situations where better weather forecasting could influence management decisions. These are: (1) weather situations that cause heavy losses and affect most growers; (2) weather situations that cause heavy losses but occur only under special circumstances or in certain geographical locations; and (3) weather situations where losses are insignificant but most growers are affected.

The study focused primarily on the events which cause heavy losses and affect most growers. The four events in this category are outlined in Table 1.

Principal Weather Events that Cause Large Losses

High Temperatures Prior to Harvest:

High temperatures during the last two weeks prior to harvest cause the lettuce to mature rapidly. This causes two or more plantings to mature at the same harvest date. This has a twofold effect on the producers' ability to market the crop. The first way it affects marketing is by preventing the salesmen from selling all the lettuce which is ready for harvest. Most orders are placed on the book five to seven days in advance. If excess quantities of lettuce mature unexpectedly at one time due to high temperatures, there is no market for the lettuce and limited storage facilities prevent the grower from harvesting the lettuce and holding it for a few days until markets are found. The other way

Table 1

Event	Operation Affected	Average Loss Per event	Savings Which Can Be Realized With Accurate Forecasts	Frequency of Event Causing Loss	Annual Per Acre Savings With Accurate Forecast
High temperature at harvest	Sales and shipping	8% of total acreage at $1.00 per case; 550 cases per acre	100% of loss could be saved	Occurs $1\frac{1}{2}$ times each season	$66.00 per acre
Rain stopping harvest	Dirty lettuce, loss of good-will	2% of total acreage at $.50 per case; 550 cases per acre	100% of loss could be saved	Occurs $3\frac{1}{2}$ times each season	$19.25 per acre
Standing water on fields caused by heavy rains	1) lost plantings	1) 6.6% of total acreage at $25 per acre	35% of loss could be saved	Occurs once in two seasons	$12.75 per acre
	2) lost harvests	2) 3.3% of total acreage at $1.00 per case; 550 cases per acre			
	3) reduced quality and yield	3) 25% of total acreage; quality at $.25 per case and 450 cases per acre; yield: at $1.00 per case and 100 cases per acre			
Rain influencing spray schedule	Insect and fungicide spray	40% of total acreage at $2.50	100% savings	Occurs 3 times each season	$3.00 per acre
				Total —	$101.00 per acre

that high temperatures just prior to harvest affect marketing is in their effect on obtaining trucks for shipping. During heavy truck use by other vegetable operations, it becomes difficult to hire trucks to move lettuce to markets on short notice. As a consequence, the lettuce is left in the field and lost.

A study of twenty years of temperature records indicates there are 2.7 high-temperature periods during the summer lettuce maturing period of June 16 through September 15. This was determined by noting periods when two days or more had maximum temperatures over 80°F, alternating with periods of three days or more when maximum temperatures were below 80°F. However, only a portion of these high temperature periods is not adequately anticipated by the growers and cause losses. The growers consulted for this study stated that one or two times each season, lettuce was left in the field because of high temperatures prior to harvest. They estimated that as a minimum, 12% of the total acreage on the farm each year was lost. Using the projected average yield of 550 cartons per acre (two dozen heads per carton) and a loss of $.50 per carton production costs and a loss of $.50 per carton overhead costs, the average loss was found to be $66.00 per acre per year.

To prevent this problem from occurring, an accurate forecast of temperatures five to seven days in advance is needed. This would enable the salesmen and growers to predict daily harvests more accurately. Thus order taking and truck reservations could be handled in advance of the anticipated increase of lettuce ready for harvest.

Rain Interfering with Harvest:

The second most important weather situation which growers face is the occurrence of rains during the morning harvesting period. The rains may cause a skip or reduction in that day's harvest or if harvesting is carried out the lettuce will often be dirty. Losses may occur for any of three reasons. If harvesting is stopped, some orders must be filled a day later, but at a lower price because of a drop in market price. Another way a grower can lose is by having to fill an order a day late; if the market price has risen he must fill the order at the price originally agreed upon. And lastly, the grower can lose because he has to discount dirty lettuce and obtains a lower return.

Twenty years of weather records indicate that rains occur during the harvesting period of 6:00 A. M. to noon for the period of June 25 through September 15 an average of 7.8 times each season.

The produce salesman was consulted for the estimate of loss from this factor and he indicated that losses from this event occurred three to four times each season. The loss was determined by assuming an average loss of $.50 per carton, a projected average yield of 550 cartons per acre and an estimate of 2% of the acreage affected during each occurrence. This is a loss of $5.50 per acre for each occurrence and a seasonal loss of $19.25 per acre.

To avoid this loss the grower needs an accurate twenty-four-hour forecast of rain with a reasonably accurate prediction of its starting time. If the rain will not start until late in the day, the grower will harvest early on that day in order to get the best possible production from the planting. However, if the rain will start early in the day the grower will harvest the planting a day in advance.

Heavy Rain Causing Standing Water on the Field:

The third weather situation which produces large losses is the occurrence of heavy rains which cause water to stand on the surface of the field. Losses occur in three ways. New plantings are washed out or germination is greatly reduced by saturation of the soil. Harvests may be lost because of dirt on the lettuce or the inability of the grower to get into the fields to harvest it when it's ready for harvest. In addition, standing water will reduce both quality and yield of lettuce in the intermediate stages of development. The standing water will increase the susceptibility of lettuce to disease, cause nutrient imbalances which produce unevenly maturing lettuce and physically damage the lettuce.

The growers indicate that the frequency of this event is about once in every two years but this frequency is difficult to substantiate by Weather Bureau records because of the unevenness in rainfall patterns, especially for the infrequent torrential rains. The actual flooding of a marsh is often the consequence of a series of rains that saturate the soil and then eventually flood the marsh, rather than one single rain.

The computation of the loss is as shown in Table 1 and is based on an occurrence of this event every other year. Only 35% of the loss or $8.39 per acre was considered to be savable by preventing water from standing on the field. With a twenty-four-hour-forecast of heavy rains, most standing water could be removed by lowering irrigation ditches and by digging surface ditches in the field. This would by no means prevent all losses due to heavy rain. It should, however, reduce the severity of the problems caused.

Rain Influencing Spray Schedules:

The fourth weather situation which causes large losses is rain washing off insecticide and fungicide sprays. The lettuce grower would not apply these chemicals if he could be reasonably certain of a forthcoming rain. If a serious disease or insect problem existed the grower would spray anyway but there would be enough instances when he would not spray if he could be sure of rain to make this a significant loss.

The loss was estimated to occur three times each season and could be avoided if precise weather information was available. The loss is estimated at $3.00 per acre each year.

The annual loss from the four principle weather situations evaluated in this study averages $100 per acre. This figure becomes significant when compared to the average return per acre of $900 (450 cartons at $2.00). Thus, if the losses from these weather conditions could be prevented, the return per acre would be increased more than 10%. The gain from this improved forecasting will likely be divided both between the producer and the consumer. Initially the producer would realize the majority of the gain but as more and more producers take advantage of the improved weather information, competition would likely establish that most of the gain was passed to the consumer.

Other Weather Conditions which Cause Large Losses

There are four other situations where it was felt that losses were significant but not of major consequence because the losses are limited to certain geographical locations or special conditions. The first of these is high wind under dry field conditions. This can cause losses to new plantings which are blown out or to mature lettuce which is filled with dirt. This situation is limited to fields lacking windbreaks. The value of a forecast is of indeterminate use because the grower cannot do much to prevent losses. He may irrigate to hold down dirt but then dirt from other fields may blow in. He might erect long snow fences to keep dirt from drifting but the value of such procedures is largely unproven.

Frosts which damage lettuce constitute the second situation where weather forecasts could be extremely valuable to certain lettuce crops. In cases where the frost is caused by radiation cooling and a temperature inversion close to the ground is produced, damage to the lettuce can be minimized. When the inversion is close to the ground and the increase of temperature with height is large, helicopters can be used to mix the air vertically and raise the temperature at ground level. This situation will affect late plantings in Wisconsin, and growers in Florida during the winter. The forecast needed is the usual frost forecast and the prediction of conditions which would favor a temperature inversion. The cost of both reserving and flying a helicopter is great enough to make this forecast very important to those growers who might be affected.

The third situation where information could be helpful is in the prediction of extreme drying conditions which cause heating of the soil surface and burn-off of seedlings. If such a forecast were available, an application of water or foam to the rows could be used to prevent injury. It is not known how effective these preventative methods would be, so the value of this information is indeterminate. The occurrence of these conditions is relatively infrequent except in certain geographical areas.

The fourth situation where weather forecasts could help growers is when temperatures are high and trucks are in short supply. If a forecast of high temperatures were given, the shipper would be certain to reserve trucks with adequate cooling capability to meet the extreme conditions. The infrequency of this problem and relatively low loss that occurs if the shipment is delayed until the temperatures go down, make this factor insignificant.

Other Situations Considered

The last group of weather situations affecting management decisions was looked at and dismissed as insignificant because of infrequent occurrence or minor financial loss. Included in this group were rain interfering with irrigation, watering of roads to prevent dirt blowing into lettuce, timing of the arrival of harvesting crews, wind affecting fungicide and insecticide application and wind influencing herbicide application.

Summary

Precise weather information would be of significant value to lettuce operations. A saving of $100 per acre could be realized for lettuce operations on organic soils of Wisconsin with precise information. The major saving would be realized for losses relating to the following weather-associated events:

1. Unexpected high temperature periods causing rapid crop maturity and producing excess quantities of lettuce that cannot be sold.
2. Sudden rain during harvesting periods so that orders cannot be filled on on time or causing lettuce to be harvested dirty.

3. Heavy rains causing flooding of the fields and causing total loss of some plantings and reduced yield and quality of other plantings.

4. Rains washing pesticides from the plants.

Other weather-associated events such as frost injury and wind injury may produce significant injury but losses were not of a general concern to all growers and were restricted to only certain geographical locations or special conditions.

It is necessary that these indicated weather events be studied by meteorologists to determine the anticipated accuracy of forecasting for these indicated events so that the loss estimate can be adjusted accordingly.

A CASE STUDY TO DETERMINE THE IMPACT ON THE GROWING OF PEAS (PISUM SATIVUM L.) AND THE OPERATIONS OF THE PEA CANNING AND FREEZING INDUSTRY RESULTING FROM RECENT ADVANCES IN SATELLITE METEOROLOGY

Earl T. Gritton*

Abstract

Peas rank among the top four vegetables grown for commercial processing in the United States, on the basis of both acreage and value of product. Almost one-third of the U. S. acreage is in Wisconsin. 130,000 acres, with a farm value of $15,500,000 annually. Thirty-nine companies operated sixty-two plants for processing peas in Wisconsin in 1968.

The total production of peas varies from year to year. Oversupply one year customarily results in a reduction in acreage the following year. Much of the variation in yield and quality is due to weather conditions during the growing season. The first peas are planted as early in the spring as the ground can be worked, about April 5-10. Subsequent plantings are scheduled on the basis of daily temperatures since development of the pea plants is proportional to temperature. A base of 40°F is used since this is about the minimum temperature

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at which peas will germinate and grow. Daily highs and lows are averaged, the base temperature of 40°F subtracted, and a heat unit accumulation day by day recorded. Since varieties are quite constant relative to each other in the heat units needed to reach the processing stage, this procedure has been found very useful in helping to schedule a uniform supply of peas for processing throughout the season, and is used by all pea companies. Predictions of temperature would aid in scheduling plantings. Predictions of rain which would interfere with planting would likewise help. Field operations could be shifted within a fifteen-to-forty-mile radius of most processing plants to avoid bad weather at planting time.

Application of herbicides and insecticides is affected by wind and moisture, especially, though other climatic factors are also important. Predictions of atmospheric conditions contributing to air pollution which could damage peas might enable preventive measures to be taken at the pollution source.

Accurate weather predictions, particularly for temperature and moisture, would be of great help in scheduling labor, supplies, and equipment for the start of harvest and processing. They would permit more accurate daily estimates of the amount of peas to be harvested and processed. Because weather has such a great influence on yield, accurate forecasts would permit more accurate estimates of yield.

Peas must be harvested within a very narrow range of maturity for optimum quality. They pass through this range in as little as twelve hours during hot dry weather or as long as three to four days during cool moist conditions. Accurate long-range predictions would, therefore, help in scheduling harvests and the quality should be improved. Peas may develop off-flavors within two hours after harvest at 80°F but at 40°F more than four hours may be allowable between harvest and processing. Advance knowledge of the temperatures to be encountered would thus be of benefit. Harvesting operations could sometimes be shifted out of areas expected to receive rain and into areas where harvesting could be carried on more efficiently.

Most producers and processors would like to receive weather forecasts over radio or television. They would like the information presented in such a way that it could be interpreted for their specific area by personnel relatively untrained or unskilled in technical aspects of meteorology and climatology. Forecasts should be presented at least three times daily and even hourly would be desirable during planting in April and May and during harvest June 15 to August 15. Wind direction and speed, amount and duration of precipitation, hourly temperatures for each day, radiation, and cloud cover are the most important factors. The greater the advance notice the more valuable the prediction will be. Even a few days will be of great benefit if the prediction is accurate for areas of a few square miles, while one to two weeks would be even more helpful.

Case Study for Peas

This case study on the growing of peas and associated operations of the pea canning and freezing industry deals with one facet of the potential impact on agriculture deriving from recent advances in satellite meteorology. The purpose of this case study is to examine the effect on production, harvesting and processing of green peas, which could result from more precise and advanced weather prediction information to be derived from the United States weather satellite program.

Peas rank among the top four vegetables grown for commercial processing in the United States, both on the basis of acreage and total value of product. The production and processing of peas therefore affects the efforts and livelihood of a very large number of people, and the quality and quantity of the product is of direct concern to the consuming public. Between one-fourth and one-third of the peas grown for processing in the United States are grown in Wisconsin. Approximately 130,000 acres are devoted annually to this crop in Wisconsin, and farm value of the peas produced averages about $15,500,000 annually. Thirty-nine companies operated sixty-two plants for processing peas in Wisconsin in 1968.

Peas for processing are grown under contract to a processor, who will can or freeze the peas produced. The contract will set a price for pounds of fresh shelled peas produced, taking into account quality of the peas, type, and costs of production and harvesting. Contract negotiations usually take place during January and February for the growing season immediately following. The acreage desired by each processor is dependent upon the carryover of present stocks, the anticipated demand, and the expected production. Above-average production one year will likely result in increased carryover of stocks, and occasion a subsequent drop in acreage contracts for the following year.

Typically, in Wisconsin, the farm land is owned by someone other than the processor. The farm owner may agree to do no more than furnish the land for pea production, with the processor performing all of the functions necessary to grow and harvest the crop. In other cases the farm owner may perform all operations up to and including planting the seed, with the processing company performing all subsequent operations.

Pea seeds are large and heavy and are seeded at about 250 pounds per acre so that many pounds are required annually for planting. This seed is produced mostly in the western states of Idaho, Washington and Oregon, to reduce the likelihood of carrying seed-borne disease organisms. Processors place tentative orders with these seed producing firms in the spring, so the seed can be produced for planting in Wisconsin the following year. The amount of seed of each particular variety desired will be specified. These decisions must be made a year in advance, with no knowledge of the growing season to be encountered during the seed-producing year or in the following year, when the seed will be used to grow a crop for processing.

If conditions unfavorable for seed production could be anticipated, the acreage would be increased correspondingly. Adjustments which might be made with advance knowledge of the environmental conditions to be encountered during the season of growing for processing will be discussed subsequently.

Seed is normally shipped by rail from the western states to Wisconsin during February, March and April. Travel time is about two weeks. The weather has little effect on this operation except for occasional extremes, such as one year when railroad tracks were flooded by the Mississippi River, temporarily halting shipments. Removing bags of seed from rail cars to the processor's storage warehouse can be inconvenienced by rain, but this is not a serious problem.

The decision as to which fields on a farm will be used for growing peas may be made either in the fall or in the spring. If peas are to be planted as early as possible in the spring, which would be in early April, then land will probably be plowed in the fall so it can be worked up and planted to peas earlier in the spring. It is difficult to plow very dry soil, and occasionally fall plowing will be postponed until moisture conditions improve. Other times the soil is too wet and plowing must be delayed. Precise weather predictions would help the farmer decide on when and how much land to plow. Fall plowing may continue until the ground freezes. Advance notice as to when this will occur would permit decisions as to how much labor and equipment need to be devoted to plowing at any given time, so that the desired amount of land can be fall plowed.

The soil must be worked up to prepare the seedbed in the spring, but it cannot be worked while wet. A prediction as to when the ground in given fields would be dry enough for tilling would help the farmer, or processing company, be prepared to start on that date. The drying rate of the soil is dependent upon the amount of moisture in the soil, when frost has left the ground, precipitation, wind, and sun or radiation. Soils dry out very slowly under cool temperatures, cloudy skies, and low wind speed, and drying will be further delayed by precipitation. The moisture status of the soil at any given time might be determined through use of infrared photography. Utilizing this measurement, plus predictions of wind, sun, and precipitation, might permit forecasting of the time at which given fields could be prepared for planting peas. The longer advance notice the better, so that labor, machinery, seed, fertilizer, etc. can be readied for that date at that location. Farmers can estimate this fairly well themselves three to four days in advance.

Peas are planted as much as possible on a schedule determined by temperature, variety, and capacity of the processing plant. Capacity of the plant is known from previous experience, or, if some alterations have been made in the plant, can be predicted quite accurately. Most profitable use of the plant will come from full use of it. It is desirable to start operations as soon as possible in the season, continue as long as possible during the season and have just the right amount of peas coming into the plant for processing during the season for it to operate at optimum capacity.

The varieties of peas to be grown will differ in various agronomic characteristics, including the amount of time it takes from planting to reach the proper harvesting stage. A range of maturity types will be planted. Fast maturing types, requiring approximately fifty-six days from planting to harvest, will be used to start the processing plant. Progressively later maturing varieties will be used to extend the processing season. Planting dates of the various varieties will also be scheduled so as to provide a continuous supply of the proper amount of peas for processing from the beginning of the processing season—approximately June 15, until the end—approximately August 15, at which time most plants will change over to processing sweet corn.

The best yields can be expected from the earliest planted peas because the cool moist early spring weather is more favorable for production than the warmer drier weather of summer. Early planted peas stand a greater risk of injury from frost, but this danger is more than offset by the better growing conditions.

In spite of the advantages of early planting, not all peas can be planted then. To do so would result in so many peas maturing simultaneously that harvesting and processing operations could not keep up. To avoid this problem, plantings are scheduled according to temperatures, or "heat units." Temperature appears to be the one most important variable affecting the rate of maturation of peas.

The base temperature used in computing heat units is 40°F because this is about the minimum temperature for pea germination and growth. Temperatures above this base result in a "heat unit accumulation." For example, if the average temperature for a day is 62°F, the heat unit accumulation for that day is 62° - 40° = 22 heat units. Heat units thus accumulate slowly during the cool spring and rapidly as the season advances.

The number of heat units needed for a variety to reach the processing stage is fairly constant. This makes it possible, by referring to temperature records of past years, to predict the date on which the variety will be ready to harvest. Since it is known approximately how many heat units will accumulate each day just before harvest, the number of heat units which must separate plantings is known. Because of the large difference in temperatures, several days separation at planting time may be required to separate harvests by only one or two days. The exact number of heat units needed for a variety to reach harvest may vary somewhat with season and locality, but the heat unit system still works very well because the differences between varieties remain remarkably constant.

Rain during the planting period is a serious problem in growing peas for processing, since it interrupts the planting schedule. Accurate predictions of the amount of rain, on which areas it will fall, and when, could be extremely helpful at planting time. Thus, if no precipitation is anticipated, planting will proceed on schedule according to the rate of heat unit accumulation. If a light shower were predicted, slightly more acreage would be planted to make up for the slight interruption in planting. If a prolonged period of not being able to plant were to be anticipated, then it would be desirable to plant a correspondingly greater acreage before the suspension of planting occurred. Forecasts are needed which would predict the amount of precipitation, its duration, where it would fall, and at what date and time. Even highly accurate one-to-two-day forecasts are a great help but one-to-two-week forecasts would be much better. Since acreage within a radius of approximately fifteen to forty miles of a plant, even up to seventy-five miles, is used for growing peas, it would be possible to shift planting out of an area of anticipated rain and into an area where planting could proceed on schedule.

Unavoidable gaps in planting due to rain or other causes could be at least partially adjusted for by choosing other varieties. Seed of alternate varieties would have to be obtained, though, so some advance notice of the need to change varieties would be needed. A few days might be enough in some cases but in others one to two weeks would be needed.

Sometimes herbicides are applied which must be incorporated into the soil almost immediately. Rain can prevent this incorporation and result in ineffectual herbicide action. Other herbicides require rain soon after application for best performance.

Soil temperature may be an important factor in the rate of pea development, yield and the extent to which soil pathogens develop and injure plants. This factor does not receive a great deal of attention now because of the difficulty, time and expense of determining soil temperature. It might prove very useful if it could be determined quickly and easily over large areas as, for example, by a satellite.

Predictions of frost would be of little benefit at the present time because no protective measures are feasible for the pea crop. If protective measures do become feasible in the future, then forecasts of frost would be of benefit. Damage is dependent upon the temperature reached and the duration of that temperature.

Air pollution is an increasing problem. Peas appear to be less sensitive than some crops, but the time may come when pollution will be of major concern for their production. When and if this occurs, forecasts of conditions, such as inversions, which could cause problems might permit preventive measures to be taken, such as closing down some factory operations, etc.

Few, if any, field operations are required during the period between pea planting and harvesting. One operation which may be necessary is spraying. Insecticides might be used to control aphids and/or a larval complex made up mainly of armyworms and green loopers. Herbicides might be employed to control weeds, especially to prevent flower bud formation in Canada thistle, as these flower buds become mixed with the shelled peas during harvesting and lower the quality of the finished product if they are not removed. Removing them creates extra expense since it requires hand picking from an inspection belt in the factory.

Insecticides may be applied with either ground sprayers or aircraft. Ground sprayers are most frequently used unless the fields are too muddy to permit their travel, or if it is necessary to get the fields sprayed sooner than would be possible with ground equipment. Almost all herbicide is applied with ground equipment because of the danger of drift of the material to susceptible crops and their subsequent injury. Aircraft may be used only when a serious weed problem develops and field conditions do not permit use of ground equipment. Accurate weather forecasts would be of considerable benefit here. Absence of wind is desired because of the danger of drift, and drift will become of greater concern as the country becomes more urbanized.

Wind speed of about ten mph is considered maximum for most spraying, but where ultra-low volume is being used even lower speeds may be necessary. The hours between 4:00 A. M. and 8:00 A. M. are usually expected to have least wind and are, therefore, considered the best times for spraying. Spraying may continue throughout the day, however, in order to get the necessary acreage treated. Spraying could be scheduled a few days earlier or a few days later, if it were known that conditions would be more favorable at one time than another. Likewise, the choice of fields to be treated at any given time would be based on the areas where the weather would be most favorable. It is necessary for the spray to remain on the plants for a time in order to be effective. Spraying would not be scheduled within twenty-four hours or so of rain. Aircraft must be engaged for spraying from a day to a week in advance. Sometimes they are engaged and are unable to be used at the designated time and place because of unfavorable wind or rain. With accurate weather predictions of one day to a week or more, they could be all set to spray at the best time and place. Some insecticides, for instance, have a threshold temperature below which their effectiveness is greatly diminished. If the temperature could be predicted accurately they could be applied only when the temperatures are going to be favorable.

The development of most diseases is greatly influenced by the weather. Splashing rain and runoff water can disseminate disease-causing organisms. High humidity is favorable for infection and development of many pathogens. Wind, especially when driving rain or sand, can injure plants and predispose them to disease. Spores of pathogens can be carried long distances by air currents.

Forecasts would help anticipate disease problems and aid in deciding when and how to apply preventive measures. They would enable chemical suppliers to anticipate demands for their products. Remote sensing might detect disease or stress problems before they are recognizable on the ground, and permit prompt action to be taken. Sprays might be used to control pathogens before damage became widespread. Only areas in potential danger might need to be treated, eliminating the need and expense of treating large acreages. Now some overtreatment is inevitable. This could be eliminated.

The date on which pea harvest will commence is of considerable importance. Approximately 2,000 migrant workers are brought from Texas to Wisconsin to work with peas during the harvesting season. They are given about a thirty-day advance notice of when they will be needed, and then are actually brought to Wisconsin about two days prior to the anticipated start of harvest. They are not brought sooner because of the extra expense to the processing companies of caring for them, and the workers do not wish to come earlier because they are not given full pay until they actually start work. On the other hand, in some plants it is difficult to get processing in full swing until the workers are on the job.

The start of harvest is also important from the standpoint of having the harvesting labor and equipment ready for the field, and labor, supplies, and equipment ready at the processing plant. Forecasts which would permit more accurate prediction of the actual initiation of harvest would thus be of benefit to both labor and the processing companies. Temperature and moisture are the two most important variables. Very cool moist weather can delay the start of harvest while hot dry weather can hasten it.

During the growing season company management may require periodic crop reports from their production personnel. The estimated production is used in deciding whether to liquidate carryover stock or whether to buy, what types to retain or sell, and what prices are appropriate. A general report at the beginning of the season would indicate the general prospects, while reports every two weeks or so during the season would predict crop prospects for the next two-week period. These reports are written on the basis of the outlook at the time the report is being prepared, but a change in weather conditions can change the outlook even before the report is submitted to management. For instance, during a prolonged warm dry spell, the report could predict low yields and perhaps low quality, but a heavy rain accompanied by cooler weather could move in even while the report is being typed and alter the outlook completely. The general report for the season would need weather predictions one to two months in advance while the periodic reports would need one-to two-week predictions. Many variables would be of importance since yield and quality are influenced by so many environmental factors. Temperature, precipitation, radiation, cloud cover, humidity, soil moisture, and wind speed are some of the more important weather factors.

Peas for processing are harvested in a green succulent stage. Their maturity is commonly measured by a device called a tenderometer, which measures their resistance to crushing and shearing—the more mature the shelled peas, the greater their resistance to crushing and shearing and the higher the tenderometer value. Peas harvested at a very low tenderometer value do not yield as well as more mature peas and may be damaged considerably in harvesting and processing. Peas harvested at a high tenderometer value yield better, but are hard, starchy, and unpalatable. Only a fairly narrow range in maturity is acceptable for processing, and peas progress rapidly through this range. Generally, they must be harvested within about a twenty-four hour period or their quality will decline significantly. However, this depends a great deal upon the temperature and soil moisture supply. If the weather is cool and the ground is moist, the tenderometer value of the peas increases slowly and harvest may take place anytime over a two-to-four-day period. If temperatures are high and the soil is very dry, tenderometer values increase very rapidly, so that harvest must take place within about a twelve-hour period for optimum quality.

Thus low temperatures and moist soil are helpful during harvest as they slow the rate of maturity and allow a greater period of time for harvesting the peas. Decisions as to which fields to harvest and when to harvest them are made daily, or even hourly, during the harvest season.

Rain during the harvesting period is important for reasons other than the rate of maturity of the peas. Any amount of rain will wet the foliage, reducing efficiency of the harvesting machinery. The wet foliage and mud will clog the sieves in the mobile viners (machines which thresh the shelled peas from the vines) resulting in "carryover" of shelled peas, which are then returned to the field along with the threshed plants. Heavy dews can cause the same problem. If it were known that rain or heavy dews would occur in one area but not in another, it might be possible to shift to the dryer area for harvesting, returning a few hours or perhaps a day later after the moisture had dried. It might also be possible to cut and windrow the peas before the shower or dew covered all plants. Only plants on the outside of the windrow would then get wet while those on the inside would be sheltered. Consequently, the entire windrow would thresh more efficiently. Twenty-four-hour advance notice of these conditions would be quite helpful; but, of course, several days notice would greatly aid in making decisions as to what areas the equipment will be moved to and when. If equipment is to be moved from one processing plant area to another, twenty-four to thirty-six hours advance notice is needed.

Heavy rains or prolonged wet periods cause serious problems at harvest time because of the difficulty of moving the machinery through muddy fields. Harvest will need to continue on schedule because the peas will continue to mature, and the processing plant needs a supply of peas to keep the labor and equipment productively employed. Mobile viners weigh about 18,000 pounds and the tractors used to pull them weigh about 10,000 pounds. Other tractors, windrowers, pickups, cars, and trucks for hauling also need to traverse the fields. Under very muddy conditions it is difficult for this equipment to operate. The rate of harvest thus decreases, fewer peas are delivered to the plant in any given time, peas continue to mature resulting in more acres than need to be harvested, and more breakdowns are experienced because of the greater strain on the equipment. If wet conditions of this nature were accurately forecast, several alternative decisions could be made. Fields that would mature during the wet period might be harvested ahead of the rains. Quality would be higher than if harvest were delayed. Extra tractors could be secured to help pull the other tractors and equipment through the muddy fields. Factory labor and supply commitments could be held down in line with the reduced supply of peas to be available for processing.

If harvesting has been delayed for any considerable period of time, or if hot weather has matured peas extremely rapidly, it is probable that some pea fields will not be harvested for processing because they have become too mature. Weedy fields or those with marginal yields may be by-passed in favor of better fields. Payment to the farmer for such acreage which must be skipped is handled according to the contract agreement, but usually results in less return to the grower than if his peas are harvested. He, therefore, is unhappy when some of his peas are by-passed. The processing companies are generally optimistic with regard to the rate at which they can catch up in their harvesting, and often fail to by-pass enough acreage. This means they harvest too many peas which are more mature than they should be, and the quality of the processed product is correspondingly lower. With accurate forecasts of even one week, but preferably two, giving particularly the temperature and moisture conditions, planning would be greatly facilitated and quality of the product would be improved. When a company could predict that it would have either a deficit or excess of peas to process during any given time, it might buy or sell acreage. Harvesting machinery could be moved and operated where it could be used most efficiently. Since environmental conditions play such an important part in pea yields, an estimate of the amount of production could be made.

Pea harvesting equipment is moved from field to field and area to area on the road. Small companies will only be moving within approximately a fifteen-to-forty-mile radius of their plant while large companies with several plants have the potential of moving their machines 100 miles or more. Weather conditions are important from the standpoint of highway safety. Forecasts of storms and times of darkness would be of help as road travel would not be scheduled during storms and travel after dark would be held to a minimum.

Fluctuations in the amount of peas to process result in fluctuations of labor, equipment and supply needs of the plant. When favorable growing conditions have resulted in many peas that need processing in a short period of time, then the plant must be prepared to work to its capacity. Extra labor will be needed and extra shifts may have to be added. Only a few days' supply (sometimes two to three days) of some expendable items such as sugar, salt, butter, and cans are normally kept on hand. Different sizes and types of cans are used for different types of peas, and these differ from the cans used for other products. Thus, it is necessary to arrange for extra cans of the proper type to handle extra amounts of peas. Now, in fact, many can companies watch crop production forecasts as carefully as the processors. Since the supply of peas could be estimated more accurately and further in advance with more accurate forecasts, such forecasts would be of tremendous help to the processing company. The further ahead the prediction can be made the more benefit it will be. Even a few days would help but one to two weeks would be much better.

Shelled peas deteriorate rapidly in quality so the time interval between threshing of the peas from the plants and their processing must be kept short. This becomes more of a problem the further the shelled peas must be hauled for processing. The higher the temperature the more quickly the peas must be processed. Above 80°F only about two hours can elapse before off-flavors develop, while at 40°F, four hours or more between threshing and processing may be permissible. During periods of high temperatures the shelled peas can be held for longer periods of time by holding them in cold or iced water. Arrangements for ice need to be made twenty-four hours or more in advance and even the use of cold water will require some adjustment in the harvesting, hauling, and processing operations. Many days during July and August will be hot enough to cause problems, but many days will also be cool. Accurate forecasts of two days or more would be of considerable benefit in arranging for cooling the peas. If no cooling is to be used, it would be very helpful to know that the time available between harvest and processing would be reduced.

Many plants which process peas also process sweet corn. For most efficient factory operation it is desirable to keep the supply of peas coming in until the first corn is ready to be harvested for processing. A few days, usually ten or fewer, are necessary between the pea and corn harvests for converting the factory from peas to corn. It would be of great help in preparing for this conversion if the date of the last pea harvest and that of the first corn harvest could be predicted accurately a week or two in advance. Temperature and moisture are the two most important variables.

Weather is probably of less concern once the crop has been harvested than earlier, but it is still important. Canned peas must be kept from freezing so insulated and/or heated rail cars and trucks are used during freezing weather. Presently a given calendar date, about November 15, is usually chosen after which the use of unprotected shipment is considered too risky. If the initiation and duration of freezing temperatures could be predicted far enough in advance, some flexibility in securing and using the more expensive protected shipping equipment could be exercised.

Another problem with the canned product concerns merely differences in temperature which the cans encounter. If they are moved from one temperature to another, moisture may condense on them. This can discolor and loosen labels, and result in rusting of the cans.

It appears that no processing companies presently subscribe to any sort of a weather prediction service, and none employ specialized personnel to interpret forecasts or to measure environmental variables. At least some, if not all, would be willing to pay for such services if they could be shown to be of definite economic benefit. The larger the company, the more potential benefit and the more interest in the possibility of improved forecasts and weather measurements.

Climate control may become possible in the future. If so, knowledge of desired conditions and of conditions as they will exist without control could be used in adjusting the weather to the most favorable conditions feasible.

Weather predictions carried over radio and television can be received by farmers, processors, and others in the future, just as they are now being received. If forecasts were made more valuable by being made more accurate, or by covering a greater period of time, provisions could be made for receiving these forecasts more often. Some farm tractors now have radios and more could be so equipped. Processors have regular AM and perhaps FM radios at the plant and many of the field vehicles do also. The plants are connected with key vehicles by short-wave radios. Television sets could be set up at plant offices to receive forecasts. Other receiving equipment could be employed, but it appears radio and TV are considered the two best sources at present. As much of the forecast as possible should be left to local interpretation so they can be interpreted for specific areas. However, this should not require highly trained personnel at the farm or processor level. Some farmers and processors feel that morning, noon, and night forecasts would be sufficient. Others feel they should be available almost continuously, especially during the harvesting season.

Summary

Weather is an extremely important variable in the growing and harvesting of peas for processing. Accurate forecasts of one day to two weeks would permit much more efficient field and processing plant operations. A more stable supply of peas would be insured and their quality would be improved. The most important weather factors are temperature, precipitation, humidity, cloud cover, radiation and wind. Disturbances such as storms are important. Predictions are presently received from radio and television and these appear to be the most logical means for the future. Television is especially attractive because of the visual interpretation possible. Application of forecasts to small specific areas suggest that interpretation should be made on the local level. However, this should not require highly trained or skilled people. Payment for improved weather forecasts might be agreeable to farmers and processors if they could see adequate economic benefit, and if they were convinced there was good reason the service should not be provided through state or federal taxes.

A CASE STUDY TO DETERMINE THE NATURE OF THE IMPACT ON SWEET CORN RESULTING FROM RECENT ADVANCES IN SATELLITE METEOROLOGY

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The specific purpose of this case study was to determine the nature of the economic impact which would result if advanced weather predictions, derived from data emitting from the United States weather satellites, were available for use by the producers and processors of sweet corn. To this end the growing and marketing operations for sweet corn as related to certain weather phenomena occurring during the growth cycle have been detailed. Attention was given to changes in production strategy and the subsequent economic impact which improved weather predictions, based upon satellite data, would have upon yield and quality of this crop. Weather is of major concern in the production of a rapidly changing, highly perishable crop such as sweet corn where quality in addition to yield is a major consideration Production and marketing of the crop fall into three major categories:

1) for processing by canning and freezing as in the Midwest and Pacific Northwest;

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2) for fresh market as in the Metropolitan Northeast; and

3) for winter market as in Florida.

Weather-forecasting programs for agricultural use have been established in several states throughout the country. Growers monitor these available sources of weather information by radio, television, the public press and private forecasting services, to obtain the best possible summaries and predictions.

This constant analysis of weather information is the basis for the decisions affecting the scheduling and conduct of each field operation and for the sale of the produce to processors or on the market, e.g., land culture, date of planting, choice of varieties, use of agro-chemicals, harvest, effective use of machinery, schedule of labor. Significance of weather with respect to these operations will be detailed. Any improvement in accuracy, timeliness or detail of weather information would be of immediate and significant importance to producers, processors, and consumers. For these reasons the Wisconsin Canners and Freezers Association appointed a special committee to provide counsel and resources for the study.

The investigator has obtained information from growers and processors as to improved weather prediction needs, as well as benfits to production and quality of sweet corn, from planting through harvest. Insofar as possible the needs and benefits for the separate major producing areas of the country were or will be determined.

Discussions were held with individuals acutely aware of production and environmental requirements for representative climatic areas of the country.

Interviews had been held or scheduled with representatives of the following organizations:

Libby McNeill & Libby

Green Giant

The Larsen Company

The Oconomowoc Canning Company

Florida Sweet Corn Exchange

New Jersey Market Growers Association

The weather-growth cycle of corn in the North Central United States consists of the following units:

—preplanting, prior to May 1, especially March and April.

—planting, in May and June.

—growing season, from May through September (through November for field corn).

—harvest, in August and September (September through November for field corn).

—post harvest, after the crop is removed from October through February.

Winter production of market sweet corn, principally in Florida, involves special weather relationships.

Information in this report on corn production relative to the Weather Satellite Program is organized with the following points in mind:

1) weather relationships of corn.

2) procedures and practices followed in corn production.

3) procedures and practices which would be altered if more detailed weather information were available.

4) how these procedures would be altered together with the results expected, and

5) projected plans for next year.

Weather Relationships of Corn

Examples of weather growth relations for corn in Dane County, Wisconsin, are well illustrated over a three-year period. In 1966, a July frost was disastrous in localized areas, resulting in acreage abandonment. In 1967, an excessively wet September with as much as seventeen inches of rainfall in some areas seriously interfered with harvest operations. In 1968 there were no serious weather problems during the growing season which lasted well into October with the result that bumper corn yields averaging highest in the country were produced.

Preseason precipitation provides about half the moisture needs of corn. Where it is dependable, such as in Ohio and Indiana, there is little correlation with corn yield. On the other hand, deviations of three or four inches in Iowa, for example, have a significant influence on corn yield.

A warmer than normal spring favors high yields since it hastens decomposition of plant residues and permits early planting. A warm spring also hastens germination and emergence and promotes early growth.

Early summer rainfall is an important factor in successful corn production. Generally, the Corn Belt is characterized by light rainfall in the winter but increasing amounts through April and May into June, followed by decreasing amounts until September with higher amounts again in September and

October. This distribution of rainfall in the north central states seems related to the path of the jet streams and their related storm paths. These streams migrate northward until late summer and then move southward again in August and September.

Much work has been done on average amounts of rainfall during the summer months relative to the time of maximum moisture needed by the corn crop. On the average, more rain falls during June than the crop can utilize. July and August are deficit periods. Approximately six to seven inches of moisture are needed during the peak water requirement period of July. Only about half the July water requirement of corn falls during this month. Optimum amounts of rainfall are near four inches in June, seven inches in July, and four inches in August. June rainfall ranges from two to ten inches. Seven inches in June may adversely affect yields whereas seven inches in July would be highly beneficial. Generally corn yields more as July rainfall increases. This is related to the stage of growth of the corn plant and can be altered by planting date and choice of varieties, as well as average temperature conditions.

Distribution of rainfall in July and August is of tremendous importance. A warm, dry period just at pollination is particularly damaging to yields. The critical period for rainfall for corn is from July 15 to August 15. The average value of an inch of rainfall in five-day units increases from early June to a peak at the end of July and drops sharply toward the end of August.

The correlation between August rainfall and corn yield is not high. The effect of August temperature overshadows the influence of rainfall. While optimum rainfall for August is about four inches, corn will yield quite well on two or three inches of August rainfall. More than normal amounts in August results in higher humidity and increased damage by disease.

Yields decline appreciably as average monthly temperatures rise above 70°F in August. This is the time kernels are filling. With increasing temperature, respiration of the plant increases and there is less storage of the photosynthate. The plant utilizes its products rather than storing them. Consequently, a hot August results in smaller kernels and lower yields.

Warmer than normal weather in September and October is beneficial to the maturing crop but may be associated with lower than normal rainfall.

Cooler than normal weather in September may be accompanied by early frost which kills the plant before maturity, reduces yield, and interferes with drying.

The weather variables contributing most to corn yield variability are June temperature, July rainfall, and August temperature. Fluctuations in yield due to weather are great. One year may bring a bumper crop and the next a drought. While there is no way at present to predict these fluctuations, there is evidence that favorable years tend to alternate with unfavorable years in the Corn Belt. The pattern is not rhythmic and not predictable, but approaches periodicity in twenty-year intervals.

<u>Production Practices Related to Accuracy and Resolution of Weather Predictions</u>

Initiation of planting depends upon spring temperatures and soil moisture conditions both before, during, and after the immediate planting operation.

Procurement of seed, fertilizers, and pesticides in ample supply prior to this date is necessary. Acreage contracts as well as arrangements for labor and machinery must be in order to advance of this deadline. Accuracy and resolution of weather predictions will minimize misunderstandings and costly delays at this point.

Moisture supply in the soil prior to planting assumes major importance for a crop such as corn which obtains only about half of its water needs from growing season precipitation. Preplanting temperatures are an important consideration as they influence time or delay in planting which, in turn, affects length of growing season. Advance information on these conditions will influence choice and volume distribution of varieties from the standpoint of maturity and even the decision to shift to another crop.

With a highly perishable crop such as sweet corn, maximum effort is made to schedule planting dates to assure uniform flow of a high quality raw product to the factory at time of harvest. This is facilitated by use of thermal units based on temperatures above a 50° vital point in contrast to calendar days. Because of seasonal differences in average temperatures, a seven-day spread between fields at planting does not mean a seven-day spread at harvest. If weather prognosis for a two-week interval in May indicates a cool period with few effective temperatures above 50°, planting operations will be markedly slowed or labor and machinery shifted to a site of greater thermal unit accruement. Refinements in use of this technique envision interaction of precipitation and cloud cover data as they become available as well as temperature in scheduling planting dates. Accurate temperature information in connection with use of thermal units is assuming greater influence on planting and harvest schedules since present trends are toward fewer varieties in the processing industry to assure greater uniformity of product. In the past, use of different hybrids with a range in maturity has been one of the means of extending the harvest season.

Application of pre-emergence pesticides for control of insects, disease, and weeds has become a common production practice with corn. Effectiveness of these agricultural chemicals varies extensively with rainfall and temperature, particularly during the immediate post-application period. Time and rate of application would be altered to assure maximum effectiveness given reliable weather predictions.

Nutrient availability varies with soil moisture and temperature. Choice of fertilizer formula as well as rate of application consequently will be influenced by the forecast for these two environmental variables.

During the growing season, effectiveness of various production practices is constantly at the mercy of the weather. Here also prediction of rain will have a bearing on time and rate of application of herbicides, insecticides, and fungicides. For example, it is a common practice to add nitrogen to the growing corn plant during June as a sidedress application in bulk or as anhydrous ammonia. Rainfall, temperature, and relative humidity have a bearing on feasibility and uniformity of this application.

Insecticides are applied by aerial application from fixed wing planes or heliocopters. The influence of rain and wind as it affects drift of these dusts and sprays has obvious implications and emphasizes the need for accurate information on rainfall and the diurnal wind pattern.

Winter and preplanting temperatures have a profound effect on winter survival of insects and fungal spores. The initial contract for spraying and dusting with insecticides and fungicides will depend upon prior weather information in the over-wintering regions. The corn borer over-winters in the Corn Belt, survival depending upon winter temperatures and weather conditions. The corn leaf aphid migrates from the south each year and is consequently dependent for survival upon winter weather conditions in that area and on direction of prevailing winds and currents for northward movement. It initially feeds on barley and moves to corn at tasseling. The northern and western corn root worm over-winters in the north central area. Rainfall is related to the effectiveness of pre-emergence chemical treatment used in its control as previously mentioned. The corn ear worm over-winters here, survival primarily depending on temperature. Contract arrangements for treatment operations and purchase of appropriate chemicals are based upon estimates of predator populations. These estimates as well as actual treatment operations would be improved by accurate and advance weather forecasts.

Humidity and cloud cover, as well as precipitation and temperature, are highly correlated with plant disease. Rust, helminthosporium, and smut infections are related to conditions in the south since spores survive in the southern states and migrate northward. Certain diseases such as Stewart's wilt are spread by the flea beetle and other insect vectors. Seriousness of these diseases depends on the winter survival of disease-transmitting insects. Accurate forecasting will contribute markedly to extent and effectiveness of control measures.

Supplemental irrigation is becoming increasingly important in corn production, even in areas where precipitation is adequate on the basis of averages. Fluctuations in yield as related to rainfall clearly indicate that the moisture factor is one of the last remaining major variables in yield fluctuation. Accuracy and resolution of rainfall prediction has an obvious effect on this production practice.

Dependable frost warnings, particularly during September and October, are necessary for a crop such as corn which makes full use of the growing season. Frost also is a continual threat to the winter production of market sweet corn in the south. A frost warning will permit the producer to alter temperatures two or three degrees over his field by use of smudge fires, oil heaters, sprinkling, and air circulation by fans. In case of a severe frost advance warning, harvest will be speeded to capacity in the interval. Similarly, harvest can be hastened to minimize loss of quality and even acreage abandonment if a protracted period of severely wet weather is predicted.

Weather forecasts influence initiation and rate of harvest operations, a major phase of the processing industry. Time of harvest will determine level of hiring and transport of migrant labor as well as procurement of food and lodging for this work force. Weather, as it affects harvest, in turn influences flexibility of multiplant operations, initial lease of equipment, and maneuvering of equipment to the demand site. Accuracy in weather forecasting will help fieldmen synchronize harvest of varieties with like characteristics. It will also help mesh canning operations from one species to the next during the season to assure maximum utilization of plant facilities.

Temperature, as it affects quality, has far reaching implications for sweet corn. The processor has a choice of cream style or whole kernel pack, as well as size of can (family vs. institutional size). Given unseasonably warm temperatures, rapid maturation and loss of quality, there will be emphasis on cream style and institutional packs. Also relative volume of the different grades such as fancy, extra standard, and standard will have a bearing on promotion activities and advertising. Unseasonably hot weather during processing may force outright abandonment of acreage or transport of the product to other company factories for processing. Icing of the raw product for transport becomes a consideration. Purchase to alleviate shortages and sale of surpluses are practices facilitating flexibility which are in turn dependent upon the weather.

If temperature and rainfall can be predicted accurately on a fortnightly basis, yield forecasts will be greatly improved. Pricing structure of the raw product by the processor is traditionally based on a premium price as an incentive for early planting. It is also a practice to base price on quality of the raw product which is in turn affected by date of harvest and weather conditions, particularly temperature.

The canned product is shipped in temperature controlled cars, although at greater cost, if warranted by the humidity and temperatures enroute.

Shelf space in retail outlets is at a premium. Smoothness of harvest and shipping operations facilitated by accurate weather forecasting will enable the processor to maintain his quota under the company label.

Addendum for Field Corn

Weather relationships and growing season production practices for field corn are similar to those for sweet corn. Accurate weather information will have similar salutory results. At harvest there are different considerations largely related to flexibility of use. Sweet corn is harvested while immature when kernel moisture is approximately 70%. Field corn for grain is left to maturity when kernel moisture is in the 20% to 30% range. Field corn for silage is harvested when kernel moisture is in the 40% to 50% range.

There is an increasing rend toward early planting and choice of specific varieties of field corn to better synchronize period of maximum demand with period of maximum available moisture. Accuracy of weather forecasting will contribute toward refinement of this practice.

There is much to be learned about periodical fluctuations in weather and their causes. Such knowledge is particularly pertinent to long-range planning of acreage allotments of crops such as field corn which are under production control. Development of policies governing storage of surplus commodities also must be based on assumptions about future production.

Weather forecasts in August will contribute to an earlier prediction of yield of field corn which will in turn better enable the farmer to gauge his relative position in the market. It will influence his decision to feed his corn crop at home or sell it for cash.

If an early fall frost is predicted, the farmer will put larger quantities of his crop in silage which can be harvested before maturity when moisture content of the kernel is as high as 50%. He may wish to arrange for temporary trench silos if the frost is markedly early, resulting in large acreages of immature corn. On the average, 50% of the corn crop in Wisconsin is placed in silos. Fluctuation of this percentage is in a large measure related to weather conditions.

Frost assumes particular significance for a high income, frost-sensitive crop such as seed corn. Dependable frost warnings will enable seed producers to ward off frost or at least mitigate temperatures within a two- to four-degree temperature range by such practices as smudge fires, sprinkling, and air circulation.

If severe late fall winds are predicted, the farmer will be able to minimize serious stalk lodging and harvest complications by speeding up picking to capacity prior to their onset.

Fall rains provide an ideal environment for ear and kernel rots and stalk rots. An accurate prediction of protracted periods of precipitation will enable the operator to hasten harvest for maximum quality.

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A CASE STUDY TO DETERMINE THE NATURE OF THE IMPACT ON THE SWEET CORN INDUSTRY, RESULTING FROM RECENT ADVANCES IN SATELLITE METEOROLOGY

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I

Agricultural production has always been subject to a great deal of uncertainty. In recent years, this uncertainty has been decreased to some extent by the introduction of machinery into all areas of production and by other various applications of science and technology. In another very real sense, however, the uncertainty that has plagued farmers in the past has been decreased very little, for the primary source of this uncertainty has always been the weather, and the weather, even in this technological era, continues to be unchecked and, more often than not, poorly monitored. That such a situation should continue to exist indefinitely, however, is not likely. While it may be true that absolute weather control—and along with it an effective elimination

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*Dept. of Economics, University of Wisconsin. We wish to acknowledge the assistance of Frederick H. Boness; Professors R. H. Andrew and G. G. Weis; Paul E. Schulz, Libby, McNeill, Libby; Jack L. Hartzheim, Stokely Van Camp Inc.; A. L. Anderson and R. D. Jones, Green Giant Co.; and L. A. Polzak, The Larsen Co. Of course, none of the above persons or institutions are responsible for any errors that remain.

of uncertainty and weather-related crop disasters—is impossible at the present time, significant improvements in the length and quality of weather forecasts are real possibilities, especially in view of the potential capabilities of satellite meteorology. Furthermore, in theory at least, these improved weather forecasts should allow the farmer to plan his operations more accurately and over a longer period of time, with the ultimate result being improved production and fewer losses. The purpose of this study is to determine whether or not these postulated benefits of improved forecasts will actually accrue in a real situation, and if they should accrue, to determine how great those benefits will be.

The real situation on which this report will focus will be sweet corn production in Wisconsin. In absolute terms sweet corn production in Wisconsin has not been insubstantial, being valued at over $10, 000, 000 per year for each of the last two years and between $6 and $10 million annually for the last ten. Yet, despite these figures, in relation to the total corn crop (which includes field corn and silage corn), sweet corn is basically a minor crop, representing only a small proportion of the total production. The central position that sweet corn occupies in this report, therefore, is not justified simply by the gross value or size of the crop; rather justification for this study comes from the fact that the problems involved in sweet corn production are representative of the problems involved in the production of several other crops and, as a result, can probably be used to form a framework for inquiry which will be useful in other specific crop studies in the future. Sweet corn, after all, is a form of corn, and it is reasonable to assume that many of the factors that are significant

in the production of sweet corn will also be significant in the production of field or silage corn, most of which, incidentally, is produced in the corn-belt states, whose growing seasons and weather conditions are roughly similar to those under which sweet corn is grown in Wisconsin. In addition, sweet corn is usually classified as a vegetable—along with peas and beans and lettuce and carrots and other consumable crops—and can be related to the other vegetable crops in certain respects. Whether they are processed first and then marketed or simply marketed fresh, for example, most of the vegetable crops, including corn, must meet fairly restrictive quality standards, and the quality, in turn, is often dependent upon the weather conditions at the time of harvest. Thus, if weather conditions which adversely affect the quality of sweet corn are singled out, then those conditions will probably have a similar bearing on at least some of the other vegetable crops. It should be noted that the total value of these vegetables is considerable, even in relation to the total corn crop. A final justification for the use of sweet corn in this report is the existence of relatively detailed records on past production and losses. These exist because sweet corn is a commercial crop, whose output levels are often planned and recorded accurately by processing companies so that contract requirements and market demand will be met as efficiently as possible. Needless to say, such records are extremely useful in conducting an empirical study, and the fact that they do exist for sweet corn makes a study of sweet corn more attractive.

II

The way in which corn production is approached in this report and the conclusions which are derived from this approach are based on some fairly specific assumptions concerning the nature and quality of the weather forecasts of the future. Before getting into the actual report and conclusions, therefore, these assumptions will be outlined, and the reason for their selection over a second set of assumptions will be explained.

Of the two sets of assumptions which have been put forth, the one on which this report was begun and on which it has ultimately been based was that weather forecasts will be vastly improved, i.e., will be accurate seven to fourteen days in advance (instead of one day as they are now). The overall project of which this report is a part, however, encompasses a variety of disciplines and is not restircted simply to researching the effects of longer range forecasts. Another area emphasized in the project, for example, involves research into methods of improving the communication of weather information. It was in view of this second area of emphasis that the alternative set of assumptions was proposed. Under this alternative, the weather forecasts would have remained as they are now, accurate for one day, but the methods of reporting the forecasts would have been vastly improved. It would have been assumed, in short, that the farmer would receive the current level of weather information more rapidly, more often, and in greater detail than he does at the present time. Reasons for basing the report on such assumptions would have been twofold. First of all, the technological methods necessary for improving the weather communications system already exist, whereas the ability to make a vastly improved, seven-to-fourteen-day forecast, while it will exist in the future, does not exist at the present time. By concentrating on the effects of improved communications, then, this report would have emphasized the more immediately soluble problem, and along with other research directed toward this area could have been expected to lead more rapidly to actual improvements. A second reason for concentrating on the effects of improved communications could have been based on the assumption that the problem of infrequent and incomplete weather reports is a critical one, which must be ameliorated before any level of forecasts could be truly effective. It would have followed, then, that there would be little point in determining the effects of better weather forecasts if it were not going to be possible to communicate that information to the farmer. The more logical alternative would have been to ascertain the effects of improved communications first, and thus presumably to contribute to the development of an adequate system for distributing weather information, a system which would then be in existence whenever the seven-to-fourteen-day forecasts became a reality.

If there were reasons for emphasizing the effects of an improved weather reporting system, however, then there was also a reason for disregarding such an emphasis and concentrating instead on the effects of the longer range forecasts. The basis for this lay in the fact that the benefits from a standard one-day forecast—even if the information were communicated rapidly, accurately and without loss of detail—would at best be of limited value. This is because the effectiveness of the fast and accurate one-day forecast is still limited by the farmer's ability to respond. Any decision which would require planning over an extended period of time, such as planting and harvesting, would not be affected significantly by any type of short-term forecast, whether it be slow and inaccurate or rapid and up-to-date. Moreover, those operations (i.e., the harvesting and to a lesser extent the planting) which would be essentially unaffected by simple communication improvements are also the most critical operations, and the losses incurred during these periods form a large part of total losses. This will become more apparent later on, but by not being able to affect these losses, the short-term forecast would leave the area of greatest potential saving virtually untouched. The only operations which would be affected by an improved communications system would include tasks like herbicide and insecticide application, fertilizer utilization, and perhaps some of the more flexible parts of the planting operation, all of which are important to the ultimate success of the crop, but whose costs still constitute only a small part of the total costs of production.[1] As a result, any savings in these areas would probably fail to be of significant value, and a study of the economic effects would probably show no important deviations from current levels of production. If any important deviations are to be found, moreover, it will probably be because of longer range forecasts and the longer range planning that such forecasts would make possible. It seems, therefore, that more meaningful results can be derived from ascertaining the effects of the seven-to-fourteen-day forecast than from determining the effects of an improved weather reporting

[1] "Costs and Returns, Sweet Corn," Wisconsin Farm Enterprise Budgets: Field and Forage Crops (Department of Agricultural Economics, University of Wisconsin, June 1969), p. 12; see Table A1.

system, and for that reason it is toward the effects of the longer range forecasts that this report has been directed.

III

In order to determine the effects of longer range weather information, sweet corn production was approached on a basis of three periods, the spring planting period, the mid-summer growing period, and the late-summer harvesting period. These periods were selected for analysis because they were all critical times, during which the sweet corn crop was vulnerable to adverse weather conditions and also during which longer range weather information could probably be used to decrease losses or to improve production.

In theory, the planting period seemed to be a time in which seven-to-fourteen-day forecasts could have significant effects, because the planting operation itself is a relatively complex task, where the dates of planting for different fields must be staggered and where, as a result, specific decisions concerning the planting must be mapped out in advance of the actual operation. Actually there is an optimal planting period of about two weeks in length in which sweet corn can be planted safely without fear of frost and at the same time be expected to give its highest yields. If the entire sweet corn crop could be planted during this period of time, it would clearly be an ideal situation, since yields would be maximized and the planning requirements simplified. In reality, however, this is not done, since sweet corn which is planted at the same time in the spring will also mature and be ready for harvest at the same time later on. This would probably make the harvesting operation more difficult, but more important it would put a heavy strain on the processors. Most of the sweet corn which is produced is produced for processing, either canning or freezing, and most processing facilities have a limited capacity and would probably be incapable of handling a whole year's harvest in a period as short as two weeks. For this reason, the processors like to have the crop mature and be harvested over an extended period of time, thereby making it possible to maintain a controlled, uninterrupted flow of corn to the factory. One of the ways of achieving this goal is to stagger the planting dates for different fields; another is to use several different hybrids, each of which matures at a different rate. To a certain extent, this latter method would allow the entire planting operation to be concentrated within a short time period, but it is probably less desirable than staggering the planting, since different seed types will produce corn with varying appearances; and this in turn is looked upon dimly by processors who are trying to market a uniform kernel. Whichever method is used to spread out the harvest period, however, it is clear that if it is to lead to a successful harvest the planting operation cannot be carried out haphazardly, that it must instead be planned and coordinated carefully in advance.

The probable effect that improved weather forecasts would have on the above planting scheme would be to make the preplanting planning easier and more accurate, for instead of interrupting planting schedules and causing the loss of time and effort, as they often do now, poor weather conditions could be foreseen and measures taken to work around them. It seemed reasonable to assume, for example, that the planting could be speeded up or slowed down in response to a seven-to-fourteen-day forecast, since processing companies in Wisconsin often do their own planting and, as a result, possess enough machinery and other resources to undertake such measures effectively. Moreover, what is lacking at present is the time and knowledge required to allocate these resources in an optimal manner, and it would be this gap that the longer range forecasts would fill.

Beyond this point in the analysis, it was no longer possible to operate on a relatively broad, hypothetical level. Having determined that improved weather forecasts could be applied during the planting period, it then became necessary to determine the magnitude of the effects that such an application would have. By drawing upon processing company records of previous weather-related planting losses, it was hoped that an estimate could be arrived at which would be representative of the potential savings. Somewhat surprisingly, however, records of planting losses—of the number of acres that have had to be abandoned and replanted, for instance, or of the number of delays that have taken place because of bad weather—have not been kept. In almost every case, the reason for this has been simply that losses due to weather conditions at planting time have not assumed significant proportions. A field manager for one of the canning companies noted, for example, that as far as he knew his own company had never had to replant in the spring because of weather conditions.[2] Another official for a different company acknowledged that "weather does affect

[2] Correspondence of October 5, 1970, with Jack L. Hartzheim, District Field Manager, Stokely Van Camp, Inc.

our planting schedules," but that "the losses are negligible due to the fact that we plant heavier to make up for days missed or replant when plantings are bad due to adverse weather."[3] Thus, even though the planting period is significant to the production of sweet corn and seems well-suited to an application of longer range weather forecasts, the benefits from such an application would probably be of only limited value, since there are only a limited number of weather connected losses during this period.

The second period for which effects from improved weather forecasts could be hypothesized was the period of rapid growth which begins in June and extends through the end of July. Since the corn is growing rapidly at this time and since rapid growth requires a large and relatively uninterrupted supply of water, the most important weather factor for the entire period and especially for the latter part of the period is rainfall. On an overall level the need for sufficient rainfall at this time has been borne out by the disasters which occur whenever there is a severe mid-summer drought. On a more specific level, various crop studies have shown that the correlation between increased rainfall and increased yield becomes greater during the June-July growth period. One researcher found, for example, that for every inch of rain which fell during a five-day span in late July there would be a five-to six-bushel increase in yield at harvest. On the basis of such observations, then, it seemed that the need for water at specific times may be critical enough to justify the selective

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[3]Correspondence of November 12, 1970, with Robert D. Jones, Agriculture Production Planning and Services Control Manager, Green Giant Co.

use of supplemental irrigation during such times and that longer range weather information could be used to predict the dry spells accurately enough and far enough in advance so that the equipment needed to carry out such an irrigation program could be obtained.

Unfortunately, when examined more closely, this hypothesis has proved to be unworkable, for although the improved weather forecasts could undoubtedly be used to predict impending dry spells, the cost and difficulty of implementing such information would probably render any gains which might be forthcoming insignificant, if they did not in fact eliminate those gains entirely. The basic problem involved here is that irrigation is not the sort of operation that is easily conducted on a part-time basis, for only a few days out of the year. This is because an irrigation program has a number of relatively heavy, fixed costs associated with it, including investments for a well and pump, for a power plant to run the pump, and for pipes and sprinklers to distribute the water. Since the rental of such equipment is not common at the present time, anyone who wishes to irrigate his crop, even on a part-time basis, must be both willing and able to bear all of these initial investment costs, which total about $18,500 for a 160-acre farm or about $115 per acre.[4] Significantly, in areas in Wisconsin in which large amounts of sweet corn are grown, most farmers have not been willing to bear these costs, and irrigation has not become a common practice—a situation which reflects the fact that the rainfall

[4]From estimates compiled at the University of Wisconsin Experimental Farm, Hancock, Wisconsin; see Table A2.

in these areas provides a sufficient level of moisture in about four out of every five years and that the need for irrigation under such conditions is too restricted to justify the investment. In areas in Wisconsin where there is a need for irrigation, moreover, sweet corn is not commonly grown. The reason for this is not that irrigation cannot bring about improvements over nonirrigated yields, because it can. One study conducted at the University of Wisconsin Experimental Farm at Hancock from 1958 to 1962, showed that sweet corn which was irrigated an average of six inches per year yielded on the average about six tons of husked corn per acre, whereas nonirrigated corn yielded 3.4 tons per acre.[5] The irrigated yield thus amounted to an increase of about 75% and would probably have made the difference between profit and loss. Sweet corn is still not produced in this area, however, because the net returns that can be realized from it are modest in relation to the returns that can be realized from other crops[6] and it is understandable that the crops which offer the highest returns should be preferred, especially when an expensive irrigation system must be financed and maintained in order to produce them.

Ultimately, therefore, the effects of a seven-to-fourteen-day forecast during the mid-summer growth period would probably be insigificant, since there is no flexible way of responding to the information. It is not possible

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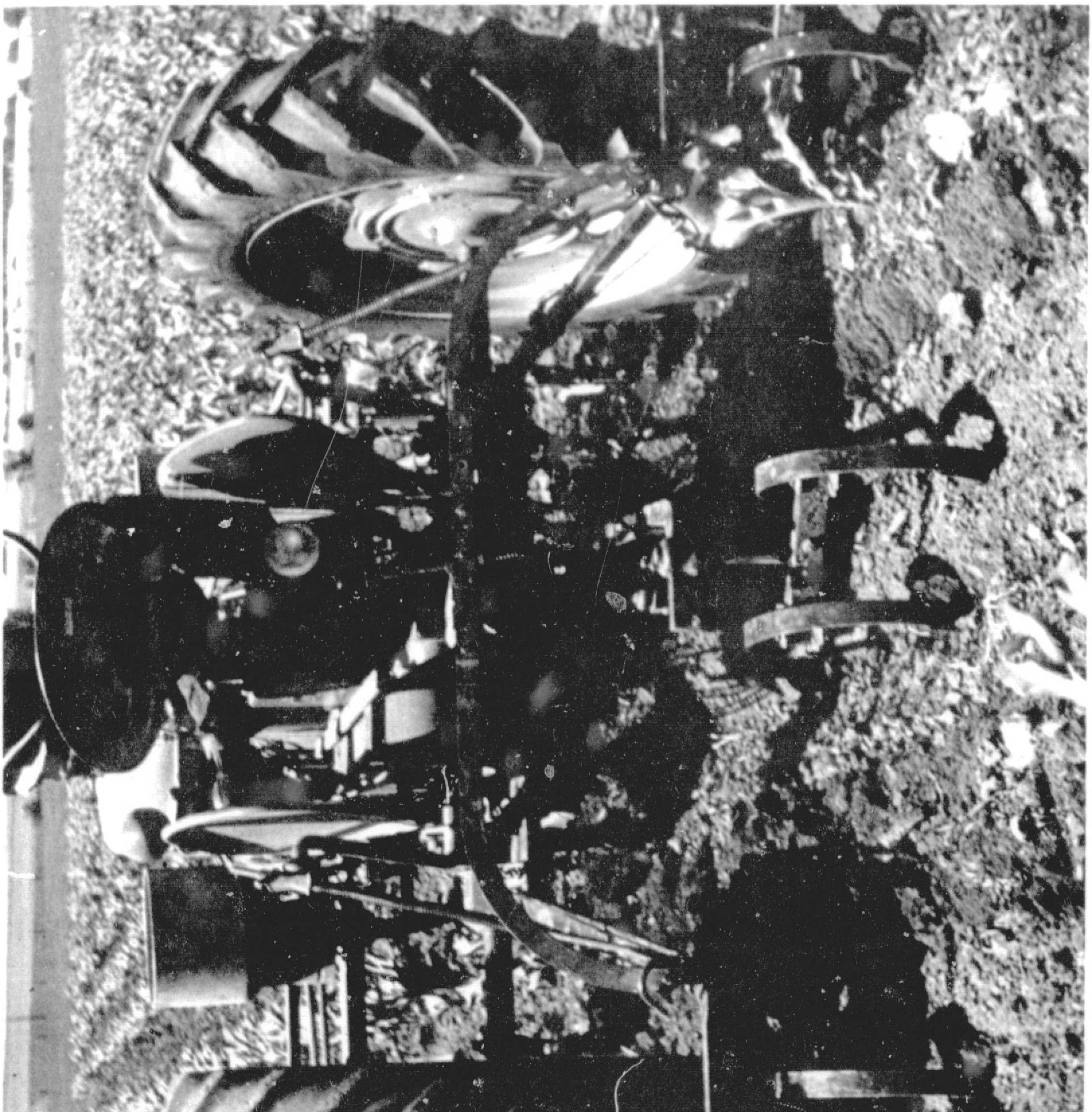
[5]Andrews, R. H., and M. C. Groskopp, "Sweet Corn Cultural Studies on Loamy Sand Under Supplemental Irrigation," Research Report 13, Experiment Station, College of Agriculture, University of Wisconsin, p. 8.

[6]From estimates compiled at the University of Wisconsin Experimental Farm, Hancock, Wisconsin; see Table A3.

to rent out an irrigation system for a short time, and when a complete irrigation system must be paid for, the costs are so high that the irrigation is not practical in the areas which produce a large part of Wisconsin's sweet corn. And, finally, even in the areas where irrigation is needed, the information could not be used to significantly affect sweet corn production, because sweet corn is not grown in great quantities in these areas.

The final area which was selected for analysis was the harvesting operation. Lasting from four to six weeks and taking place in August and early September, the harvest is an especially critical period for sweet corn, during which adverse weather conditions can significantly affect the quality of the sweet corn and on occasion can even cause the abandonment of entire fields. This extreme sensitivity of the sweet corn at harvest reflects processing requirements, which severely limit the time span in which the crop is mature enough to be harvested but not so mature that it is worthless to the processor. The factor with which the processors are most concerned is moisture content, since the amount of water which the grain contains will largely determine how tender that grain will be. Usually only sweet corn with a moisture content between 70% and 78% is considered fit for processing. Anything below 70% is probably too tough for commercial consumption, whereas anything above 78% is probably too immature and would yield poorly. In addition, within the 70%-78% span, price and quality distinctions are often made, with the grain which has a higher water content receiving a better price and being placed in a higher grade than the corn with less moisture. In terms of time, since sweet corn which has begun to mature loses water at a rate of about 1% per day, the farmer has about one week in which he can successfully harvest his crop. Although short, this week-long harvest period does not normally present the farmer with any special problems. However, if the weather should become hot and dry, as it often does in August, the sweet corn will lose moisture at a faster rate, and the farmer will be left with an even shorter harvesting period. At present, such a situation is potentially dangerous, since it can catch the farmer unprepared and force him to abandon portions of the crop that mature before they can be harvested. Field abandonments can also be a problem following heavy, unforeseen rains at the time of harvesting. Although the rain tends to slow down the rate of moisture loss, it can also make the fields impassable to the harvesting machines and thereby slow down the harvest enough so that part of the crop is lost because of overmaturity. The problem at harvest time, therefore, is not so much that the corn is positively damaged by the weather, but that the harvest period is so short that the farmers and processors are often unable to adapt adequately to rapid, unexpected changes in weather conditions.

In view of the above situation, it was not difficult to conceive of the role that a seven-to-fourteen-day forecast might assume during the harvest period. As with the planting operation before, the improved forecasts could offer the farmers and processors the time and knowledge which they would need in order to deal adequately with losses which excessive heat or rain could bring about. Specifically, this would involve speeding up the harvest in response to poor weather conditions so that it could be completed before any part of the crop could become overmature. The execution of such an operation, of course, would require the use of extra resources: extra labor and machinery to bring



in the crop, and extra processing facilities to handle the increased loads of corn. This would not present a problem, however, since to a certain extent these additional resources either already exist, or else they can be obtained fairly easily. To have a real impact, nevertheless, such resources would have to be allocated at the right times and in the right amounts, and it is clear that current weather forecasts do not offer enough information to allow this to be done. As stated before, however, the longer range forecasts could fill this gap and, in doing so, could conceivably lead to a real reduction in losses, the magnitude of which would depend upon the nature and magnitude of the harvesting period losses.

In order to determine the level of savings that could be achieved during the harvest period, the production records of processing companies along with the annual production summaries of the U. S. D. A. were examined. When a similar investigation was undertaken earlier in hopes of determining the savings which would be forthcoming during the planting period, the search for records proved futile, and the possibility of savings insignificant. In this latter case, however, the investigation was much more productive, with the records which were found providing both a means of confirming the nature of the harvesting problem and also a basis for making estimates of an overall level of savings.

As presented on a hypothetical level, the nature of the harvesting problem rested on basically two conditions, both of which tended to be borne out by specific data. In one of these conditions, the passing over or abandonment of overmature sweet corn was attributed to the disruptive effects that heat waves and rainy spells could have on the harvest operation. That heat and rain can actually have such effects was then borne out by matching the specific days on which abandonments took place with the weather conditions for those days. In 1968, for example, the records of one company showed that 66% of the acreage which had to be abandoned that year was abandoned within a four-day period (August 21 to August 24) in which the weather was hot and dry. Before and after this period, when the temperatures were more moderate, the losses were either reduced or did not occur at all, with one exception being a flurry of abandonments in early September which coincided with a period in which rain fell on seven out of the first nine days of the month.[7] Empirical evidence existed, then, which indicated a link between these particular weather conditions on the one hand and harvesting abandonments on the other. This was important, because with the existence of such a link one could be reasonably confident that a forecast involving heat or rain would also involve some abandonments and that preventative measures taken in response to these weather events would act to cut down the losses. If the link had been less direct, however, and there had been no positive connection between specific weather events and the number of abandonments, there would have been less of a reason for concluding that weather forecasts could be useful in the prevention of such losses.

The second condition on which the theoretical analysis of the harvest rested involved the importance of overmaturity as a cause of crop abandonments.

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[7]Crop data taken from correspondence of July 29, 1970, with Paul E. Schulz, Associate Director of Agricultural Research, Libby, McNeill, and Libby; weather information taken from U. S. Department of Commerce, Weather Bureau, Climatological Data, Wisconsin, Vol. 72-73, 1967-68, pp. 123, 127, 135, 139 (under listings for Janesville, Wis.); see Table A4.

As it was presented initially, overmaturity was a central factor which could be implicated as the ultimate cause of most of the weather-related abandonments during the harvest period. As it turned out, judging from the reasons for abandonment which were listed in processing company records and from a number of subjective opinions, this initial statement was correct. In fact, when the reasons for abandonment were listed specifically in production records, overmaturity turned out to be the primary factor, accounting for the greater part of the recorded losses. Although it would be difficult to base a sweeping generalization on such evidence, there was thus some basis for concluding that overmaturity is at least one of the major factors in sweet corn abandonments and that it may very well be the primary one.

Given this apparent significance of overmaturity in the overall scheme of sweet corn abandonments, it became possible to estimate the benefits that seven-to-fourteen-day forecasts could bring about. Using the annual crop production summaries of the U.S.D.A. as the source of information, the number of acres not harvested and the value of that acreage for each of the last ten years was calculated. For the greater part of this period, the number of acres not harvested amounted to between 5% and 10% of the planted acreage for the year, and in one year (1965) abandoned acres with a value of about $2.3 million amounted to 23% of the acres planted. Although all of these losses could not have been caused by overmaturity and could probably not have been prevented even if longer range weather forecasts had been available, overmaturity undoubtedly did account for a significant proportion of them, and this proportion would constitute the amount that improved weather information could help to eliminate. At most, then, these overall figures represent an upper limit on the amount of savings that could be brought about. But even so, assuming that losses without the improved forecasts would run at about 8% per year (as they have averaged for the last decade), it would not be inconceivable if two-thirds of these abandonments (equivalent to about 5% of the planted acreage) could be consistently prevented.

APPENDIX

Table A1

Costs and Returns Per Acre of Sweet Corn

I. Receipts*	
1. Gross Returns per Acre	$123.75
2. Net Returns per Acre	13.52
Variable Costs	
1. Fertilizer and Lime Cost	$ 15.50
2. Seed	5.50
3. Insecticide and Herbicide	10.25
4. Machine Operation	25.70
5. Interest on Above (6 months at 8%)	2.28
6. Total Variable Costs	$ 59.23
III. Fixed Costs	
1. Machinery and Equipment	$ 5.00
2. Land—annual charge at 8%**	40.00
3. Labor—3 hrs. /acre at $2/hr.	6.00
4. Total Fixed Costs	$ 51.00

*Based upon a yield of 5.5 tons per acre and a harvest time price of $22.50 per ton.

**Land charges allow 6% for interest and 2% for taxes and repairs.

Source: "Costs and Returns, Sweet Corn," Wisconsin Farm Enterprise Budgets: Field and Forage Crops (Department of Agricultural Economics, University of Wisconsin, June 1969), p. 12.

Table A2

Investment in Land and Equipment for Determining Irrigation Costs
1970

		Est. Life
Land—160 acres of sandy soil at $100/acre	$16,600.00	
Pipe—2560' of 6-inch main with valve outlets, tees and 4 laterals, 1250' long, 4 and 4 inch all aluminum pipe	10,356.35	20 years
Sprinklers—100 - 2 nozzle - 20 gpm	1,500.00	5 years
Well—100 feet - 18" or 20" casing and screen	2,350.00	20 years
Pump—Turbine - 1200 gpm	1,900.00	10 years
Power Plant—Electric 75 hp	2,400.00	10 years
INVESTMENT IN IRRIGATION EQUIPMENT	18,406.35	
Investment in irrigation equip./A, 160A	115.04	
TOTAL INVESTMENT (land and equipment)	34,406.35	
TOTAL INVESTMENT (per acre of cropland) 150 acres	229.38	

Source: University of Wisconsin Experimental Farm, Hancock, Wisconsin.

Table A3

Treatment on Alternate Years	Net Return over Variable Costs 1964	1965	1966	1967	1968	Average
1. Potatoes	367.50	390.56	50.97	117.43	96.72	205.04
2. Peas - Snapbeans	138.80	369.96	51.96	101.60	237.77	180.02
3. Peas -- Soybeans	84.70	373.06	18.96	152.54	80.41	141.93
4. Snapbeans	41.25	376.81	54.07	46.45	120.51	127.80
5. Peas	39.97	317.31	20.25	89.68	70.59	107.56
6. Soybeans	53.25	376.51	34.42	109.42	14.84	117.69
7. Sweet corn	58.25	360.26	-2.23	117.02	27.76	112.21
8. Field corn	62.85	371.51	2.22	152.75	39.36	125.74
9. Barley	20.07	370.11	-32.22	169.91	-18.16	101.94

Source: University of Wisconsin Experimental Farm, Hancock, Wisconsin.

Table A4

Sweet Corn Abandonment and Weather Conditions

Date	Acres abandoned	% of total abandonments	Temperature high	Temperature low	Precipitation (inches)
8/12/68	28.80	3.5%	77	54	-
8/13/68	-	-	88	63	-
8/14/68	-	-	84	63	-
8/15/68	-	-	84	56	.06
8/16/68	10.00	1.0%	90	70	.11
8/17/68	25.60	3.0%	80	63	.02
8/18/68	22.50	3.0%	77	54	trace
8/19/68	30.60	4.0%	90	67	.07
8/20/68	30.51	4.0%	95	69	.58
8/21/68	130.11	16.0%	92	74	-
8/22/68	238.09	29.0%	93	72	-
8/23/68	56.47	7.0%	94	74	-
8/24/68	114.20	14.0%	89	74	-
8/25/68	16.50	2.0%	74	59	-
8/26/68	20.30	2.5%	70	51	-
8/27/68	-	-	75	46	-
8/28/68	-	-	76	43	-
8/29/68	-	-	78	51	-
8/30/68	-	-	78	52	-
8/31/68	-	-	73	59	-
9/ 1/68	-	-	73	55	.64
9/ 2/68	-	-	76	50	.34
9/ 3/68	-	-	87	58	-
9/ 4/68	-	-	82	67	.01
9/ 5/68	15.14	2%	76	52	.76
9/ 6/68	10.86	1%	69	49	.33
9/ 7/68	62.95	8%	73	44	-
9/ 8/68	-	-	73	63	.48
9/ 9/68	-	-	69	57	.72
9/10/68	-	-	63	54	trace

Sources: Crop information from correspondence of July 29, 1970, with Paul E. Schulz, Associate Director of Agricultural Research, Libby, McNeill and Libby; weather information from U. S. Department of Commerce, Weather Bureau, Climatological Data, Wisconsin, Vol. 73-72, 1967-68, pp. 123, 127, 135, 139 (under listings for Janesville, Wis.).

Table A5

Wisconsin Sweet Corn Losses (1951-1969)

Year	Non-harvested acreage (total and % of planted acres)	Yield (tons/acre)	No. of tons abandoned	Value of non-harvested acreage per ton	per acre	total
1969	5,000 (4%)	3.57	17,850	$23.70	$84.50	$ 422,500
1968	10,800 (7.8%)	4.35	46.980	23.00	100.05	1,080,540
1967	10,100 (8.1%)	3.76	37,976	22.00	82.72	835,472
1966	4,300 (3.6%)	3.95	16,985	19.70	77.81	334,583
1965	26,600 (23.2%)	4.19	111,454	20.70	86.73	2,307,018
1964	5,900 (6.2%)	3.75	22,125	19.30	72.28	426,452
1963	2,500 (2.5%)	3.86	9,650	18.70	72.18	180,450
1962	9,200 (7.9%)	3.67	33,764	18.20	65.99	607,108
1961	6,000 (5.3%)	3.49	20,940	17.60	61.42	368,520
1951-60	7,260 (6.6%)	3.02	21,925	19.20	57.98	420,934

Source: "Annual Summary Vegetables—Processing," USDA Statistical Reporting Service, Crop Reporting Board, Washington, D.C., 1962, 1964, 1966, 1969.

THE IMPACT ON THE HAY INDUSTRY OF IMPROVED SATELLITE WEATHER FORECASTS

Kenneth R. Smith, Frederick H. Boness and Dale Smith*

Introduction

The present paper is concerned with how weather forecasts will affect the value of the Wisconsin hay crop. While weather is an important variable at various stages in the production process with most agricultural crops, for the hay crop the effect occurs primarily during the harvesting operation. Once hay is cut it must remain in the field until the moisture content has been reduced to about 20% If drying conditions are poor, the value of the hay may decline significantly. With modern technology, today's farmer has an opportunity to adjust the cutting date, select a harvest method, and increase the value of the crop of reliable weather forecasts are available.

The possibility of quantifying this improvement arises because the value of the hay can be expressed in terms of the total digestible nutrient

*Social Systems Research Institute, University of Wisconsin. We wish to acknowledge the invaluable assistance of Professors P. N. Drolsom and D. A. Rowheder (Agronomy). We would also like to thank A. Torkelson and L. Werner for computational and programming assistance. We are, of course, solely responsible for any errors that remain.

(TDN) and crude protein contents of the hay. Studies have shown that the quantity of milk produced by dairy cattle is directly related to their TDN and protein intake. If the TDN intake from hay alone is insufficient to obtain a high level of milk production, then the farmer must supplement with corn grain and, perhaps, some protein to increase the nutrient intake. This involves a variable cost to the farmer since he must purchase the protein supplement outright and forego the opportunity of selling his otherwise marketable corn. The magnitude of this cost will depend on the TDN content of the hay that the farmer harvests. The crop can therefore be evaluated in terms of the TDN content and the effect of weather forecasts on the expected value can be determined.

Objectives

Our approach is, first, to develop a model which will provide an estimate of the expected cost associated with hay as it is being harvested under present conditions (without weather forecasts) and, second, to modify the model so that we can estimate the expected cost associated with hay as it would be harvested if weather forecasts were available.

The following considerations affect the scope of our estimates. First, we have attempted to estimate the improvement due to weather forecasts only for Wisconsin. However, our conclusions are likely to be applicable to Minnesota, Michigan, New York, and Ontario, Canada. In all these major hay-producing areas, weather patterns at the time of cutting are similar and the hay is used primarily for the same purpose—as feed for dairy cattle.

Table A-1 in the appendix provides information on the amount of activity in states where the results apply. Second, our data and conclusions are limited to alfalfa and alfalfa mixtures (which are mainly alfalfa). To include other types of hay would require a separate study since many of the relevant factors are different for each type of hay. However, alfalfa is the largest single type of hay grown, accounting for 75% of all hay grown in Wisconsin. Third, we concentrate most of our attention on the June harvest as it is most susceptible to bad weather and it represents the largest cutting, constituting 50% of the total crop when three cuttings are made and 65% of the total crop when only two cuttings are made. Fourth, we have not taken account of the possibility of producing low moisture silage. If the farmer chooses to make silage rather than hay he could reduce the length of the drying period by a day. This would tend to reduce the size of the benefit we derive by assuming all alfalfa is made into hay. However, the total effect was not felt to be significant because the amount of alfalfa silage produced in Wisconsin is only about 10% of the total crop, most of which is made from the first cut, and also the ability to expand silage production is limited by the availability of silo space.

Development of the Model

TDN Content of the Hay

Several features in hay harvesting are relevant to determining the TDN content of the hay crop with or without weather forecasts. First, there exists a desirable cutting date which reflects the fact that the TDN content of hay reaches a maximum at first flower and thereafter declines. Thus, if the farmer were assured good drying conditions, he would obtain maximum TDN yields per acre by cutting the hay crop on the date of first flower.[1] In our calculations we use the average date that first flower has occurred over a number of years. This average date occurs later in June, the farther north in Wisconsin that one goes. Therefore, the state of Wisconsin is divided into regions according to date of first flower and according to common rain probabilities. Approximately the same first flowering date and rain pattern occurs within a region. (See Table A-2 and Figure 1 in the appendix for further information on the division of the state into regions.)

Second, in reality, the length of the drying period required to obtain hay with 20% moisture will depend not only on whether or not it rains but also on weather factors, such as temperature, humidity, cloud cover, and wind. To develop a model which incorporates all these factors would be very difficult. Therefore, in an attempt to take account of some of the possible variation in the length of the drying period, we have explored two alternative sets of assumptions about the length of time required to dry the hay. In both cases we assume that the hay is cut on a dry day. In the first case, we assume that to dry the hay satisfactorily requires three consecutive dry days; that is, to obtain top quality hay (the best possible for a given cutting date) the first three days must all be dry.

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[1]In Wisconsin, maximum quality alfalfa hay has been estimated to have a TDN content of 70%. We used this figure as the maximum TDN content throughout the study.

For our second case, we assume that if the two days after the cutting date are both dry, then the hay will have attained maximum value for the given cutting date. However, in the absence of such ideal conditions, the drying period is either two or three consecutive dry days, depending on whether the rain occurs shortly after cutting or when the hay is almost dry.

Third, we account for the loss in value from nonideal drying conditions after the hay has been cut. Once the hay has been cut, its value (TDN content) cannot increase. If drying conditions are poor, the value of the hay will decline, perhaps significantly. This loss in value occurs for a number of reasons. If the hay is rained on shortly after being cut, it dries slowly, permitting enzymes in the hay to remain active and reducing the amount of total digestible nutrients. It may also encourage uneven drying, resulting in either excessive loss of leaves or the possibility of mold. On the other hand, rain occurring when the hay is almost dry will result in leaching of soluble minerals and excessive loss of leaves due to shattering. We incorporate these factors into our model by evaluating the hay on the basis of the rain pattern during the six days that follow the cutting date.[2] If the drying requirement has not been satisfied after six days, the hay will have

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[2] Because we use only rain as the determinant of whether or not to cut, we are forced to assume the farmers completely disregard any presently available weather forecasts. We have selected rainfall greater than .1 inches for determining whether or not a day is wet or dry. See Feyerherm, Bark and Burrows, "Probabilities of Sequences of Wet and Dry Days in Wisconsin," Kansas Agricultural Experiment Station Bulletin 139g, 1965.

reached its minimum TDN value. There are sixty-four different configurations of wet and dry days that can occur in the six-day evaluation period. For each possible configuration it was necessary to assign a TDN value to the hay. We have grouped these sixty-four possibilities into nine categories, each category consisting of those possibilities which have a common TDN value. Table A-3 in the appendix indicates in detail the various types of drying periods used and the estimated TDN content assigned to each. It should be noted that the groupings are not identical for the two cases examined. We let p_{ij} represent the probability that the j^{th} $(j = 1, \ldots, 9)$ drying category occurs for hay cut on the i^{th} $(i = 1, \ldots, 14)$ day. This is computed by determining the probability that the specific sequences of wet and dry days included in the j^{th} grouping will occur beginning on day $(i + 1)$. (See Table A-6 for an example of the p_{ij}.)

Fourth, we take account of the decline in TDN content following the peak value at first flower. To do this we subtract three-fourths of 1% of the TDN content for each day the hay is left standing in the field after first flower up to seven days. For the next seven days, to reflect the accelerated nature of the decline, we subtract 1-1/4% of the TDN content per day. The farmer will almost always cut within fourteen days of first flower, so that a second and possibly a third cut can be achieved later in the season. From the previous two considerations we obtain a matrix T_{ij} $(i = 1, \ldots, 14,$ $j = 1, \ldots, 9)$ where the ij^{th} entry is an estimate of the TDN content of hay cut on the i^{th} day and dried under the j^{th} type of drying pattern.

The Cost of Supplement

Because most of the hay grown in Wisconsin is used on the farm where it is produced, there exists no well-established market price which satisfactorily discriminates between hay of various TDN contents. This fact eliminates the possibility of computing directly an expected benefit from weather forecasts. However, as we have already indicated, it is possible to evaluate the hay by estimating the cost associated with bringing the hay to a specified nutritional level.

For this study, a nutritional level which would yield a milk output level of around seventy-five pounds per day was chosen. This high level of milk production is achieved by only a few farmers but it was the opinion of agronomy staff, familiar with the dairy situation, that this is the level of milk production which the farmer should aim for and the one appropriate for evaluating the hay. Table A-4 in the appendix illustrates the cost associated with hay of various TDN contents.[3] These data are used to transform the T_{ij} matrix, which provides estimates of the TDN content associated with hay cut on a particular day and dried under specific conditions, into an S_{ij} matrix giving the corresponding costs of supplement.

It should be pointed out that, because we have assumed in this study

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[3]The estimates of cost are based on bringing a ton of hay up to a specified nutritional level. A factor which is not included in the estimates is the likely decline in hay consumption by the cow if the TDN content is very low. This fact would tend to raise the cost of obtaining a constant milk output level. However, we have ignored it because there is no satisfactory way of taking account of this intake factor.

that hay of maximum quality (that is, hay cut on first flower and successfully dried without rain) has a 70% TDN content, our estimates imply that the minimum cost which the farmer must pay for supplemental feed is $17.28 per ton of hay and that this minimum cost will occur only when his hay has been cut on first flower and dried under ideal conditions. We will be interested in determining from the models how much more per ton the farmer will have to pay on the average to supplement the hay without weather information than he would have to pay with weather information.

The Decision to Cut

The difference between the models with and without weather forecasts occurs in the method used to determine when the farmer will cut his hay. In the model with weather forecasts, the decision to cut is made on the basis of the weather knowledge. That is, the probability that the farmer will cut on the date of first flower is the probability that this date and the next three days (or two for the second case) will be dry. Similarly, the probability of cutting on any of the next thirteen days is equal to the probability of that date plus the next three days being dry given that the hay has not already been cut. This procedure insures that for whatever day the farmer cuts the hay (during the first thirteen days), he will have maximum value for that particular date, since by assumption the hay is always successfully dried. We should note that these decision procedures implicitly assume that the weather forecasts are for at least three (or two) days into the future and are always perfectly accurate.

In the model without the weather forecasts we assume the grower used the naive decision criterion of cutting the hay at the first opportunity after first flower that he has two consecutive dry days. That is, the probability that the farmer cuts on the first flower date is equal to the probability that the preceding date and that date are both dry. Similarly, the probability of cutting on any day following first flower (up to the fourteenth day) is equal to the probability that the day preceding and the day itself are both dry, given that the hay has not already been cut. The decision criterion is based on the notion that the farmer will not cut the hay if it is wet and also that he operates on the rule of thumb that tomorrow will be like today. As noted earlier in the paper, both models terminate at the fourteenth day because the grower wants to get a second and possibly a third cut later in the season and because the value of standing hay starts to decline quite rapidly beyond fourteen days past first flower. We let c_i $(i = 1, \ldots, 14)$ represent the probability of cutting the hay on the i^{th} day where $i = 1$ is the date on which first flower occurs.[4]

The Expected Cost

The expected cost of supplementing the hay can be computed by multiplying the cost associated with a particular outcome by the probability of

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[4]Tables A-5 and A-6 in the appendix provide information on the probabilities of cutting on various days and the probability of various drying periods' occurring for hay cut at first flower. A more complete summary of all the data is available from the authors upon request.

that outcome occurring and then summing over all possible outcomes. This can be written in precise mathematical form using the notation developed above. We then have the expected cost of supplemental feed per ton of hay for the model without weather information is:

$$\hat{C}_{NI} = \sum_{i=1}^{14} c_i \{\sum_{j=1}^{9} p_{ij} s_{ij}\}.$$

For the case with weather information the expected cost of supplemental feed per ton of hay can be written;

$$\hat{C}_I = \sum_{i=1}^{13} c_i p_{i1} s_{i1} + c_{14} \{\sum_{j=1}^{9} p_{14j} s_{14j}\}$$

where $j = 1$ represents ideal drying conditions (no rain).[5]

Empirical Results

The results of the empirical analysis are presented in Table 1. For the case in which a three-day minimum drying period was assumed, the expected costs of supplementing the hay ranged from a low of $32.45 to a high of $38.47 without weather forecasts and from a low of $20.14 to a high of $23.30 with weather forecasts. The average cost is $35.83 without and $21.93 with forecasts for the first crop of hay in June. The savings in cost of supplement due to weather forecasting ranges from $12.26 to $15.57 per

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[5]To compute the expected cost figure, we take the average of the costs associated with each TDN content rather than the cost of the average TDN content. These alternatives would differ because the relationship between TDN content and the cost of supplementing the hay is not linear.

Table 1

Expected Cost of Supplenting one Ton of Hay

Sector	3-day minimum drying period			2-day minimum drying period		
	Weather without forecasts	With weather forecasts	Savings/ use of forecasts	Without weather forecasts	With weather forecasts	Savings/ use of forecasts
1 Spooner	$36.09	$21.78	$13.81	$30.58	$18.92	$11.66
2 Minocqua Dam	37.96	23.31	14.65	32.56	19.54	13.02
3 Merrill	35.92	21.97	13.95	30.85	18.97	11.88
4 Sturgeon Bay	34.12	20.99	13.13	29.32	18.62	10.70
5 Eau Claire	36.40	22.12	14.28	31.29	19.11	12.18
6 Marshfield	38.47	23.30	15.17	30.05	19.54	10.51
7 Virocqua	35.49	21.70	13.79	30.51	18.90	11.61
8 Hancock	35.18	21.59	13.59	30.26	18.79	11.47
9 Plymouth	32.45	20.19	12.26	28.09	18.37	9.72
10 Darlington	36.66	22.39	14.27	31.49	19.22	12.27
Average	35.87	21.93	13.89	30.50	18.96	11.50

ton or an average of $13.89.[6]

For the case in which a 2-day minimum drying period was assumed, the expected cost with and without weather forecasts was lower than the corresponding expected cost for the case of a 3-day drying period. This is to be expected since the probability of successfully drying the hay is increased. For a 2-day minimum drying period, the range is $28.09 to $32.56 without and $18.37 to $19.54 with weather forecasts. The average savings resulting

[6]Recalling that the cost of supplement for hay dried under ideal conditions is $17.28 per ton of hay, this means that without weather forecasts the farmer is paying an average of $18.50 per ton more for supplement than he would have to if his hay were always cut and dried under ideal conditions whereas with weather forecasts he would only pay an average of $4.65 more per ton.

from weather forecasts is also somewhat smaller, being $11.50 for the first crop of hay in June.

Our results indicate that the expected cost can be reduced with weather forecasts by approximately $10 to $15 per ton of alfalfa hay. Since this range applies only to the June cutting, we must estimate the quantity of the total hay production cut in June. Table 2 summarizes the magnitude of the savings for the state at a saving of $10 per ton and also at a saving of $15 per ton, for three different assumptions based on the quantity of hay cut in June. In the first case, we assume that 50% of the total hay production is cut in June; this is likely to be the case when three cuttings are made. In the second case we assume that 65% of the total hay is cut; this would be the situation where only two cuttings are made. Finally, the agricultural extension service recommends three cuttings in the southern two-thirds of Wisconsin (sectors 5-10) and two cuttings in the northern one-third of Wisconsin (sectors 1-4).

Table 2

Value of Total Savings at June Cutting for the State of Wisconsin

% of hay cut in June	Tons cut in June	Total savings, if savings is $10.00 per ton	Total savings, if saving is $15.00 per ton
(1) 50% entire state	4,258,000	$42,580,000	$63,870,000
(2) 65% entire state	5,586,000	55,860,000	83,790,000
(3) Extension service recommendation	4,432,000	44,320,000	66,480,000
65% (sectors 1-4)	755,000	7,550,000	11,328,000
50% (sectors 5-10)	3,677,000	36,770,000	55,155,000

The implication of these three alternatives is that the expected aggregate savings will fall in a range with a minimum of approximately $42 million when 50% of the total production is cut in June with a saving of $10 per ton and a maximum of approximately $84 million when 65% of the total production is cut in June with a saving of $15 per ton. The expected aggregate savings under the extension service's recommendation is $44 million when the saving is evaluated at $10 per ton and $66 million when the saving is evaluated at $15 per ton. In order to put these expected aggregate savings in perspective, we observe that the total value of the milk sold to plants and dealers in Wisconsin was slightly over $800 million in 1968. This implies that our expected saving is 5% to 10% of the value of the milk sold (by farmers) in Wisconsin.

We have also explored the sensitivity of our final results with respect to two of our restrictive assumptions. First, we have determined the savings that would result from weather forecasts for the July and August cuttings. The model was analyzed for selected regions using rain probabilities from mid-July and from late August. The results indicate that the expected costs without weather forecasts decline about $4 per ton (for both July and August cuttings) while expected costs with weather information would decline about $2 per ton. Hence, the saving would in general be about $2 less per ton than in June (that is, the range was $8 - $13). This would increase the total benefit in Wisconsin by a substantial amount. This conclusion did not seem to represent adequately the real situation. Experience indicates that the farmer is much more likely to dry his hay successfully in July and August than in June. The reason for this is not only the decrease in the likelihood of rain occurring but also that temperatures are likely to be much higher in July and August so that the hay may actually dry in one to one and a half days rather than the two or three days assumed in our models. Because our model takes account of the decreased probability of rain, but not the shorter drying periods, it seems likely that the expected cost without weather forecasts in particular has been overestimated and hence the expected savings may be considerably less for July and August than our selective investigation indicates.

Second, we examined the effect on our results if the weather forecast is not perfectly accurate. Specifically, if the probability of cutting remains unchanged in the model with weather forecasting, but for some percentage of the time the forecast is wrong and rain occurs on the second day of the drying period, the expected cost incurred from following the weather information will be higher than if the forecast is perfectly accurate. By evaluating the hay for each of the possible weather patterns which could occur on days three through six, the model with a two-day drying period indicates that a weather report of 70% accuracy will have the same value to the farmer who uses the weather forecasts as would a naive decision rule. For the model with a three-day drying period, or for an inaccurate forecast involving rain on the first day, this break-even percentage would be somewhat lower. If the accuracy of the weather forecast is greater than this break-even level, then it will pay the farmer, on average, to follow the forecast rather than his naive decision rule. If the forecast is less accurate than this percentage, it should be ignored. Thus, within this context, this study provides evidence that dairy farmers could, with weather forecasts of only two or three days length, reduce their feed costs quite significantly. This conclusion of course depends upon the forecasts being accurate and, in addition, the farmer being willing to base his harvesting decision on these forecasts.

The expected savings derived in this study are applicable to farmers who supplement their hay in order to obtain a high level of milk output (our gross estimates of savings assumed that all farmers do this). However, if the farmer is to receive actual cash benefits he must be able to sell, at the current price, the corn which he no longer requires as supplement for his hay. Alternatively, he may reduce the amount of corn he plants as feed; his savings will then amount to the reduced costs of corn production and also any profit he is able to make by putting the land to some other use. Any resources devoted to producing forecasts that are accurate less than 70% of the time are simply wasted.

APPENDIX

Table A-1

1967 Alfalfa Hay Production in the U. S., Selected States and Canada

State	Rank among the 50 states	No. of acres harvested	No. of tons produced	% of total U. S. production
Wisconsin	1	2,988,000	8,068,000	10.87
Minnesota	3	2,332,000	6,063,000	8.17
Michigan	11	1,282,000	2,756,000	3.71
New York	8	1,231,000	3,087,000	4.16
Total of these four states	-	7,833,000	19,974,000	29.92
Total for U. S.	-	28,162,000	74,204,000	100.00
Ontario, Canada[7]	-	3,440,000	8,944,000	-

Source: Agricultural Statistics 1969, USDA 1969, pp. 269-270. Quarterly Bulletin of Agricultural Statistics, Jan.-March 1968, Dominion Bureau of Statistics, p. 23.

[7]This figure applies to all tame hay production, not just alfalfa.

Table A-2

Division of the State into Regions

Sector number	Weather station whose rain probabilities were used	First flowering date (June)	Total amount of hay (alfalfa) produced in sector (1968, tons)	Total number of acres harvested (1968)
1	Spooner	21	421,430	180,200
2	Minocqua Dam	21	42,720	21,700
3	Merrill	21	72,280	29,800
4	Sturgeon Bay	17	625,610	246,300
5	Eau Claire	14	835,330	290,000
6	Marshfield	14	932,440	348,700
7	Virocqua	9	1,297,930	465,000
8	Hancock	9	1,477,940	492,000
9	Plymouth	9	887,220	291,100
10	Darlington	5	1,923,100	624,500

Sources: First flower dates: Smith, Dale: "The Establishment and Management of Alfalfa," College of Agricultural and Life Sciences, Bulletin 542, June 1968, p. 18. Acreage and tons: 1970 Wisconsin Agricultural Statistics, Wisconsin Statistical Reporting Service, June 1970, p. 28.

Table A-3

Estimated TDN Contents of Alfalfa Hay for Various Types of Drying Periods

Drying period number	Type of drying period (3-day min. dry period)	TDN content	Type of drying period (2-day min. dry period)	TDN content
1	DDD---	70	DD----	70
2	WDDD--	65	WDDD--	62
3	WWDDD-	55	WWDDD-	55
4	WWWDDD	41	WWWDDD	50
6	DWWDDD	45	DWWDD-	45
7	DDWDDD	50	DWWWDD	40
8	WDWDD	41	WDWDD-	41
9	Anything else	35	Anything else	35

D means a dry day, W means a wet day, - means either, because hay has already been removed from the field.

Table A-4

Estimated Total Cost of Corn and Protein Required to Supplement One Ton of Alfalfa Hay*

TDN content (%)	Total cost
100	$ 0
80	11.52
70	17.28
60	38.44
50	51.20
40	61.16

*Corn valued at $.024/lb. and protein supplent at $.07/lb.

Table A-5

Probability of Cutting on a Given Date for Eau Claire Sector (c_i)

	3-day minimum drying period		2-day minimum drying period	
Day	Without weather forecasts	With weather forecasts	Without weather forecasts	With weather forecasts
1	.57044	.34174	.57044	.44152
2	.12885	.07719	.12885	.09973
3	.12890	.07722	.12890	.09976
4	.06574	.07722	.06574	.09977
5	.04257	.07752	.04257	.06193
6	.02503	.05496	.02503	.04823
7	.01533	.04678	.01533	.03783
8	.00985	.04315	.00948	.02961
9	.00550	.03453	.00550	.02095
10	.00327	.02818	.00327	.01568
11	.00189	.02365	.00189	.01171
12	.00110	.01996	.00110	.00861
13	.00064	.01658	.00064	.00642
14	.00090	.08132	.00090	.01825

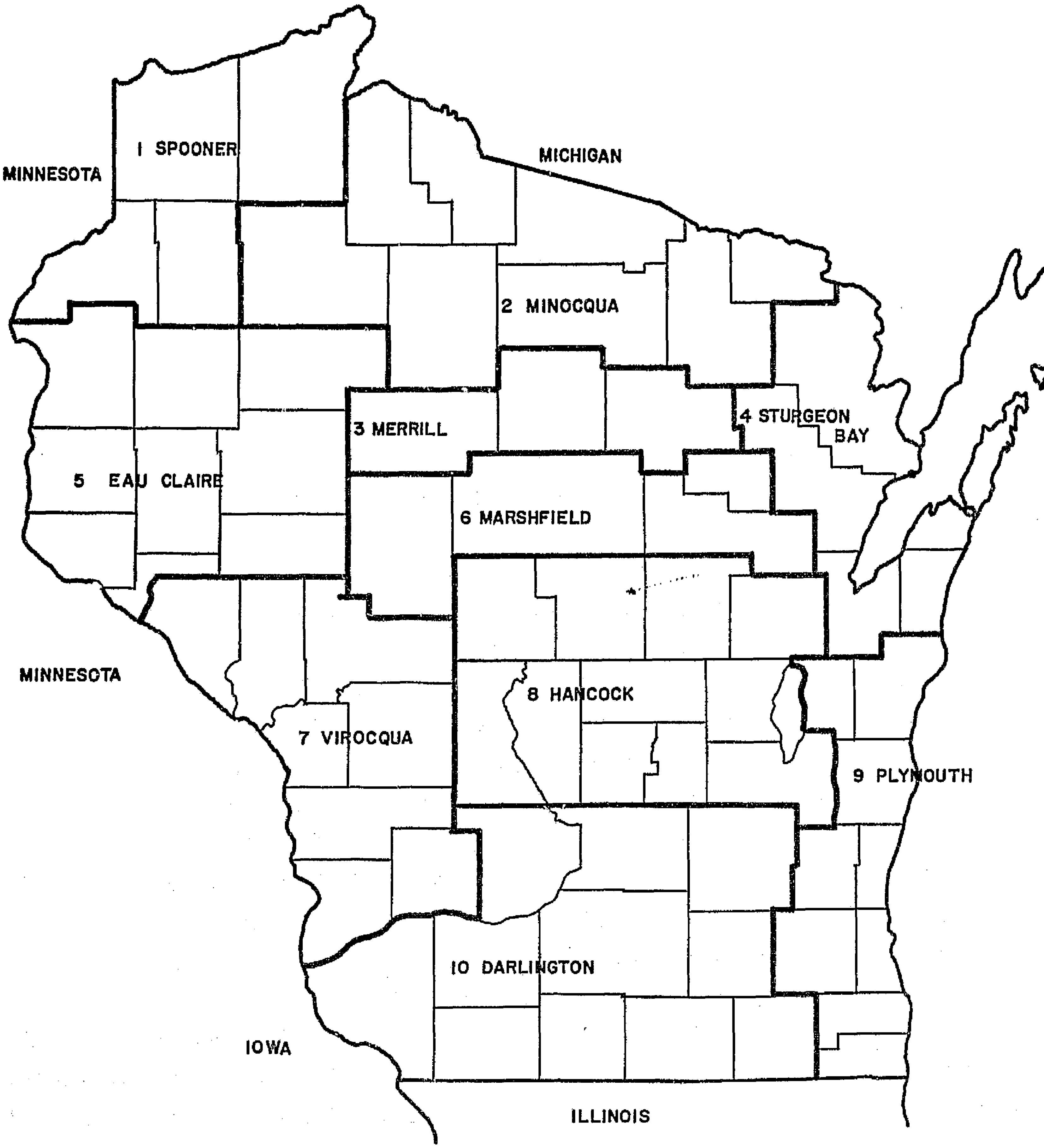
Table A-6

Probability of Different Drying Periods Occurring for Hay Cut in Eau Clair Sector (p_{ij})

(3-day minimum drying period)

Day (i)	Drying Period Number (j)								
	1	2	3	5	8	4	6	7	9
1	.464	.086	.032	.066	.012	.012	.024	.052	.253
2	.464	.086	.032	.067	.012	.012	.025	.052	.252
3	.464	.086	.032	.067	.013	.012	.026	.055	.245
4	.465	.086	.034	.071	.013	.011	.023	.055	.241
5	.467	.092	.030	.070	.014	.010	.022	.055	.239
6	.469	.091	.030	.071	.014	.010	.023	.055	.239
7	.469	.091	.030	.071	.014	.010	.023	.055	.239
8	.469	.091	.030	.071	.014	.010	.023	.055	.238
9	.469	.091	.030	.071	.014	.010	.023	.055	.237
10	.469	.091	.030	.071	.015	.010	.025	.059	.229
11	.471	.092	.032	.076	.015	.009	.021	.059	.226
12	.473	.098	.027	.075	.016	.007	.021	.059	.224
13	.475	.097	.027	.076	.015	.007	.021	.060	.224
14	.475	.097	.027	.076	.015	.007	.021	.060	.224

STATE OF WISCONSIN COUNTY OUTLINE MAP



FIGURE, I

THE ROLE OF TECHNICAL LANGUAGE AND COMMUNICATION SYSTEMS IN DISSEMINATING METEOROLOGICAL INFORMATION TO USERS

John E. Ross*

Introduction

The capabilities of the National Weather Service to deliver increased amounts and kinds of information are obvious. Agriculture is a sector that can benefit.

Given the existence of new satellite meteorological information and given cost/benefit justification of its importance, there is the very real chance that potential users of the technical information will not use it.

There are several reasons why this might happen.

1. It is clear that lack of communication can act as a constraint on the use of the technical information. If it doesn't get distributed all the way to the user, it doesn't get used.
2. Users may not understand the content or the meaning of the technical information because of (1) the technical vocabulary load, (2) the abstract concepts involved, or (3) the format of presentation. There

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is considerable evidence that vocabulary and format can be hindrances in technical communication. Studies have been conducted among farmer audiences by the senior author of this paper and others at the University of Wisconsin, in such areas as pesticide use, rural civil defense, animal and soil science technology, and in comprehension of graphic formats.

3. Intervening attitudes can affect the willingness of users to make use of a particular technological system. In the case of meteorological data there is the possibility that folklore is in fact decisive at the point of making a decision. In addition, the credibility of the information or of its source can be a factor in its use.

These all suggest that you could influence the use of the technical information by changing the format and content of the information service whether in broadcast or print media.

Instrument and Sample

This study concentrates on the following questions:

1. What is their comprehension of the technical vocabulary?
2. What are their current media habits in using weather information?
3. What is the current use of weather information among a sample of Wisconsin farmers?
4. How do farmers assess opportunities in using
   a. different weather parameters?
   b. on what time scale?

A copy of the questionnaire is attached as an appendix to this report. The questionnaire sought responses on:

1. Mass media use and preferences in gathering weather information.
2. How weather information is used in making agricultural decisions.
3. Comprehension of sixteen technical weather terms in a multiple-choice format.
4. Comprehension of seventeen technical terms of relative weather intensity in a matching format.
5. Perceived usefulness of fifty-six parameters of weather information, including temperature (4) frost, (6) moisture, (15) storm warnings, (3) wind, (3) cloud cover, (3) warm air masses, (3) cold fronts (3) air pollutants, (9) and general (7).

The sample is purposive, i.e., a mail questionnaire was sent to 258 farmers or farm associated individuals from lists available to the University of Wisconsin College of Agricultural and Life Sciences. These individuals can be expected to be among the top operators in agricultural production. This is not a random sample, which is somewhat more expensive to gather. Based on information gathered informally from other sources, we would expect the individuals surveyed here to be quite similar to top farmers in other parts of the country in their specific interests and in their level of knowledge of weather information. We expect that their responses are somewhat above a random sample of farmers. However, these individuals do represent the bulk of agricultural production.

This survey included:

1. Wisconsin Certified Seed Growers -60
2. Vegetable Growers -49
3. Fruit Growers -25
4. Canning and Freezing Industry Reps. -108
5. Potato Growers -30
6. Lime and Fertilizer Dealers -48
7. Forage Farmers -47

The response rate to the questionnaire was 70. % of [illegible]e total mailing. The questionnaire was pretested in a farmers' club.

The information presented here is descriptive, although some contingency analysis was done. Only the lime and fertilizer dealers stood out as generally significantly less interested in weather information than the other groups.

Results

A. Comparison

The first section of results is concerned with comprehension of technical terms. The terms were selected from weather reports and are in common use. Reported here are the proportions of errors arranged from the "easiest" to the "most difficult" in this test.

The second table gives the actual test and the way in which the respondents answered. In this table, the correct answer is marked X. In each case, the total number equals 258.

Table 1

Technical Terms
(Multiple Choice)

Evaporation	3
Solar Radiation	4
Barometer	5
Precipitation	5
Air Mass	5
Dew Point	9
Smog	13
Atmospheric Pressure	15
Condensation	18
Anemometer	21
Isobar	27
Front	32
Frost Line	36
Degree Day	42
Relative Humidity	48
Cold Wave	49

Table 2

Technical Terms

Nature of Errors

1. Precipitation
   - X a. All forms of falling moisture.
   - 10 b. The point where it starts to rain.
   - 2 c. Water vapor in the air.
   - 0 d. The amount of condensation.

2. Anemometer
   - $9\frac{1}{2}$ a. Measures the high and low relative humidity.
   - X b. An instrument for measuring the force or velocity of the wind.
   - 19 c. An instrument for measuring the atmospheric pressure.
   - 3 d. The speed at which hurricane winds blow.
   - 21 e. No answer

3. Relative humidity
   - $4\frac{1}{2}$ a. A prediction of precipitation
   - $95\frac{1}{2}$ b. The amount of water vapor contained in the air.
   - 2 c. The point at which water vapor condenses.
   - X d. Water vapor in air compared to that required for saturation.
   - 2 e. No answer.

4. Solar radiation
 X a. Energy from the sun which turns into heat
 4 b. The time of sunrise and sunset.
 3 c. The amount of clouds in the sky.
 1 d. Spots on the sun which are believed to cause storms.
 3 e. No answer.

5. Dew point
13 a. 70% relative humidity.
 1 b. The chain of radar stations in North America.
 7 c. The amount of dew that forms.
 X d. The temperature at which water vapor condenses.
 3 e. No answer.

6. Barometer
 X a. An instrument for measuring atmospheric pressure.
 2 b. Predicts the speed and direction of the wind.
 4 c. Sea level pressure.
 5 d. An instrument for measuring relative humidity.
 2 e. No answer.

7. Cold wave
 1 a. The temperature at which the ground freezes.
 $9\frac{1}{2}$ b. A prediction of how long the cold weather will last.
111 c. A continuous period of more or less evenly cold weather.
 X d. A rapid and marked drop in temperature during cold weather.
 1 e. No answer.

8. Smog
 8 a. The point at which the health of plants and humans is affected.
 9 b. Air filled with sand and dust particles.
11 c. The amount of sulphur dioxide in the air.
 X d. A fog made heavier and darker by smoke.
 4 e. No answer.

9. Atmospheric pressure
 4 a. The force of the wind.
17 b. 29 inches.
 X c. The weight of a column of air.
 9 d. The amount of moisture the air will hold.
 7 e. No answer

10. Degree day
$74\frac{1}{2}$ a. The high and low temperatures of the day.
 1 b. The temperature at which moisture condenses.
18 c. The normal temperature for the season.
 X d. A unit for measuring the amount of heat.
12 e. No answer.

11. Condensation

6 a. All forms of falling moisture.
X b. The changing of water vapor to a liquid or solid.
30 c. The changing of a liquid or solid to water vapor.
4 d. The amount of dew.
6 e. No answer.

12. Frost line

X a. The maximum depth to which the ground becomes frozen.
2-3/4 b. The line of Arctic air.
55-3/4 c. How far south the freezing temperature will go.
11-1/4 d. 32° F.
4 e. No answer.

13. Isobar

3 a. Predicts the amount of ice or snow to be expected.
34 b. A subunit of pressure, being 1/100 of a bar—used to measure atmospheric pressure.
7 c. The amount of atmospheric pressure at sea level.
X d. A line connecting places having the same barometric pressure.
24 e. No answer.

14. Evaporation

1 a. The amount of dew to be expected.
3 b. The change of water vapor into a liquid.
3 c. The point at which the soil becomes dry.
X d. The change of liquid water into vapor.

15. Front

25 a. A widespread body of air which approximates horizontal homogeneity.
12 b. A mass of cold air from the polar region.
X c. Long, narrow bands of changing weather between two different air masses.
39½ d. Air in natural motion relative to the surface of the earth—any direction, any speed.
4 e. No answer.

16. Air mass

8 a. A cold air front.
0 b. Atmospheric pressure.
X c. A large body of air which has essentially uniform conditions.
3 d. The force per unit area expressed in inches or millibars.
3 e. No answer.

Table 3 gives the percentage of the sample that missed a given number of the terms, for example, 19% missed five or more terms

Table 3

Number of Technical Terms Missed

	%
0 - 1 wrong	27
2 - 3	37
4 - 5	17
5+	19

The farmers were also asked to assess terminology which indicated relative intensity of weather. Following are the results. This was a matching test.

Table 4

Comprehension Weather Intensity

	% Wrong
Blowing Snow	25
Ice Storm	25
Tornado Warning	24
Freezing Rain	24
Tornado Watch	23
Drifting Snow	19
Snow Squalls	17
Thick Fog	17
Dense Fog	14
Snow Flurries	14
Drizzle	10
Frost	5
Showers	4
Tornadoes	4
Heavy Snow	3
Severe Thunderstorm	3

Table 5 gives the average scores by commodity groups for both tests.

Table 5

Average Comprehension Scores

	Seed	Veg.	Fruit	Canners	Potato	Forage	Lime-Fert.
multiple choice	77.34	79.2	80.0	81.4	81.6	77.1	76.6
matching test	81.3	80.2	83.4	86.0	90.5	81.8	88.1

B. Media and Use

This part of the schedule was designed to determine which information media are now used, which are preferred, why, the helpfulness of the information received, and the farmers' credence in it. It also measured the frequency with which they seek out weather information and elicited some feedback on their interest in a two-week forecast. The farmers' interest in a continuously available weather forecast was asked and they were given an opportunity to place a dollar value on this information. It also gave them an opportunity to list information they do not currently receive, but would like to have available.

Table 6 indicates (1) percentage of sample currently using specific media, (2) preference among the media in current format, and (3) preference in event of continuous availability.

Table 6

Media Use and Preference

Media	Current Use	Rank Current Preference	Rank Continuous Forecast
Radio	95%	1	1
TV	94%	2	3
Own Observations	51%	4	
Newspaper	47%	5	
Farm Publications	26%	6	
Telephone	22%	3	2
Private Meteorology	3%	7	

Note the interest in the telephone.

The next table shows percentage of farmers who specified reasons for their media choice.

Table 7

Reasons for Media Preference

Available when I need it	54%
It is the latest word	46%
More information is given	45%
It is more convenient	43%
It is more accurate	25%
I can understand it better	24%

Eighty percent of the sample found present weather reports helpful, but 20% indicated that they did not. Seventy-one percent of the farmers sampled tried to plan their activities around the weather forecast. When asked which they found helpful, the farmers indicated that one-day and five-day forecasts were most often helpful.

Table 8

Currently Helpful

1 - day advance	92%
2 - day	76%
5 - day	82%
30 - day	35%

Seventy-five percent of the group sought out weather report data at least twice a day, which would indicate that there is an interest in up-to-date, accurate weather forecasts.

Table 9

Seek Information

Once/week	1%
Sev. /week	2%
Once/day	21%
Twice/day	35%
Three/Day	27%
Four/day	13%

When asked why they did not seek out weather information more often, only 50% answered, and they checked the following answers.

Table 10

Reasons for Non-seeking of Weather Information

Not convenient or available	34%
Sufficient or not necessary	32%
Forecasts don't vary; no new information	13%
Not accurate enough	8%

Accuracy criticisms seem low here, but note the number of references to accuracy in voluntary comments listed later.

When asked "Would you be willing to pay for some sort of continuously available forecasting system?" 32% of the farmers said yes, and 51% said maybe. It is interesting to note that 16% of the farmers said NO—that they would not be willing to pay anything for this information. The questionnaire then asked them to specify how much they would be willing to pay.

Table 11

Willingness to Pay for Weather Information

	$1-2	$5	over $5
224 farmers	31%	21%	14%

When told that weathermen would soon be able to supply forecast data to the public with two-week forecasts as accurate as present one-day forecasts, 93% of the farmers said they would find this new development either extremely or very useful.

A variety of responses was obtained from the group when asked in an open-ended format what information they would like to receive which they presently do not. Data are presented here by commodity groups.

C. Assessment of Opportunities

Table 12

Demands for Additional Weather Information

	--Commodity Groups--						
Information requested	Seed	Vegetable	Fruit	Potato	Forage	Canner	Lime Fertilizer
Accuracy	X	X	X	X	X	X	X
Wind speed	X					X	X
Short-range forecasts	X	X	X	X		X	
Long-range forecasts		X	X	X			
Heating units	X						
Historic data						X	
Hail				X			
Humidity				X			
Localized weather infor.							X
Rain					X		X
Frost warnings			X		X		
Soil temp.						X	

The farm audience was also asked to assess the usefulness of weather parameters defined as useful in other parts of the overall study. Responses are reported as the percentage of the total assessing each parameter as critical or useful.

Table 13

Useful Criteria

	% Critical	% Useful
Temperature — current	14	69
low for day	37	53
high for day	19	67
duration	23	68
Frost— time of arrival	64	34
duration	35	52
lowest temperature	49	42
early or late	44	47
ground freeze	22	50
depth frost	5	53
Moisture — rain	52	47
sleet	17	52
freezing rain	18	54
drizzle	14	65
freezing drizzle	17	52
fog	9	61
dew	5	68
hail	50	36
snow	16	62
time arrival	59	38
how much	49	47
duration	48	46
snow cover	6	68
how long between	27	59
drying condition	35	57

Table 13 (continued)

	% Critical	% Useful
Storm warnings — lightning	6	53
severity	34	58
direction	23	64
Wind — speed	29	63
direction	11	70
duration	15	70
Warm Air Masses — where	10	77
when arrive	12	78
what effects	11	71
Cloud Cover — Amount	9	65
duration	11	68
direction	5	55
Cold Fronts — where	28	62
when arrive	33	61
what effects	22	64
Relative Humidity	12	68
Barometric Pressure	5	64
Dew Point	5	49
Solar Radiation	5	41
High and Low Pressure Systems	8	71
Soil Moisture	28	60
Soil Temperature	26	60
Air Pollutants — sand or dust	3	26
sulphur dioxide	2	23
soot or fly ash	1	17
ozone	2	15
nitrous oxides	1	16
carbon monoxide	3	24
flourides	1	11
PAN	-	9

This completes the descriptive analysis.

Farmer Comments

We are including a summary of unsolicited comments arranged by commodity groups for the insights they provide. These are individual comments. At the end of each comment are the scores that the individual got on (1) the multiple-choice test and (2) the matching test.

Group 1—Certified Seed Grain Growers.

> An accurate one-week forecast would be invaluable. Wind is especially important during the spraying season—the month of June. Would like three- and five-day forecasts. Do most radio listening on WTMJ and WHBL because the best reception—not much agricultural type forecast. What station would you suggest? (81 - 1/4 - 100)
>
> Long-range frost or severe freeze forecast. The most valuable information to us would be a long advance notice of and duration of severe freeze. (87 - 1/2 - 40).
>
> I would like to know the number of heat units each day in the spring through to the fall. (62 - 1/2 - 76)
>
> Six-day forecast (43- 3/4 - 52)
>
> We receive all the information we need but it isn't very accurate. (93 - 3/4 - 100).
>
> More accurate long-range forecast. (81-1/4 - 88)
>
> It would be interesting and helpful at times if weather forecasts for Canada were included—that part of Canada directly north of Wiscon-

sin, Minnesota and Michigan. When visiting in Canada, we hear weather forecasts for the States. (87-1/2 - 88)

More accurate temperature in fall as to frost.

Degrees of humidity

Heat units per day—and total to date. (8-1/4 - 64)

Frost information. (50-76) (50 = knowledge of weather terms, 76 = knowledge of weather intensities)

Group 2 — Vegetable Growers

Any improvement in thirty-to-sixty-day forecasts from the standpoint of accuracy would be most beneficial to use (87-1/2 - 76)

Monthly weather probability to plan agricultural work (90 - 52).

Frost warnings and wind velocity—are available but seldom ac-accurate. (100 - 76)

I want accurate information, not longer range. (93-1/2 - 100)

Need a more accurate wind forecast. May 5 - June 15 wind velocity is critical. Twenty mph is OK but thirty mph if after two dry days can cause a crop failure. Most forecasts are ten to twenty mph, twenty to thirty-five mph, etc. (93 3/4 - 100)

Percentage area to receive precipitation in place of or in addition to percentage chance. (93-3/4- 52)

Present availability okay—need more accuracy. (81-1/4 - 88)

Anything would be better than the weather reports this summer (1969). It's done just the opposite all summer. (62-1/2 - 100)

They read the same forecast over and over even though it says 30% chance and it's raining. (81-1/4 - 76)

Present daily weather as related to normal as well as record high and lows. Also to use a moving average for past year's moisture instead of average for year to date. Early in the year the information for the year since Jan. 1 does not give any information as to soil moisture. (93-3/4 - 100)

I am principally concerned with percentage chance of precipitation, but it would be helpful if forecasts included anticipated quantities of rain. (93-3/4 - 100)

Would like accurate five-day forecast. Would be very valuable and would be willing to pay up to several hundred (approximately $300) yearly for it if it was accurate. (81-1/4 - 58)

Need to know amounts of rainfall expected within reasonable levels—also weekly reports of total precipitation. In spring would like to hear wind forecast more often. (31-1/4 - 64)

Group 3 — Fruit Growers

Relay system by growing area, very helpful. Cranberry growers should receive "thirty-day forecast maps" as shown in the Milwaukee Journal. (50-46)

Have very good television picture on three stations plus radio. The Today show on weekday mornings has the best and most accurate weather forecast—plus evenings, channels 3, 6, and 10 very good. (14-1/4 - 8)

A five-day forecast on telephone—could be available on a different weather telephone number as the other one is in Milwaukee that is recorded and changed every hour. It would be interesting and sometimes helpful to have soil temperature.

Temperature at ground level at the same location official temperatures are taken. (93-3/4 - 88)

Frost warning service. (81-1/4 - 100)

A forecast pertaining to fireblight in apples—check with Prof. George Klingbeil on this for data. (93-3/4 - 100)

Since 1915: Field digging in March twice—two separate years.

Field digging began April 1-22 remaining fifty-two years.

This fact is very important to our business (orchard and nursery). (56-1/4 - 34)

Forecasts of dew point, wind velocity daytime and night, humidity. (93-3/4 - 100)

Wind direction and velocity (81-1/4 - 70)

Predicted low temperature several days ahead (93-3/4 - 88).

Thirty-to sixty-day accurate forecasts of extreme weather—such as excessive rainfall or unusually dry conditions for the period April through October. A means of determining when a forecast is radically revised—as when rain is predicted in twenty-four hours and it arrives in six hours. (96-3/4 - 100). Lack of accurate reports limits use.

Sixty- and ninety-day weather forecast (68-3/4 - 70).

More accurate—my own barometer is better than many past forecasts. (68-3/4 - 76)

Dew point. (93-3/4 - 88)

Record temperature for given date (93-3/4 - 76)

More detail to the frost and freeze warnings in the spring. Also the wind speeds for daytime and nighttime hours to help us pick the best hours to spray. (93-3/4 - 100)

Group 4 — Canning and Freezing

Weather report year ago today. (62-1/2 - 12)

Anticipated rainfall. (12-1/2 - unanswered)

Road information for deliveries and receiving. (68-3/4 - 70)

Time of night which dew is expected and intensity. This could be forecast in a twenty-four-hour, forty-eight-hour and five-day forecast. Accurate long-range forecasts. (81-1/4 - 88)

Accurate forecast of rain during summer. (93-3/4 - 88)

Same as now only for longer periods of time and more accuracy. (81-1/4 - 75)

We are mainly interested in weather for our business from April 1-December 1. (87-1/4 - 58)

Low temperatures for other fruit growing areas spring and winter. (87-1/4 - 76).

Accuracy. (81-1/4 - 88)

Wind speeds for next day. (87-1/2 - 76)

Continuously available forecasting system. (56-1/4 - 76)

Solar radiation. (87-1/4 - 100)

Some sort of written report for longer (two weeks) forecasts—too long to handle verbally. More accurate intermediate range to thirty days forecasting of high, low and mean temperature and precipitation by days. (93-3/4 - 100)

High and low temperature previous day.

High and low temperature forecast at least two days in advance.

Monthly publication giving daily temperatures and rainfall for the month. (100 - 94).

Soil temperature. (93-3/4 - 100)

Length of daylight hours. (81-1/4 - 88)

Five-day forecast over TV in evening. (62-1/2 - 100)

More accuracy for this area (Sister Bay). (81-1/4 - 100)

More accurate information. (68-3/4 - 100)

Telephone service daily. (62-1/2 - 76)

The accuracy of the report is most important. We receive several reports of weather but not accurate in many cases. (75 - 76)

Mainly interested in temperature and precipitation forecasts. (93-3/4 - 88)

The type of information is O.K., but the accuracy of weather forecasts leaves a bit to be desired. Would be very interested in six-week forecasts on total rainfall—date of possible freezing temperatures. (87-1/2 - 76)

Forecasts for our particular area of operation. Measurement of solar intensity and duration. (81-1/4 - 100)

Hours sunlight expected—actual sunshine as against cloudy condition—as percent total daylight. (87-1/2 - 100)

A weather reporting service over TWX or Western Union similar to the system available to the Florida Citrus growers would be very helpful to the Wisconsin canners.

Group 5 — Potato and Vegetable growers—weather information they would like to receive which they do not currently receive:

Two-week forecasts—reasonably accurate. Development of hail storms. Accurate frost warnings—one-day and two-weeks. (87-1/2 - 88)*

Upper air flows. Daily deviations from norms (93-3/4 - 100)

Accuracy. Our main concern is having information about the conditions that are favorable for blight during the potato growing season. (68-3/4 - 88)

Accurate local weather conditions. Precipitation and temperature are very important in raising potatoes. (62-1/2 - 76)

Five-day and thirty-day too inaccurate (93-3/4 - unanswered)

Always need relative humidity—not always given. (75 - 100)

Present forecasts are adequate enough; but not accurate enough. (93-3/4 - 100)

If it were possible to forecast, months in advance, the amount of sunlight that might be expected during the growing season, I am sure that this could be useful to many people. The amount expected might be compared to a normal or average year. A person might plan an earlier or later maturing variety of a crop if he knew how much sunlight (without clouds) might be expected during the coming growing season. Summer rains in our area can be very spotty. Knowing exactly where the rains are going to fall and how much could be a tremendous help to agriculture, in planting, growing, harvesting, etc. (87-1/2 - 100)

Group 6 - Lime and Fertilizer Dealers

Often enough on radio and TV if accurate (93-3/4 - 82)

Twenty-four-hour wind velocity forecast. (81-1/4 - 88)

Specific local information (fifteen-mile radius) as to time and amount of rain during crop season to use in planning custom fertilizing and spraying operations. (87-1/2 - 100)

Wind, more accurate low temperature. We have our own auto-temp. continuous. We feel Wisconsin forecasts are right 56% of the time. We allow nine degrees for temperature error. (93-3/4 - 100)

Comparison to previous year and year before that; not ten-year average or fifty-year averages. (87-1/2 - 100)

Group 7 — Forage

Accurate two-week forecasts—even accurate one-week forecasts would be helpful. (68-3/4 - 100)

Our weather forecasts are not accurate enough. (81-1/4 - 88)

More accurate five-day or longer forecasts. (100-88)

Would like to get weather report for more specific area, especially at harvesting time. (56-1/2 - 88)

Accurate in regard to rainfall over two- to three-day period. If there are any basic cycle changesin weather patterns in regard to moisture and temperature. (93-3/4 - 88)

Longer range forecast plus weather patterns. (68-3/4 - 64)

Weekend weather Friday night. (62-1/2 - 76)

More detail into the causes of various weather patterns. (100 - 88)

Monthly temperature (daily highs and lows) graphs and rainfall charts to show past month's weather. (87-1/2 - 100)

Telephone weather service. (62-1/2 - 88)

More localized information—whether the "scattered showers" will scatter on my farm! (93-3/4 - 100)

APPENDIX - QUESTIONNAIRE

Male__________ Occupation__________________________

Female_________ If agricultural, what type of enterprise?

____

Usual source or sources of weather forecasts—check all that you use regularly.

____ a. newspaper
____ b. radio
____ c. TV
____ d. farm publications
____ e. own observations
____ f. telephone weather service
____ g. private meteorological service
____ h. other (list)______________

Which sources do you prefer? Rank three in order of importance.

____ a. newspaper
____ b. radio
____ c. TV
____ d. farm publications
____ e. own observations
____ f. telephone weather service
____ g. private meteorological service
____ h. other (list)______________

I prefer the source I ranked first because: (check all applicable answers)

____ a. It is available when I need it.
____ b. More information is given.
____ c. It is more accurate.
____ d. I can understand it better.
____ e. It is more convenient.
____ f. It is the latest word.
____ g. Other (list)________________

I find the weather forecasts in general are: (check one)

____ a. usually helpful
____ b. occasionally helpful
____ c. seldom helpful
____ d. never helpful

I try to plan my activities on the basis of the forecasts. (check one)

____ a. usually
____ b. occasionally
____ c. seldom
____ d. never

Check all of the following which you presently find helpful.

____ a. one-day forecast
____ b. two-day forecast
____ c. five-day forecast
____ d. thirty-day forecast

During the season when weather information is the most important to my business I usually try to get a weather forecast:(check one)

____ a. once a week
____ b. several times a week
____ c. once a day
____ d. twice a day
____ e. three times a day
____ f. four times a day
____ g. other (list)____________________

I do not try to get a weather forecast oftener because____________________

____

Weathermen predict that in the future they will be able to give a two-week forecast with the accuracy of the present one-day forecast. Would you find it: (check one)

____ a. extremely helpful
____ b. very helpful
____ c. Occasionally helpful
____ d. probably not helpful

Which would you prefer it if were available? (check one)

____ a. Forecasts continuously available by telephone.
____ b. Forecasts continuously available by radio.
____ c. Forecasts continuously available by TV.
____ d. other (list)______________________________
____ e. none of the above

Would you be willing to help pay for some sort of continuously available forecasting system?

____ a. yes
____ b. no
____ c. maybe

If so, how much would you be willing to pay? Check the most you would be willing to pay.

____ a. one to two dollars per month
____ b. five dollars per month
____ c. over five dollars per month

List any weather information which you do not currently receive, but would like to.

____

____

____

On these pages some terms are listed followed by possible definitions. Put an X in front of the definition you think is correct.

1. Precipitation
   ____ a. All forms of falling moisture.
   ____ b. The point where it starts to rain.
   ____ c. Water vapor in the air.
   ____ d. The amount of condensation.

2. Anemometer
   ____ a. Measures the high and low relative humidity.
   ____ b. An instrument for measuring the force or velocity of the wind.
   ____ c. An instrument for measuring the atmospheric pressure.
   ____ d. The speed at which hurricane winds blow.

3. Relative humidity
   ____ a. A prediction of precipitation
   ____ b. The amount of water vapor contained in the air.
   ____ c. The point at which water vapor condenses.
   ____ d. Water vapor in air compared to that required for saturation.

4. Solar radiation
   ____ a. Energy from the sun which turns into heat.
   ____ b. The time of sunrise and sunset.
   ____ c. The amount of clouds in the sky.
   ____ d. Spots on the sun which are believed to cause storms.

5. Dew point
   ____ a. 70% relative humidity
   ____ b. The chain of radar stations in North America.
   ____ c. The amount of dew that forms.
   ____ d. The temperature at which water vapor condenses.

6. Barometer
____ a. An instrument for measuring atmospheric pressure.
____ b. Predicts the speed and direction of the wind.
____ c. Sea level pressure.
____ d. An instrument for measuring relative humidity.

7. Cold wave
____ a. The temperature at which the ground freezes.
____ b. A prediction of how long the cold weather will last.
____ c. A continuous period of more or less evenly cold weather.
____ d. A rapid and marked drop in temperature during cold weather.

8. Smog
____ a. The point at which the health of plants and humans is affected.
____ b. Air filled with sand and dust particles.
____ c. The amount of sulphur dioxide in the air.
____ d. A fog made heavier and darker by smoke.

9. Atmospheric pressure
____ a. The force of the wind.
____ b. 29 inches.
____ c. The weight of a column of air.
____ d. The amount of moisture the air will hold.

10. Degree day
____ a. The high and low temperatures of the day.
____ b. The temperature at which moisture condenses.
____ c. The normal temperature for the season.
____ d. A unit for measuring the amount of heat.

11. Condensation
____ a. All forms of falling moisture.
____ b. The changing of water vapor to a liquid or solid.
____ c. The changing of a liquid or solid to water vapor.
____ d. The amount of dew.

12. Frost line
____ a. The maximum depth to which the ground becomes frozen.
____ b. The line of Arctic air.
____ c. How far south the freezing temperature will go.
____ d. 32° F

13. Isobar
____ a. Predicts the amount of ice or snow to be expected.
____ b. A subunit of pressure, being 1/1000 of a bar—used to measure atmospheric pressure.
____ c. The amount of atmospheric pressure at sea level.
____ d. A line connecting places having the same barometric pressure.

14. Evaporation
____ a. The amount of dew to be expected.
____ b. The change of water vapor into a liquid.
____ c. The point at which the soil becomes dry.
____ d. The change of liquid water into vapor.

15. Front
____ a. A widespread body of air which approximates horizontal homogeneity.
____ b. A mass of cold air from the polar region.
____ c. Long, narrow bands of changing weather between two different air masses.
____ d. Air in natural motion relative to the surface of the earth—any direction, any speed.

16. Air mass
____ a. A cold air front
____ b. Atmospheric pressure
____ c. A large body of air which has essentially uniform conditions
____ d. The force per unit area expressed in inches or millibars

On these pages are some weather variables which now show up on some weather reports and forecasts. Please check whether the information could make a critical difference, would be useful or would be of no help in planning your activities.

TEMPERATURE	Critical	Useful	No help
Current temperature			
Low for the day			
High for the day			
Duration of current range			

FROST	Critical	Useful	No help
Time of arrival			
Duration			
Lowest temperature			
Early or late			

FROST (cont.)	Critical	Useful	No help
When will ground freeze for good			
Depth of frost in ground			
MOISTURE—kind of precipitation			
Rain			
Sleet			
Freezing rain			
Drizzle			
Freezing drizzle			
Fog			
Dew			
Hail			
Snow			
Time of arrival			
How much			
Duration			
Amount of snow cover			
How long between measurable rains			
Drying conditions			
STORM WARNINGS			
Lightning or not			
Severity			
Direction traveling			

	Critical	Useful	No help
WIND			
Speed			
Direction			
Duration			
CLOUD COVER			
Amount			
Duration			
Direction moving			
WARM AIR MASSES			
Where			
When arrive			
What effects			
COLD FRONTS			
Where			
When arrive			
What effects			
RELATIVE HUMIDITY			
BAROMETRIC PRESSURE			
DEW POINT TEMPERATURE			
SOLAR RADIATION			
HIGH AND LOW PRESSURE SYSTEMS			
SOIL MOISTURE			
SOIL TEMPERATURE			

AIR POLLUTANTS PRESENT IN WHAT QUANTITY	Critical	Useful	No help
Sand or dust			
Sulphur dioxide			
Soot or fly ash			
Ozone			
Nitrous oxides			
Carbon monoxide			
Fluorides			
PAN			
Others ? (list)____________________			
______________________________			

If, at the present time, you don't know how to make use of the information on the amount of air pollutants present, but would nevertheless like to receive the information in the future, circle those pollutants you would be interested in.

LIST any other weather variables which you would be interested in receiving information about in weather reports and forecasts.

____

____

____

Matching test. Put the number of the proper term in front of the matching definition.

____ A multitude of minute water droplets limiting visibility to less than 220 yards.	1. Showers
____ A tornado has been sighted—take the necessary precautions.	2. Severe thunderstorm
____ Rain and lightning accompanied by strong, gusty winds and/or large hail.	3. Tornado watch
____ Visibility limited to less than fifty-five yards by a multitude of minute water droplets.	4. Tornadoes
____ Rain of short duration and varying intensity with periods of no rain.	5. Drizzle
____ A violet rotary storm small in diameter.	6. Thick fog
____ A tornado may occur but has not yet been sighted.	7. Dense fog
____ Numerous tiny droplets which appear to float or fall slowly.	8. Tornado warning

Matching Test. Put the number of the proper term in front of the matching definition.

____A small amount of surface snow blowing and reducing visibility.	1. Ice storm
____Strong winds blowing falling or loose snow into drifts.	2. Snow flurries
____A freezing rain with an accumulation of ice.	3. Snow squalls
____Rain changing to ice as it comes in contact with the ground or other objects.	4. Blowing snow
____Strong winds with snow-filled air and low temperatures.	5. Drifting snow
____Brief, intense burst of snow and wind.	6. Frost
____Snow accumulating to four inches or more in twelve hours.	7. Blizzard
____A light, feathery deposit of ice caused by condensation of water vapor directly in crystalline form on objects whose temperatures are below freezing.	8. Heavy snow
____Fall of snow of short duration with clearing between occurrences and little accumulation.	9. Freezing rain

CASE STUDY OF HIGHWAY BENEFITS DUE TO THE IMPACT OF IMPROVED SATELLITE WEATHER FORECASTING

Herman A. J. Kuhn*

Introduction

This study will be devoted to those activities related to various aspects of the movement of people and goods over streets and highways. This report will be addressed primarily to highway construction activity and that portion of maintenance activity devoted to the winter maintenance of highway systems.

While there are a number of other activities which are weather-related, e.g., maintenance functions other than winter maintenance, impacts on the road user in terms of accident losses, travel delay etc., they are beyond the scope of the present study. The highway-related activity systems, including those beyond the scope of this study, are noted in Figure 1.

The facility system—the major functional system—includes the actual physical network and requires for its proper operation three major subsystem activities, construction, maintenance and operation.

The first, construction, is at once the most costly, the most romantic, and the most obvious of the highway-related activities. It involves the bringing to

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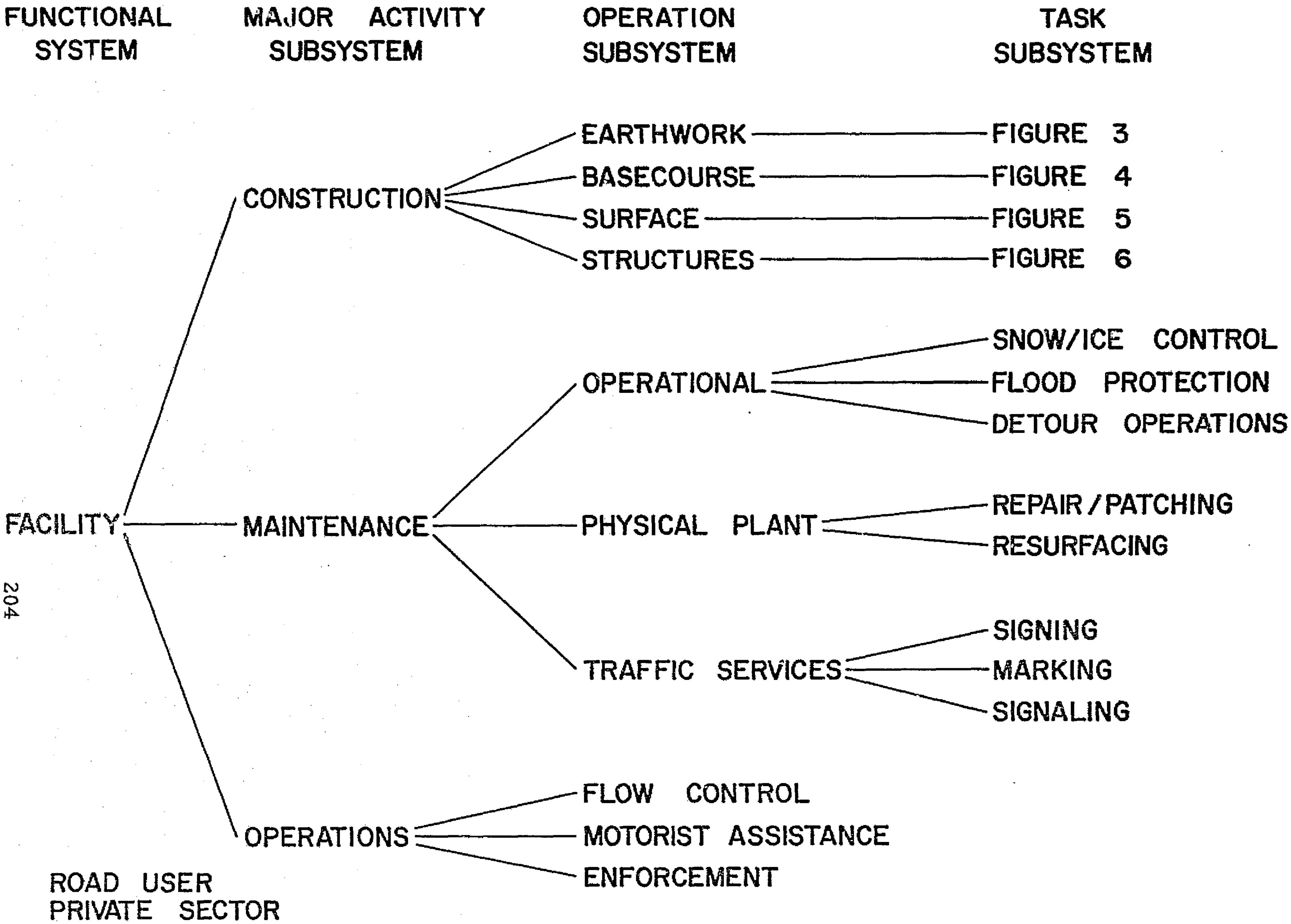

FIGURE 1
HIGHWAY TRANSPORTATION ACTIVITY SYSTEM

fruition of the designer's/planner's plans, it converts concepts in design into reality and results in new or improved street and highway systems.

The second, the maintenance subsystem, relates basically to three major types of operations: operational, physical plant, and traffic services activities. The operations activities include those operations necessary to keep a highway/street system open to traffic. Winter maintenance (snow removal), special protection of bridge piers due to flooding, and the detouring of traffic around physical roadway hazards are some of the tasks within the operational category. The physical plant operation includes such activities as repairing and patching deteriorated roadway surfaces and resurfacing roads which are in need of a new surface. The traffic services activities are those normally concerned with advising the motorists of traffic operating requirements, impending hazards, or the need to exercise some kind of control in relation to other traffic streams. These would normally include such things as various types of roadside signing, other than route or destination signing; pavement markings of various types; and intersection controls such as stop and yield signs and signalization.

The operations subsystem, the third and last within the facility functional system, includes such things as flow control, motorist assistance, and traffic enforcement.[1] It will not be studied in this report.

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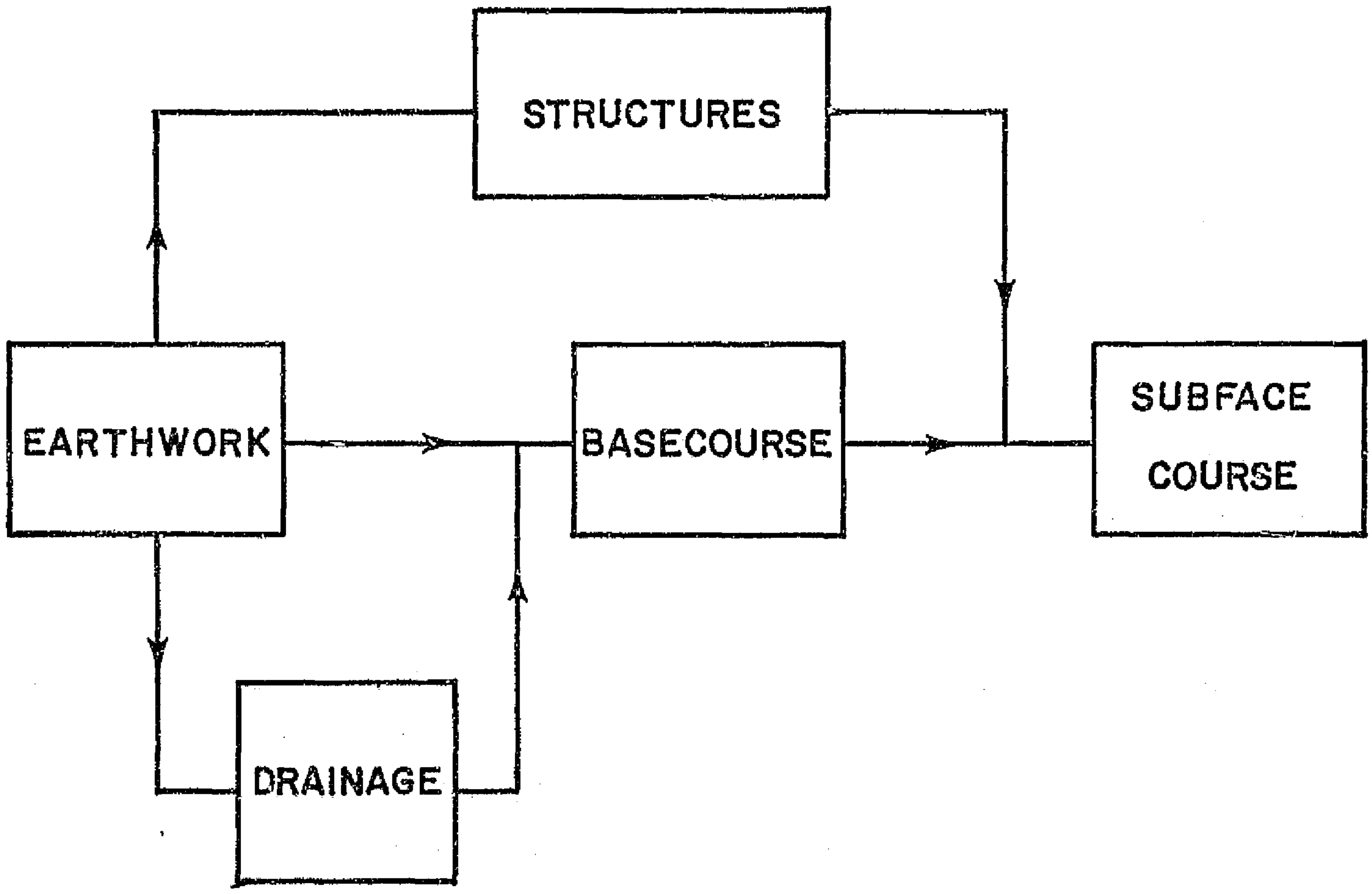
[1] Flow control includes various measures that can be taken to control either the volume rate of flow or the speed of the traffic stream. Motorist assistance includes vehicle disability assistance, assistance after accidents, and the provision of information on routes, road conditions, available facilities, etc.

In this stage of the investigation, exact dollar costs were not isolated, either in terms of benefits or in terms of the costs necessary to yield these benefits. However, it was the overwhelming opinion of the many people contacted and involved in this portion of the investigation that the dollar benefits due to improved weather forecasting could be very significant indeed. Initial evaluations indicate that the possibility exists for accruing sufficient savings in overall costs of operation, construction, and administration so that the net impact on the economy would be a positive one.

Activities Systems Case Studies

Activity Cycle

Although it would be desirable to define a typical calendar-related activity cycle appropriate to each particular case study, there is no such thing in the highway construction field. The only thing typical about the construction of a highway is the fact that various activities must precede other activities in the sequence of events which brings to fruition a highway improvement. Unlike the growing of crops, which have not only a step by step sequential process to describe the growing, harvesting, and processing of the crop, but also a time sequential process related to the growing season, the highway construction industry has no such thing as a required time sequence. It has only an activity sequence. For example, on two identical projects with construction activities identical to those noted in Figure 2, in one the beginning phase, the earth work activities, could begin in April or May and on the other project the earth work activity might conceivably not begin until August or September.



FIGURE, 2
CONSTRUCTION ACTIVITY
SUBSYSTEM

In fact, on any particular date during the normal construction season (generally from mid-April or early May until the latter part of October or early November) each of the activities noted in Figure 2 would be underway on some projects in some area.

There are several reasons why each of these various activities can be, and are, carried on during different times of the year and are not geared to seasonal requirements. On the one hand are the budgetary restraints which are placed upon the state highway organization. Because of the way funds are allocated, there is the need to program various of the activities so that the programmed construction matches the funds available to pay for that construction. On the other hand, factors such as job size requirements,[2] the need to sequence the various major activities of a particular job (which may have been let as separate contracts), the desire to build usable sections,[3] distinct climatic variations over the range of a state which covers a north-south distance of some 300 miles, and the variations in construction materials from one area of the state to the other, all influence construction activity starting times. In addition, since

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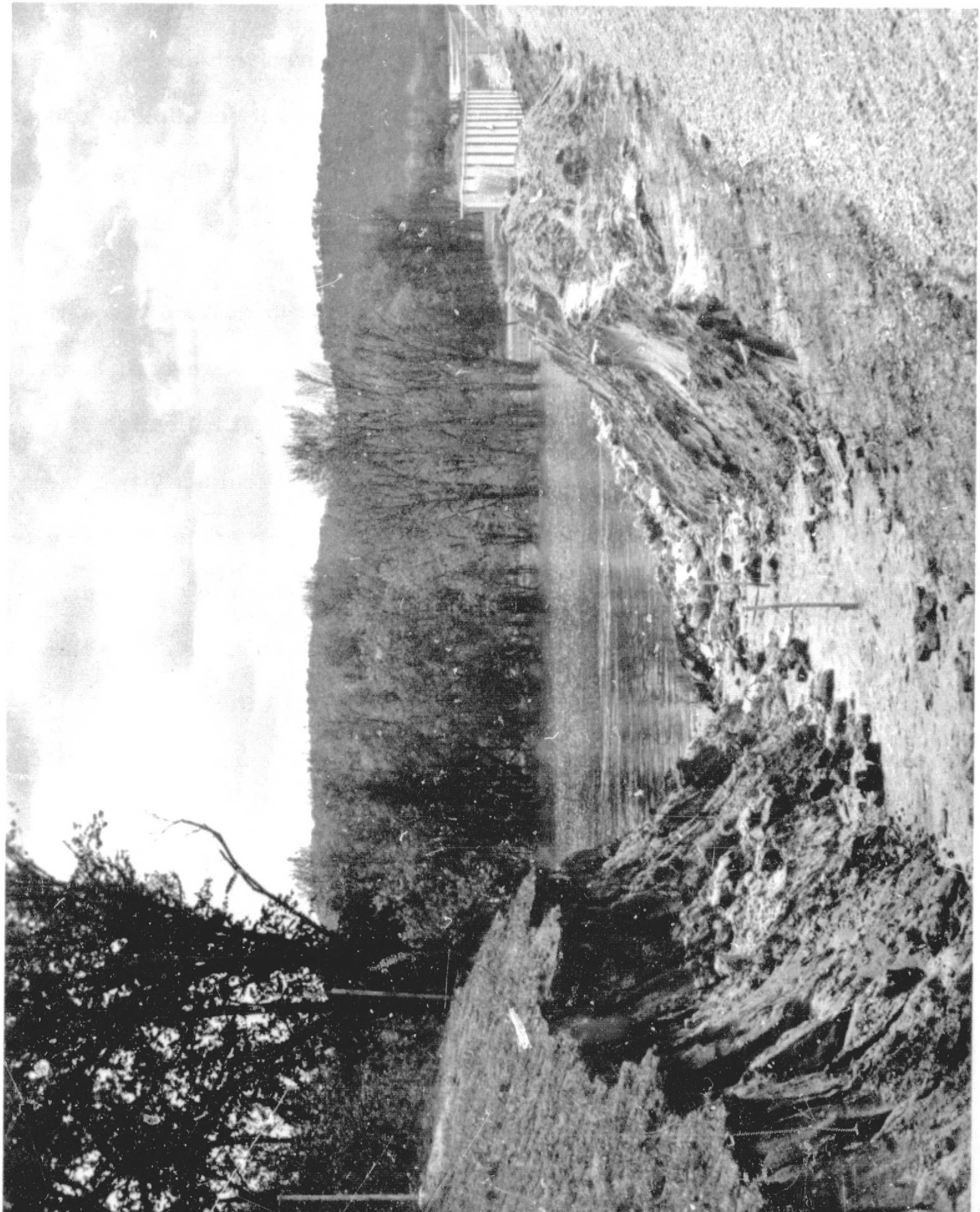
[2]Many of the contracting firms which bid on highway construction projects in the State of Wisconsin are small- to medium-size firms with limited resource capabilities. The belief that "sizing" jobs within the capabilities of such organizations promotes competition with resulting lower overall construction costs, influences to some extent at least, the selection of "job" limits.

[3]Building a "usable" section refers to the selection of project termini to permit opening portions of a highway improvement when they are completed. This can often be done by building temporary connections to existing systems.



there are a few construction activities which can be conducted during moderate weather in the winter months (certain structure work and marsh excavation work) the disbursal of highway aids on a quarterly basis makes it desirable to conduct some operations during the winter months.

Case Study Approaches—Hypothetical versus Real

In attempting to evaluate potential benefits related to weather forecasting, a basic question arises. Would a case study utilizing one or several, actual or so-called "typical" construction projects provide the best indication of possible benefits, or would the development of a hypothetical activity cycle typical of most construction activity give more realistic results? Because differences in operating procedures, variations in project size and complexity, construction staging requirements, and geographic differences in native materials and climatic conditions act as constraints on how effectively a contractor can respond to weather occurrences, the hypothetical approach, although easier, may distort the real situation.

Construction Activity Subsystem

The construction activity subsystem detailed in Figure 2 presents a simplified picture of the major basic activities involved in the construction of a highway project. Apart from the drainage activity which is normally conducted during earthwork operations, each of the four major activities (earthwork, base course, surface course, and structures) could be pursued under separate contracts by different contractors or as one large project by one contractor, possibly working through subcontractors.

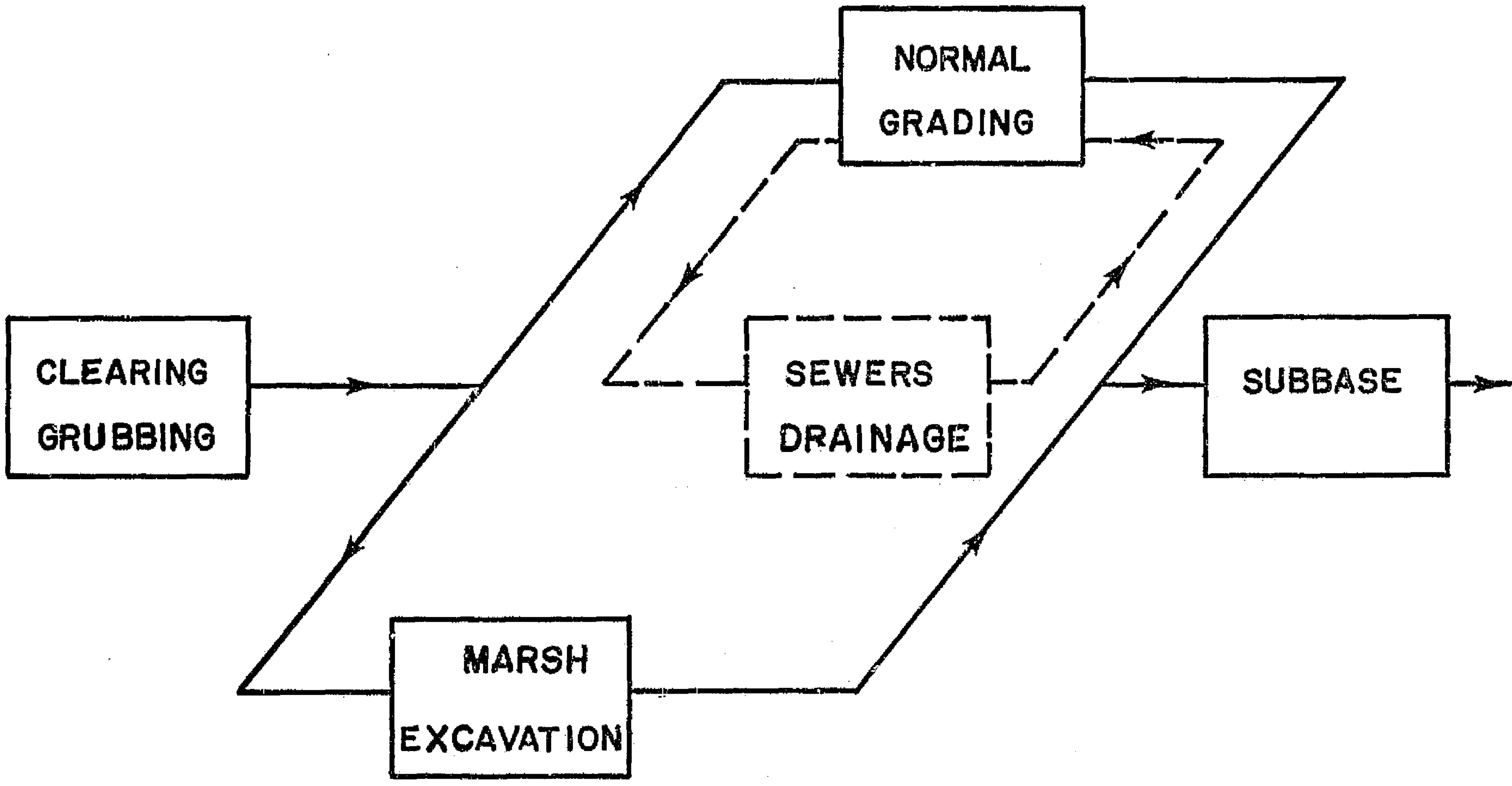
Each of the major activity areas within the construction activity system will be discussed separately with relevant weather impacts and an indication of the types of "counter measures" which might be undertaken to offset the adverse effects of weather.

Earth/Work Activities

The various construction activities associated with the earth work phase are flow-charted in Figure 3. The basic activities are these: (1) clearing the site of trees and other vegetative matter and their roots since the presence of these is unsuitable for construction, (2) removing old facilities remaining from prior activities, e.g., old pavements, sidewalks, buildings and foundations, (3) removing marsh deposits and back filling with selected sound construction materials, and (4) rock excavation. During this phase it is also necessary to construct whatever drainage facilities, e.g., culverts and storm sewers, are necessary to do the job. The latter may include the construction of manholes, inlets, catch basins, and in some cases large concrete drainage structures such as box culverts.

The most serious weather occurrence related to the earth work activity is too much rain. Heavy rains during the grading operation can cause construction losses from the delay or postponement required while the grade itself dries out. This is to say nothing of the damage caused by very heavy rains from which the runoffs are such that they create flooding in some areas or wash out completed portions of the project.

Accurate and sufficient advance warning of impending rains (twenty-four



FIGURE, 3
EARTHWORK OPERATION
SUBSYSTEM

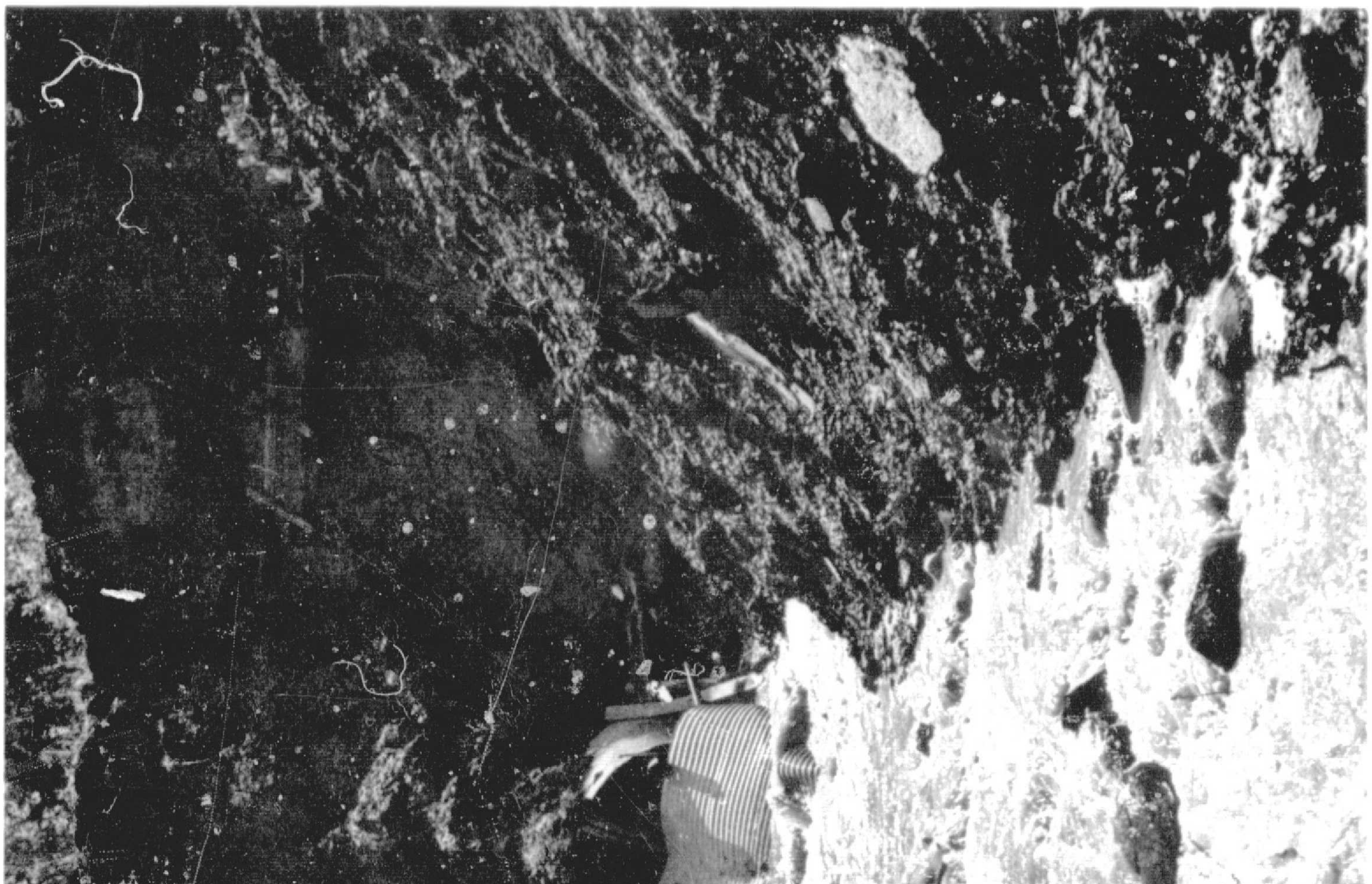
to forty-eight hour notice) would permit a contractor to bring the current stage of his earth work activity before the rain to the point where the rain could only do a minimum amount of damage. This might require shaping the top of the grade to permit runoff instead of the capture of precipitation, accelerating work on culverts to facilitate drainage and eliminate or minimize ponding, and where appropriate, postponing the opening of new grading areas until the precipitation period has passed.

The final activities of a grading project include dressing the final slopes, placing topsoil on the slopes, and fertilizing and seeding. In some areas, particularly where erosion can be an initial problem, sodding might be appropriate. The amount of damage which can be done when heavy rains come after certain of these operations, particularly the seeding and sodding operations, is readily apparent. Short-term advance warning of impending rains would allow these activities to be delayed and would preclude the need to redo or replace portions which had been rain-damaged.

At the present time typical labor contracts require that laborers be given at least twenty-four hours notice if there is to be no work during a normal working day; otherwise they must be paid two hours "show-up" time for reporting to work even though work is called off for the day. If a contractor knows with reasonable certainty that his crews will not be able to work on the following day because of rain, for example, he can, if he advises his crews at least twenty-four hours in advance, call off work for the following day without being required to pay the two hours of "show-up" time. This would be a direct savings to the contractor and might be significant if his crew were a large one. In terms of the socio-economic impact on his laborers the reverse would be true. Quite obviously the contractor benefits directly, but in the overall picture the loss to labor would partly offset the benefit.

Reliable long-range forecasts (ten days to two weeks) are most valuable in the sense that they permit better and more efficient work scheduling and, where appropriate, the shifting of crews and equipment from one project to another. Take, for example, the case of a contractor who has several jobs underway, one of them a grading contract in an area of heavy clay soils, the other a grading project in an area where the soils contain predominantly sandy materials. A relatively long wet spell would prevent any work from being done in the heavy clay soils but would not materially affect the work in the granular soils. In fact, were the precipitation relatively light, rain in the area of the granular soils could be of considerable assistance in achieving the necessary compaction of the subgrade materials. It would behoove the contractor in this instance to move much of his grading force from the area in the fine-grained soils region to the job in the granular soils area; as a result he could take advantage of the delay caused by the rain. Equipment mobility is great enough and costs of moving low enough that such a job shift would be to the contractor's advantage.

Temperature extremes, except as they affect soil drying conditions, are not as detrimental to the earth work activity as they are to other construction



activities. The only temperature restriction to grading is due to the fact that grading operations cannot be conducted on frozen soils. This, however, is rarely a problem, since earth work activities are normally carried out during portions of the year when soil does not freeze.

Base Course

In this activity (Figure 4) some type of load-carrying material, normally sand, graded gravel, or crushed stone, is placed on top of the earth subgrade before the final surface course. Depending on the type of construction this can be an unstabilized material, e.g., a material to which no chemical or other additive is added to improve its stability or load-carrying capacity, a stabilized base course material, or a combination of stabilized and unstabilized materials. Where unstabilized materials are used the granular material is laid to a certain depth on top of the subgrade, wetted if necessary to assist in the compaction of the material, and then rolled to the proper density. As with the earth work operations, the basic impediment to the construction of base course layers is rain. It is only when the base course material or a portion of it is to be stabilized[4] that temperature constraints are also critical.

Unstabilized materials are influenced by rain in that an undue amount of precipitation will cause termination of the work because the material is either too wet to be driven on by the equipment or too wet to permit adequate com-

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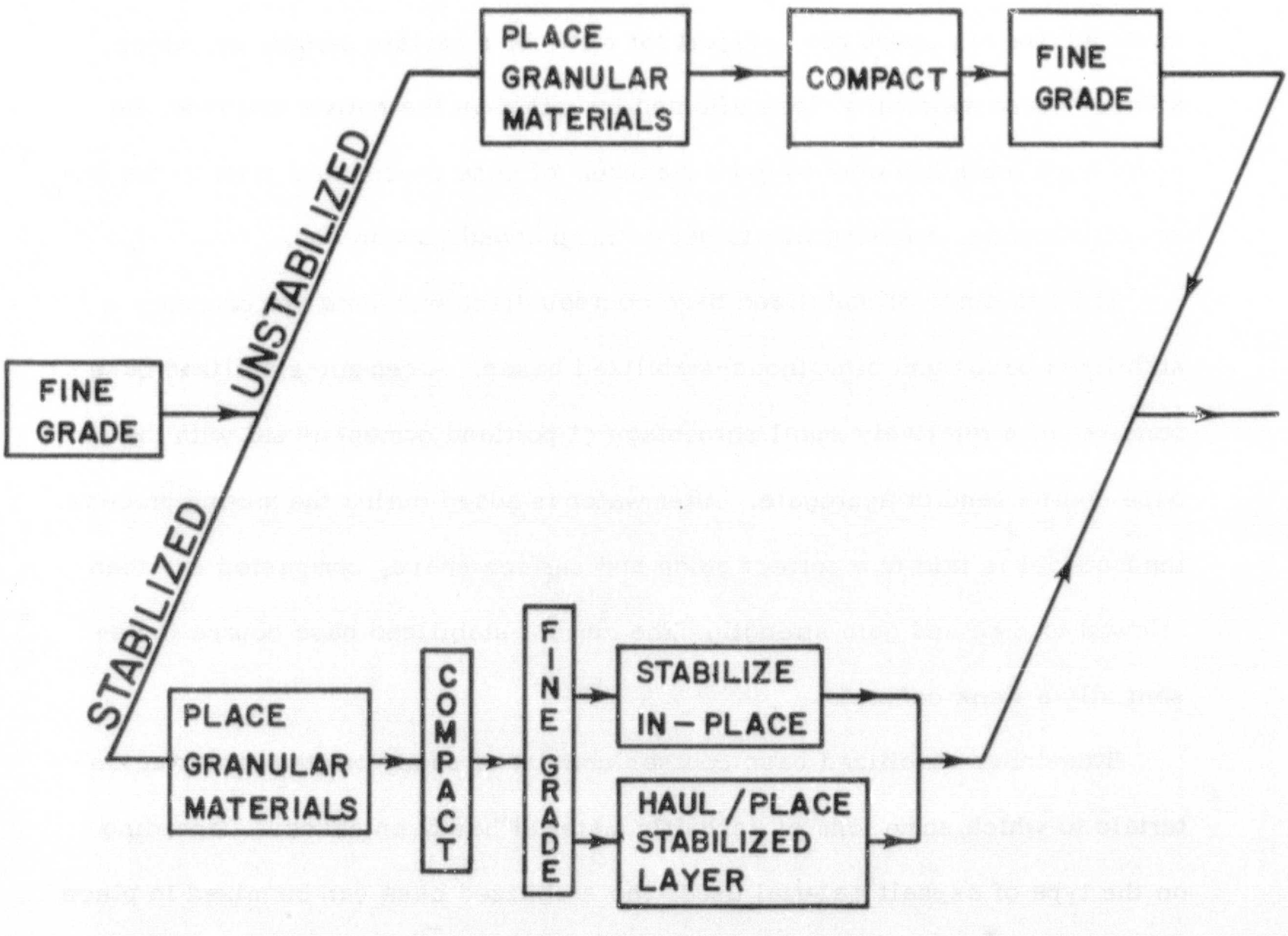
[4]Granular base course materials normally stabilized with portland cement or an asphaltic compound.



FIGURE, 4
BASE COURSE OPERATION
SUBSYSTEM

paction. Light rains, on the other hand, may be advantageous, particularly when sandy materials are being utilized. The rain may actually assist by providing the necessary water compaction. Foreknowledge of impending rains would allow a contractor to take one of two courses of action. Either he could advise his crews not to report for work for a certain period, or, since a base course material is less affected by rain than the native subgrade, he could accelerate his work to get a maximum of base course laid prior to the onset of the rains, allowing him to get a "jump ahead" on the job.

The two kinds of stabilized base courses discussed here are cement-stabilized bases and bituminous-stabilized bases. A cement-stabilized base consists of a relatively small percentage of portland cement mixed with the base course sand or aggregate. After water is added during the mixing process, the material is laid to a correct grade and surface shape, compacted and then allowed to cure and gain strength. The cement stabilized base course is essentially a weak concrete.

Bituminous stabilized base courses consist of sandy or other granular materials to which some form of asphaltic material has been added. Depending on the type of asphalt material used, the stabilized base can be mixed in place in the field (on the roadway itself) or mixed as a plant mix (mixed at a central bituminous concrete plant, hauled to the job site, and then laid down. In each case the bituminous stabilized material must be molded to the proper roadway shape and grade, compacted, and then allowed to cure for a short while.

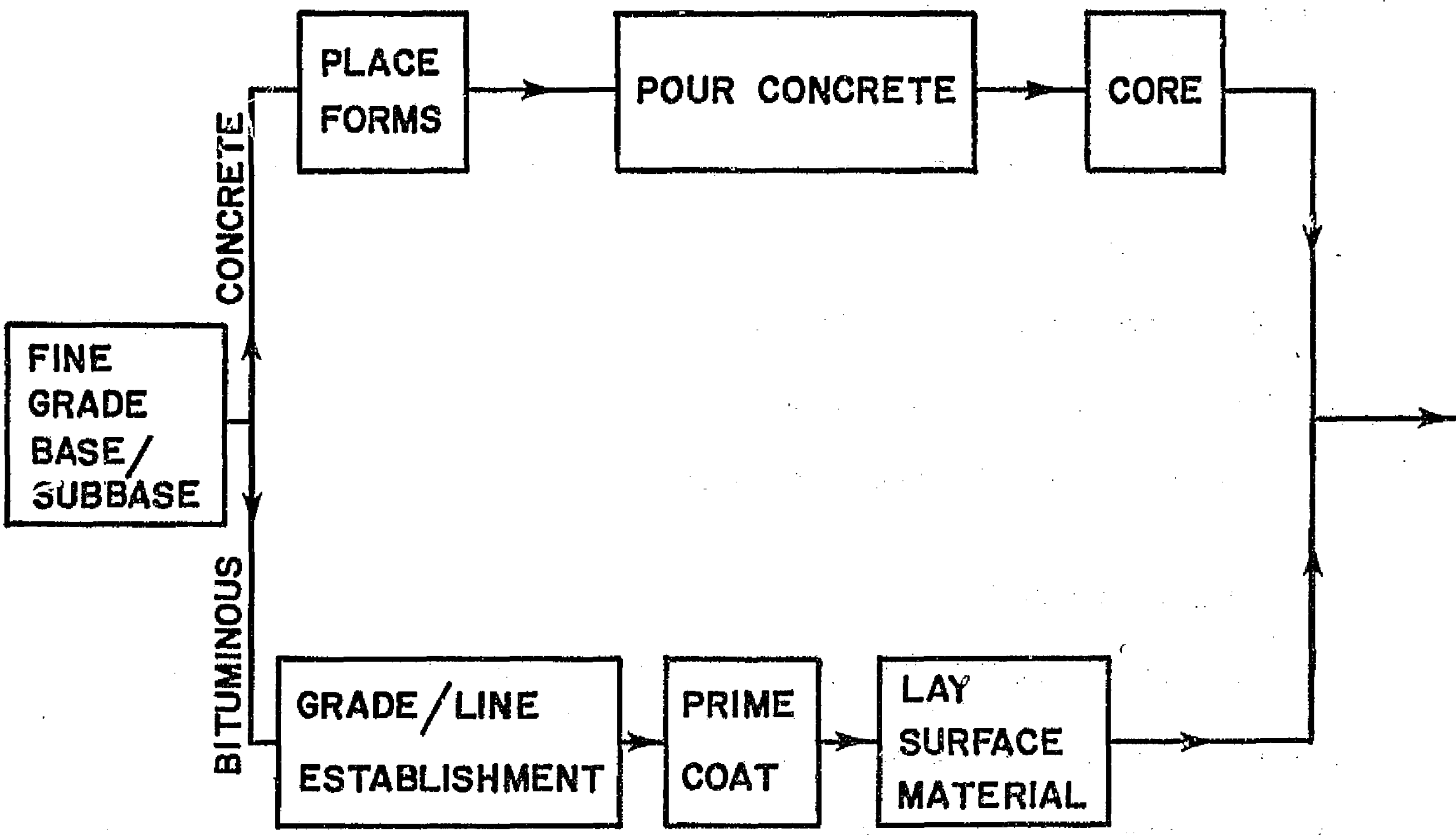
Both forms of stabilized base course have rigid temperature and precipitation requirements. Below a certain minimum temperature and under certain precipitation conditions asphaltic stabilized materials cannot be laid. In addition there is a temperature-related calendar date after which bituminous materials cannot be placed except at the risk of the contractor himself. This date has been established on the assumption that, generally, temperature ranges at the time of year specified are such that they are normally too low to allow bituminous type work.

The temperature and precipitation constraints of stabilized base courses and the possible counter-actions will not be discussed in this section because they are essentially the same for the surface course.

Surface Course Activity

The surface course activity, as noted in Figure 5, includes the construction of the final pavement-wearing course upon which vehicles travel. Two different types of surface course activity will be discussed since there are two major forms of pavement construction: portland cement concrete, and some form of bituminous concrete or a less costly, less durable bituminous-based material.

In both cases the initial activities are essentially the same. There is the need to fine-grade the final base course layers so that the surface is to the correct grade and shape. This is a very crucial stage and must be done accurately because in each case the final surface quality is dependent on the quality of the surface immediately below.



FIGURE, 5
SURFACE COURSE OPERATION
SUBSYSTEM

Portland Cement Concrete Pavement

Although there are precipitation constraints as far as concrete paving is concerned, the major constraints requiring some form of protection or possibly suspension of work are those of temperature.

As far as the concreting activity goes, two basic temperature constraints are defined. This is not to say that other temperature requirements are not also in effect including the need to have the concrete mix at a certain temperature during cold weather concreting, the need for maintaining form-work at a certain temperature, etc. Construction specifications in the Sate of Wisconsin (similar requirements are in existence in other states) require that concreting be suspended when descending air temperatures in the shade fall below forty degrees Fahrenheit. Concreting cannot be resumed again until the ascending temperature in the shade reaches thirty-five degrees Fahrenheit. Foreknowledge of expected temperatures based on weather reporting would allow a contractor to plan his work and take best advantage of the expected weather. A knowledge of descending temperatures well in advance of the decline would permit him to cease operation in sufficient time to protect adequately the concrete that had been laid and thus to preclude the need for discarding or redoing portions of the work which had been adversely affected by the falling temperature.

The other basic temperature restraint requires that freshly laid concrete pavements, or other concrete work for that matter, be protected by a minimum of twelve inches of loose straw or hay (in the case of a pavement slab) if freezing is anticipated. This applies to all pours after the fifteenth of October. After the first of October, on the other hand, materials merely have to be available on the job for use in covering freshly poured concreted slabs in the event that freezing is likely.

It is obvious that both short- and long-range weather forecasts would permit a contractor to take adequate precautionary measures, might permit him to plan his work so that he could take advantage of the better weather conditions, and might conceivably also allow the revision of the specifications to permit the concreting activity to be planned and carried out in concert with weather forecasts—rather than an arbitrary cut-off date.

Bituminous Materials Surface Courses

Various types of bituminous pavement construction are available beginning from the relatively inexpensive but low quality bituminous road-oil treatments, through the in-place bituminous road mix pavements, up through the highest and most costly grade of bituminous concrete. For the latter two categories the very general construction activities are essentially the same. In order to provide adequate adherence to the underlying granular base material a prime coat is first sprayed on the roadway. This consists of a liquid bituminous material which partially penetrates the voids of the base course and also coats the top layer to provide a surface to which the final surface course itself can adhere. In the case of the repaving of an old surface with either portland cement concrete or some bituminous material, a "tack" coat is used in lieu of a prime coat. The tack coat has the same basic function in that it provides for the adherence of the new material to the old. It, too, consists of the application of a liquid bituminous material. Once the prime coat/tack coat has been laid, the bituminous surface material, either as a road mix or as a plant mix material, is placed on top of the base course. This material consists of varying aggregations of granular materials and different percentages of various types of liquid bituminous material, depending on the kind of bituminous surface being laid.

There are a number of weather constraints, both rain and temperature, which can critically affect various aspects of the bituminous paving operations. In general the road bed must be dry at the time of bituminous paving and the other bituminous laying operations. In the case of application of the prime coat or tack coat there is the further requirement that the material not be applied before impending rains, if the prime coat is likely to be rained upon during the penetration period (the time during which the prime coat flows into the voids of the aggregate and coats the individual particles both at the surface and immediately below). The time of penetration varies for different types of prime coat material.

For road mix bituminous materials it is important that the road mix itself not be exposed to rain prior to the final compaction of the mixed materials. A road mix is a bituminous surface in which the liquid bitumen is applied to the aggregates on the road site itself, mixed either by some mechanical agitator or by a blade grader, then spread out on the road surface and compacted.

Similarly, it is important that a plant mixed bituminous concrete not be placed during a rain (or for that matter, during a snow).

Adequate and reliable advance warning of impending rains would permit a contractor in the case of short-term occurrences to plan his immediate work activities and his labor requirements to take advantage, so to speak, of the impending bad weather. In the case of forewarning of a long-term occurrence it would be possible for the contractor again to plan his work so that by working overtime, or possibly bringing in additional forces from other areas, he could complete this particular phase of the work prior to the onset of a period of bad weather.

Temperature is probably an even greater impediment in terms of various types of "black-topping" activity. Wisconsin has two basic temperature constraints, one at 40°F, the other at 50°F. Each applies to different types of activity and to the need to maintain that particular temperature as a minimum for the conducting of that activity.

Information on the occurrence of temperatures at or below the minimum, whether or not such temperatures can be expected to remain stable or decrease even more, and whether and when the low temperature will climb sufficiently to permit the resumption of work are some of the important bits of information that a contractor must know in order to plan his work activity. The work activity involves not only the actual laying of the particular material at the job site, but in the case of a plant-mix bituminous concrete it also involves the operation of a very expensive physical plant in which the materials are pre-mixed and then brought to the job site. There are cases, for example, where a contractor must haul these pre-mixed plant-mixed materials some distance to the job site. There is necessarily quite a lead or lag time involved and a number of trucks might be en route to the job at a time when bad weather is setting in. Advance warning of a severe drop in temperature would permit the cessation of operations at the plant in sufficient time to preclude the necessity of discarding any number of truck loads of material which had been en route to a job. The writer is very aware of the problems arising out of temperature changes or precipitation and has had first-hand experience with them as resident engineer on an urban construction project. On that particular project it was necessary because of rains to refuse delivery of eleven or twelve truckloads of bituminous concrete at a very considerable loss to the contractor involved. Although that incident could be considered a weather catastrophe of sorts, such things do occur all the time in relation to the construction of a project. Adequate warning would have resulted in a significant savings.

The writer also recalls a different project on which he was a resident engineer when a severe weather occurrence resulted in considerable loss and damages. In this case a considerable length of roadway was primed in preparation for a following day's black-topping operation. During the night a severe downpour occurred and literally stripped the prime material from the base course. In this particular case, the damage done to the job itself in terms of the granular base course and prime coat that had to be replaced or restored was not the only damage sustained. Because of the amount of rain and the location of the job site in relation to an adjacent development, considerable damage was also done to the interiors of several of the adjacent buildings. The torrent of rain, laden with prime coat, was so great that it ran into some of the buildings. Considerable damage resulted in numerous insurance claims for ruined carpeting and damage to other facilities inside the buildings.

Had adequate warning of the unusual rains been available, the work in this case would have been postponed—saving considerable money for the contractor and preventing considerable inconvenience to the persons whose property was damaged. In other cases improved weather forecasting would allow precautionary measures to be taken which would minimize the amount of erosion damage done.

As with the concrete paving operation there is also a calendar date restriction based largely on the state highway department's experience that weather both in terms of temperature and precipitation is apt to be bad after a certain date. This quite obviously is not always the case and there are many years when the weather is extremely good for construction after this normal calendar cutoff date. During such years, if adequate long-range weather forecasting could predict the continuance of good construction weather, this particular calendar constraint could be dropped to the advantage of both the contracting industry and the state highway department.

The calendar restriction requires that any blacktop placed after the fifteenth of October and before the first of May next, regardless of how good the weather might have been, cannot be accepted until the following year. This is not an unusual occurrence and results in the holding back of a certain amount of payment to the contractor. Although the specifications do permit the percentage retainer to be reduced "when the work under the contract has been substantially completed..." the contractor still finds it necessary to finance, at an interest rate of eight or ten percent, that portion of his payment which has been withheld. When operating at a net return of about two percent, a not unrealistic figure, overhead and profit are actually being withheld.

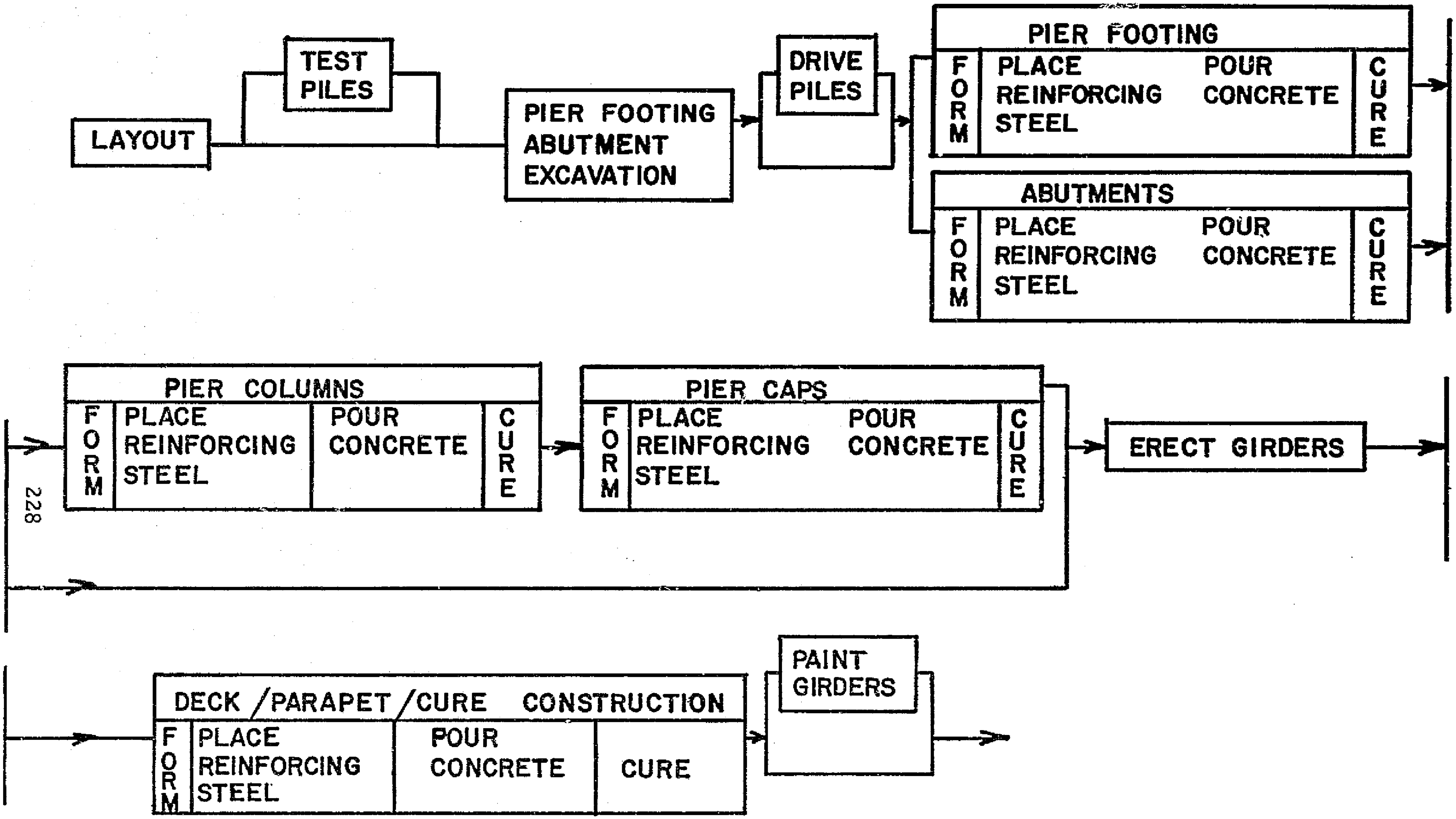
Permitting a black-topping operation beyond the fifteenth of October based on mutual (the state and the contractor) reliance on weather forecasting information and allowing acceptance of the project on that basis would be beneficial to both parties concerned. It would result in the elimination of the need to finance certain overhead costs on the part of the contractor and should result in at least some administrative savings in the organization monitoring the construction program (the state highway department).

Structures Activity

The structures activities, flow-charted in Figure 6, include the various operations required for the construction of a "typical" bridge structure. This is the one activity which can be carried on for the longest period during cold weather, since construction procedures are available for protecting concrete work from adverse low temperature. These protective measures do, however, raise the cost of building such a structure. Nonetheless, for the contractor who has the capability of doing structural work, it provides him with more of a year-round operation.

Because funds are programmed (and become available[5] on a quarterly basis some contracts should logically be let during the winter quarter. It is not unusual, therefore, to let contracts for the construction of various types of bridge structures, with the intent that construction begin in the fall and

[5]Federal aid to highways fund are normally allocated on a quarterly basis.



FIGURE, 6
STRUCTURE OPERATION 2.
SUBSYSTEM

2. FOR GIRDER TYPE STRUCTURES ONLY.

carry through as much of the winter as possible.

Except for problems of frozen ground there are no temperature constraints on the initial stages of structure construction up to the time when concreting work is ready to be done. Prior to that time the weather constraints are basically those of too much water, either in terms of rain, or possibly in terms of high water. When the structure reaches the stage at which the piers and abutments have to be formed and poured, temperature becomes a major factor. Then, depending on the existing temperature and also the forecasted twenty-four hour temperatures, certain precautionary measures must be taken. These include heating the aggregate and mix water prior to mixing the concrete, maintaining the interior of a protective enclosure at a specified temperature for a period of approximately six days, and/or the need to use insulated forms in lieu of housing and heating. Normally the temperature must be maintained for a certain protection period after which the concrete must be slowly cooled to prevent excessive thermal stressing.

As an example of temperature-related problems, one contractor (who could probably be considered typical of those who do work within the State of Wisconsin and in adjacent states) recalled the case of one winter structure project during which there was a drastic drop in temperature. The concrete had already been poured on one particular phase of the project; very low temperature required excessive heating to keep the concrete from cooling off too fast. In this case the resulting controlled cooling-off costs were more than the cost of the actual concrete itself.

One other case in which accurate weather forecasts would have meant a considerable job savings involved the operations of a contractor who does a large amount of structural highway work. During the 1968 construction season, he was required, because of contracts which had been successfully bid upon, to shift crews from current job sites to new sites in order to begin construction on new projects. Because of rainy weather in one area, work on those portions of that project which needed to be completed before the structures work could be done was delayed. During the delay the structures crew was limited in the amount of work they were able to do. The contractor estimates that this delay, during a time when the same crew could have been working in another area, resulted in a decrease of some $50 thousand[6] in profits for all of their structural work in 1968. The reason for this loss was that one crew and one crane which had normally built approximately five bridges per year ended up building only two.

It is readily apparent that in this case accurate weather forecasting and job planning by the state and the contractor based on that weather forecasting would have eliminated the delay due to the inefficient crew and crane use and would have resulted in an overall savings to all concerned.

Summary—Construction Activity Case Studies

It appears that reponse to improved weather forecasts could result in significant savings to the construction industry. The result, ultimately, should be reduced bid prices for various construction items with the result that more construction work could be done for the construction dollar.

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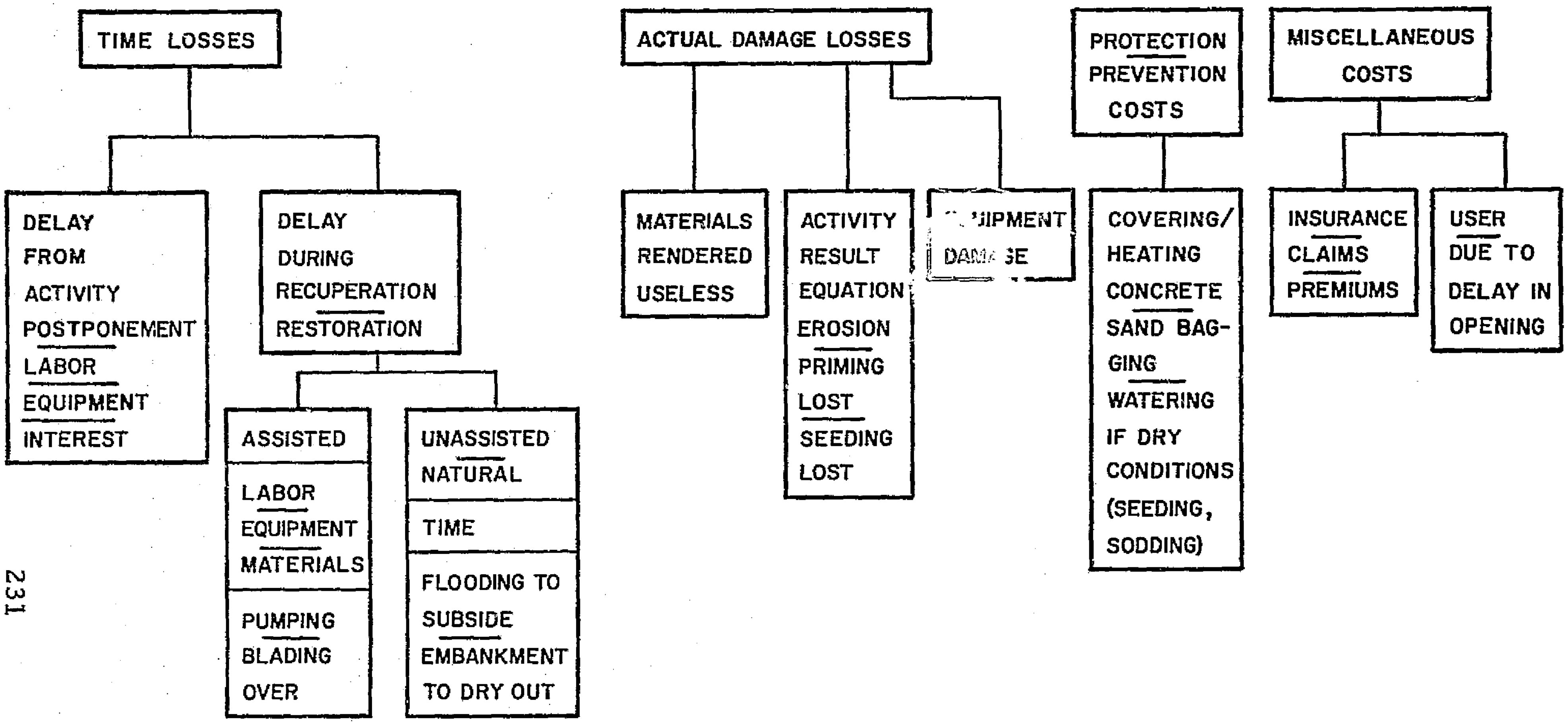
[6] This figure was only an approximate estimate by the contractor.



HIGHWAY CONSTRUCTION

LOSSES DUE TO WEATHER PHENOMENA WHICH COULD BE PARTLY OFFSET BY IMPROVED WEATHER DATA

FIGURE 7

At this stage of this study, those savings have not been quantified. They would result primarily from savings in labor and materials, cost savings which are the result of greater operational efficiency, and savings resulting from fewer damage losses. A number of these savings are noted in Figure 7. Of course, it also costs money to bring about these savings. Some costs would arise from the delays incurred in postponing operations either on a long term or on a short term basis. Other expenditures would be required to accelerate work either by increasing the size of the work force, working longer hours, or otherwise speeding the activity. Protecting against adverse weather, e.g., placing straw on concrete, also costs, as does a reallocation of resources, i.e., moving to another job.

The net benefits which accrue as a result of better weather forecasting are largely benefits in reduced costs rather than benefits in terms of improved quality. This is not to say that there are not times when the quality of work on a construction project suffers from the results of weather. There are cases when damage is done which is not apparent at the time; as a result, it does not get corrected prior to job acceptance and becomes a maintenance cost. One example would be the case in which an unexpected, and yet not too severe freeze, occurred immediately after laying a new concrete pavement. Assuming that protective measures had not been taken and that no apparent damage had been observed, the pavement would likely have been accepted. Only at a later date, if the top surface of the pavement began to spall[7] would the damage

[7]Spalling is a deterioration of the uppermost layers of a concrete pavement

have become evident.

Maintenance Activities and Their Relation to Weather

Although the maintenance activity was not investigated in great detail, some general comments can be made, particularly relating to winter maintenance. Winter maintenance includes the activities necessary to keep streets and highways in a safe usable condition during the winter months, such as snow removal, salting, and sanding. In Wisconsin these activities are carried on on the state trunk and county trunk highways by the individual counties themselves. In the cities, street clearing operations are the responsibility of the individual city street departments.

The statewide winter maintenance program included, until recently, a system of patrols (on a shift basis) on all of the principal highways at all times during the winter. Under most normal snow-clearing operations, there is no shifting of forces from one county to another since each county is responsible for its own maintenance activity and each of the counties is quite well equipped for handling winter storms. As a result it is a very unusual case when a county cannot adequately handle a storm in its own area.

In an attempt to save the costs of these patrols a program was begun on a modest basis three years ago in which various counties along the interstate system utilized the services of a meteorological consulting firm to forecast

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slab, particularly the mortar layer, because of a number of conditions, among them freezing during construction, normal freeze-thaw reaction after curing and while the pavement is in use, and the effects of deleterious substances being present in the concrete.

the magnitude of winter storms. This forecasting service has minimized the need for patrolling all highways and appears to be resulting in a considerable savings. This year, for the first time, this procedure is being attempted on a state-wide basis. It would be interesting to note at the end of this winter season the changed winter maintenance costs which are attributable to the use of the forecasting service instead of the former practice of maintaining twenty-four hour patrol networks.

This analysis should be one of the continuing aspects of the program on the evaluation of potential benefits from improved weather forecasting procedures.

Weather Forecasting Needs

Demonstrated Credibility

Before various aspects of the economy will rely on better forecasting systems and use them to best advantage, the weather "industry" will first have to demonstrate, through vastly improved short-term forecasting and communications procedures, the credibility of such systems and the ability to get information to the user. If credibility cannot be established, little use will be made of such weather forecasting.

Mutual reliance by both the construction industry and the organization responsible for the design and supervision of construction of a highway, e.g., a state highway department, could not come about without the established credibility of the forecasts themselves. Each of these organizations, as party to a construction contract, would have to accept fully the "word" of the weatherman. This would require changes in administrative procedures within both organizations and changes in the criteria which control the construction activities themselves, i.e., the standard construction specifications and individual project special provisions. It would require, for example, that a contractor who had been given a "go-ahead" based on a weather prognostication, could not be held accountable for damages or losses sustained as a result of bad weather which was in fact not forecast.

Length and Type of Prediction Needed

Basically three types of forecast are required: (1) immediate or short-range, (2) medium-range and (3) long-range. Accuracy requirements decrease as the length of forecast period increases.

1. A highly accurate short-range forecast (immediate to one or two days) of impending severe weather occurrences would permit immediate reaction to weather catastrophes.

2. Medium-range forecasts, those which look from ten to fifteen days ahead, would permit reorganization of the job task itself to allow for acceleration or postponement of certain activities to take advantage of the type of weather expected to occur.

3. Longer-term forecasts yet, on the order of from thirty to forty-five days, would permit the long-range planning of work tasks. They would be particularly useful when used in conjunction with the ten-day to two-week forecasts.

A CASE STUDY TO DETERMINE THE NATURE OF THE IMPACT ON SINGLE-FAMILY HOME CONSTRUCTION, RESULTING FROM RECENT ADVANCES IN SATELLITE METEOROLOGY

Warner E. Stone*

Chapter I—Introduction

Problem Area

The objective of this research effort is to determine a preliminary estimate of potential cost savings which would accrue to residential construction firms that have sufficient planning controls to take advantage of accurate long-range weather forecasts.

Present Weather Information Systems

The residential construction industry is affected by intermittent, day-to-day weather variables throughout the year in addition to the temperature extremes characteristic of winters in the northern regions. Contractors

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A debt of gratitude is owed to Professor James A. Graaskamp for his aid in structuring this report and for the benefit of his experience in residential construction.

In addition, valuable aid was provided by Mr. Steven Woll of the Milwaukee Builders Association and Mr. Al Nelson of Badger Meter in the Milwaukee case study.

have three basic types of forecasts available at the present time. Local meteorologists prepare a summary for their area and disseminate this information through the news media. Daily forecasts include cloudiness, temperature, humidity, precipitation, wind and pressure. Accuracy of this one day forecast is normally about ± 5° in temperature and ± 5 m. p. h. in wind. Precipitation is stated as a probability of occurrence and is accurate to ± 10%.[1]

The accuracy begins to suffer for forecasts in excess of one day; thus the five-day forecast is somewhat more vague in its prediction. Temperatures are given in terms of departures from seasonal norms and quantitative precipitation averages are given, but not defined sharply in time. The thirty-day outlook contains broad statements on the expected departures of temperatures, and precipitation is predicted as light, moderate or heavy. Thus, predictive ability and reliability vary directly with time, decreasing from the one-day to the thirty-day forecasts.

Future Weather Information Systems

Meteorologists working in the field of numerical weather prediction have stated that with satellite-aided observational coverage of the atmosphere and with improvements in the mathematical prediction models, as capacity and speeds of computers increase, more reliable forecasts of the general

[1]Based on information furnished this researcher by Professor Bruce Lusignan, Stanford University, Project Coordinator.

characteristics of weather out to periods of a length of two weeks will be possible.

Residential Construction Cost Factors

A basic problem area is the measurement of construction cost productivity in a way that will permit analysis in terms of savings due to improved weather forecasting systems. The effect of adverse weather on productivity in the construction industry has been the subject of considerable discussion. However, there is little, if any, data available on actual loss of man hours on individual sites due to weather. In emphasizing the lack of reliable information, two top-ranking members of the Bureau of Labor Statistics pointed out in a recent article in the Monthly Labor Review that "we do not even have satisfactory indexes of year-to-year changes in construction costs."[2]

This study is limited to one segment of the construction industry: single-family, residential homes. To investigate weather losses fully, in order to determine the cost of "avoidable" weather losses in homebuilding, would require detailed observation of operations over the entire period of construction and thorough analysis of the results. In addition, to be representative, a number of sites should be observed in the various regions throughout the year, so that variations in severity of weather between geographical regions could be quantified and the results statistically adjusted for these variations.

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[2]Jaquith, Laurence C., "Study Shows Weight of Wages in Building Costs," Architectural Record, November, 1967, p. 93.

General Economic Model: Frequency and Severity of Losses

Control of residential construction procedures to avoid losses related to weather phenomenon is an issue of risk management. The risk management function requires identification of loss exposure, measurement of economic loss potential, definition of alternative risk control methods and execution of a loss reduction program consistent with the marginal profit objective of the firm. Losses are to be prevented, shifted or reduced only when the cost of such remedial action is less than the cost of assuming the losses as a constant cost of production. While many aspects of the construction process are adversely affected by weather, there is question as to what degree improved weather forecasting would permit longer planning projection to achieve significant cost savings.

Since there is no risk management view of weather and home construction available, an economic model is suggested to outline the significant relationships between weather and the building process, and costs of residential construction as they determine weather-related and manageable costs or losses; and to suggest the source and magnitude of the economic benefits of weather risk control to a selected segment of residential construction as a test of the utility of improved weather data. This model is a mathematical representation of the building process and the relationship of weather as it affects the process. In order to develop the model, one must understand those aspects of single-family construction with which it deals. Information is obtained to plug into the mathematical formula from actual data from homebuilders' operations. Thus, the critical element in the modeling process is the data source, the homebuilder.

The premise of the model is as follows:

Frequency of Loss x Severity of Loss = Total Aggregate Loss

where:

Frequency of Loss = Housing Starts x Construction Days required for complete cycle x Vulnerability Factor (days of construction operations potentially affected by weather ÷ total construction period) x Weather Factor (percentage of annual construction workdays in a locale characterized by adverse weather likely to cause an eight hour work stoppage).

Severity of Loss (per construction day lost) = Avoidable Direct Weather Losses of labor per job ÷ Construction Days required per job + Indirect Costs of Construction (a function of days required to complete x average construction days lost per job).

Such a model has the potential for 1) forecasting weather-related losses per single family home, 2) forecasting weather-related losses per dwelling unit for multi-family construction, 3) forecasting weather-related losses for any single function in the critical path, and 4) forecasting impact on total construction capital of contractors in a single market for a defined season.

Research Method

To test this model concept, this researcher has done a micro-study of construction activities in one locale: a case study of Milwaukee, Wisconsin, to suggest potential losses due to weather. The case method in conjunction with direct interviews is utilized in this research effort, due to limitations of time, funding and qualified research staff. This method has the advantage at low cost of revealing the "organic dynamics" of the observed phenomenon, thus giving clues to the nature of the interactions which occur and suggesting generalizations which may explain possible causal connections crucial to analysis of the problem.

The problematic situation stems from the question of the effect of improved weather forecasting capability in terms of increasing productivity in residential construction. Thus, as a tentative hypothesis, this researcher makes the assumption that productivity will be increased as a postulated consequence. Thus, research has been directed toward relevant evidence or facts which either support the working hypothesis or disprove it.

It is felt that the research effort should be formulated in terms of ongoing experience and should be directed toward discovery of factual and conceptual relationships which suggest possible sequential relations, and that conclusions should be grounded in observed interactions in experience. Living processes and sequential perspective as revealed in the simulation of Milwaukee's construction activities in 1968 and as revealed in the characteristic business management systems of the homebuilding industry have been central in the working hypothesis. Thus, focus has been on the behavior of individuals in the industry since it is builders for whom the forecasts are intended.

Analysis, therefore, must proceed in terms of the behavior of builders searching for means to satisfy demand for housing in the face of constraints imposed not only by weather, but by individuals and institutions as well. The actual problem of weather in construction activity is not clear, and it is also not clear what actions applied at what strategic points will ameliorate the conditions that have caused the problem.

Previous Research Studies

A report prepared by the Environmental Science Services Administration of the Department of Commerce entitled "Operational and Economic Impact of Weather on the Construction Industry of the United States," attempted to assess the influence of thirteen weather conditions on forty-three operations associated with construction activity and to estimate the point at which each of the weather elements becomes critical. However, this report covers the overall contract construction industry and does not deal specifically with residential construction.

In England, Miss M. A. Clapp studied the effects of weather over the period 1953 to 1956 on five building sites. The report is entitled "Weather Conditions and Productivity—Detailed Study of Five Building Sites," Construction Series 32, Building Research Current Papers, Building Research Station, Ministry of Technology. Miss Clapp's chief concern was identifying the effects of adverse weather on labor productivity in England.

Limiting Constraints

The chief constraint throughout the research effort lay in the availability of actual builders' data to feed into the model. Accounting systems of typical homebuilders are not sufficiently refined to obtain anything other than labor losses resulting from adverse weather. Builders themselves are not able to determine the effects of weather on their operations. It is simply considered to be a fact of life that occurs and, if operations are stopped, they are merely continued when the weather clears. Losses in efficiency due to these work stoppages are unknown and assigning a dollar value is impossible. Thus, due to lack of accurate cost information from builders and lack of adequate data in general, assumptions were necessary at various points throughout the research effort. Assumptions were noted in the report as they became necessary.

Structure of the Report

The first chapter of the report attempts to provide background and serve as an introduction to the research at hand. The remainder of the report is grouped into four topic areas.

Chapter II is concerned with refining the definition of the problem. The homebuilding process is analyzed in terms of the individual activities that are necessary for the final product to be built. The activities which are sensitive to adverse weather are identified and the types of weather which are likely to cause work stoppage are correlated with each activity.

A case study of construction activity in Milwaukee during 1968 is found in Chapter III. An estimate of potential loss is made by matching estimated day-to-day construction activity with actual weather data.

Characteristics of homebuilders and in particular their behavior in terms of management systems form the basis for Chapter IV. An analysis of reorganization potential in terms of planning and management organization characteristics is made of the overall industry, then focuses in on Milwaukee homebuilders to determine the possibility of deriving benefits from improved weather forecasting.

The final chapter is concerned with an analysis of Milwaukee construction activity in 1968 and in eight of the characteristics of typical builders, the capacity of Milwaukee builders to utilize improved forecasting for a significant cost saving. Many assumptions were made in working up to an estimate of the magnitude of weather losses and possible savings that might accrue from improved weather forecasting. Wide variations in weather occur between the different regions and, in addition, construction techniques associated with different regions vary greatly. The accuracy and reliability of a national estimate remain to be tested. However, before an accurate dollar figure can be assigned to weather-influenced efficiency, a normal operational efficiency must be determined. Thus, it is felt that the accuracy of the estimate in this report could only be significantly improved at the expense of substantial amounts of time and funds in studying, in detail, operations of builders in the various regions of the country.

Finally, it is not meant that the research method as employed in this study should be doctrinnaire; but it is felt that any research method utilized must keep intact the behaving entities in the problem in order to formulate a workable test of possible solutions.

Chapter II—Determination of Weather-Sensitive Functions in the Homebuilding Process

To identify those elements of the homebuilding process which are vulnerable to adverse weather, the cycle of activities in the construction operation must be described. There are several techniques available to break out the component activities, which combined produce a home. One method is the Program Evaluation Review Technique or "PERT." PERT, as used today, is concerned primarily with optimizing costs. A related technique is the Critical Path Method (CPM). It is primarily concerned with the time sequence of activities, their dependencies on one another and the time elapsed for completion. The advantages often credited to both methods include a more pictorial view of what is going on and better opportunity to identify parts of the operation subject to modification with a net gain in efficiency. The critical path approach to activity identification is particularly useful in identifying the activities vulnerable to weather and the frequency over time with which weather might interfere. A later study with better cost data would find PERT a method of optimizing operations to anticipate weather and optimize costs.

Critical Path Algorithm

Critical path methods were first introducted to the construction industry in the early sixties. The method is described as "the representation of a project plan by a schematic diagram or network that depicts the sequence and interrelation of all the component parts of the project, and the logical analysis and manipulation of this network in determining the best overall program of operation."[1] The first step in preparing the schematic diagram is to break the process down into separate operations necessary for project completion. Each of the separate operations is called an activity and the completion of an activity is an event.

Once the list of activities has been prepared, the essential relationships between these activities must be determined. Certain of these activities may proceed concurrently; however, certain others must follow a given sequence: for example, foundations must be poured before framing can take place. The given sequence for any operation may be found by answering the following questions:[2]

1. What activities must precede the activity?
2. What activities must follow the activity?
3. What activities may be done concurrently with this activity?

In answering the questions in relation to each activity, the necessary sequences are determined. Since the completion of every activity is an event, then it follows that an event is not only the completion of a given activity, but the beginning of the next.

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[1] Antill, James M., and Ronald W. Woodhead, Critical Path Methods in Construction Practice (John Wiley and Sons, Inc., New York: 1965), p. 1.

[2] Ibid., p. 10.

With activities and their interrelationships determined, time must be assigned which is associated with each activity. In effect, most critical path diagrams are set up to reflect a normal time span of operations. The "normal" time is defined as the duration required to accomplish the job with the least expense. The job may actually be performed in a shorter period of time called the "crash" time. However, the fastest possible means of accomplishing the job may prove to be prohibitively expensive. Thus, the "crash" time is defined as that time to which the duration of an activity can be reduced given financial limitations.[3]

A list of the activities in the homebuilding process with their associated times may be found in Table 1. The right-hand column defines the interrelationships between each activity.

Preparation of the Single-Family Home Network

Given the sequence of operations and their elapsed times, a project graph can be prepared, called in CPM language, a "network." A network is a diagrammatic representation of the sequence and relationship of activities and events required to achieve the end objectives.[4]

In an activity-oriented network such as the one to be used here, the horizontal scale indicates time, left to right, with the beginning of the activity at the left. Activities are represented by arrows. The arrows are not

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[3] National Association of Homebuilders, CPM, A Plan for Progress, p. 2.

[4] Antill, James M. and Ronald W. Woodhead, op. cit., p. 11.

Table 1

Typical Critical Path Sequence for a Medium-Priced, Single-Family Home

	Activity	"Normal" Time	Must Follow
1.	Layout	1/2 day	-
2.	Bulldozer	1/2	1
3.	Footing excavation	1	2
4.	Stake footing grades	1/2	3
5.	Place footing concrete	1/2	4
6.	Garage foundation block	1	5
7.	House foundation block	3	6
8.	Grade and gravel garage and drive	1	6
9.	Enclose garage	1	6 & 8
10.	Plates and girder	1/2	7 & 9
11.	Floor framing and subfloor	1/2	10
12.	Close house	1-1/2	11
13.	Fascia and eave	1/2	12
14.	Soffit and siding	3	13
15.	Roofing	2	13
16.	Rough electric	2	13
17.	Rough plumbing	3	13
18.	Rough heating duct work	3	13
19.	Insulation and vapor barrier	2	15 & 16
20.	Hang drywall	2	14 & 19
21.	Paint exterior	3	17, 18, &20
22.	Hardwood floor and underlay	2	17, 18, &20
23.	Partitions	2-1/2	22
24.	Rough electric work (partitions)	2	22
25.	Set tub, plumbing in partitions	2	22
26.	Hang drywall	2	23, 24, &25
27.	Tube drywall	5	26
28.	Install electrical outlets & switches	3	27
29.	Hang doors	1	27
30.	Finish carpentry	3	29
31.	Sand hardwood floors	1	30
32.	Cabinets in kitchen	2	27
33.	Plumbing in kitchen	1	32
34.	Floor tile in kitchen	1	33
35.	Plumbing in baths	2	27
36.	Floor tile in baths	1	35
37.	Ceramic tile in baths	4	36
38.	Cabinets in baths	1	37
39.	Finish hardwood floor	2	28, 31, 34, &37
40.	Interior paint	3	39
41.	Hang electrical fixtures	1	40
42.	Set bath accessories	1	40
43.	Heating fittings	1	40
44.	Clean up	1	41, 42, 43

vectors; their length has no relation to the duration of the activity. The circles represent events. The heads of the arrows at the right represent a completed activity for that phase. The tail of an arrow indicates the beginning of work on that phase. The arrows are connected in accordance with the sequence of the operation. The jobs are arranged in "technological order," i.e., no job appears on the list until all its predecessors have been listed. Each arrow is thus drawn so that its tail is located at the first possible time the activity could start; the head is placed at the point where it can be completed last without delaying subsequent activities. Thus, all immediate predecessors of a given activity connect at the tail of its job arrow, and all successor jobs emanate from the head of its job arrow.

These connected arrows form paths. As can be seen in the network in Figure 1, there can be several paths—activity sequences that may be carried on simultaneously. The path which sums to the longest elapsed time is the "critical path"; it indicates the minimum time for the entire operation.

In effect, then, the critical path of the process is the "bottle-neck" route. Only by reducing the time required for jobs along the critical path can the overall project time be reduced. Thus, the CPM points up those areas that may be "crashed" in an effort to shorten the total time of the project. One other point to keep in mind is that if some event in the critical path is "crashed" in an effort to shorten the time period, the critical path itself may shift and some previously noncritical activity may now become critical.

It is pertinent at this point to discuss the concept of "float." The float of an activity is the amount of time by which an activity may be delayed without interfering with the start of any succeeding activity.[5] Obviously, if the activity lies on the critical path, it has a float of zero. On the other hand, if the activity is not on the critical path, it will have a certain amount of time by which it can be delayed without changing the total time of the project.

To summarize the steps in the critical path method, it requires (1) division of the project into activities, (2) formulation of the construction logic, or the specific ordering of activities, (3) determination of "normal" times for each activity, and (4) preparation of a project graph, or network.

Determination of Weather-Sensitive Areas of the Critical Path in Home Construction

With a critical path of defined activities for conventional home construction, it is possible to analyze each activity relative to sensitivity to delay due to adverse weather. Table 1 contains a list of the activities that must be performed in order to arrive at a finished project. This list is not complete nor could it necessarily be said to represent the operation of any individual firm. It is meant to be illustrative only, but does embody the major elements involved in the production process.

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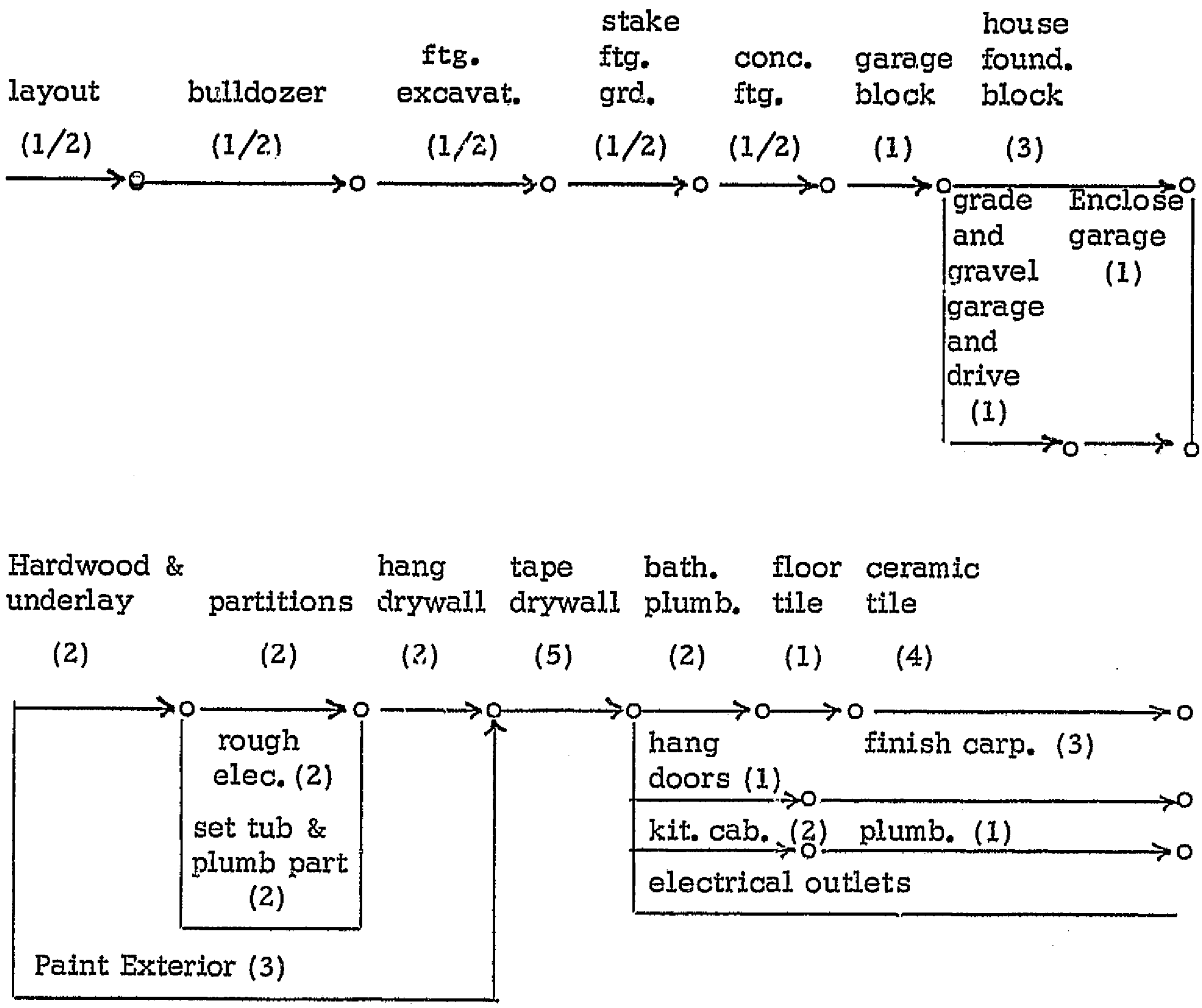
[5]Fondahl, John W., A Non-Computer Approach to the Critical Path Method for the Construction Industry, Technical Report No. 9 (Department of Civil Engineering, Stanford University, Stanford, California; 1962), p. 29.

From this listing a network diagram can be constructed. The construction logic pertaining to activities 1-44 has been worked out and the right-hand columns indicate both times associated with each activity and the interrelationship with other activities. Starting at the top of the list, we find that the first six items are all on the critical path. From "layout" to "garage block," each event depends on the prior step being completed. However, the process breaks at this point. The house foundation block can be poured simultaneously with grading and graveling the drive, and enclosing the garage. Since the longest time period, three days, is associated with the house foundation, this is the critical path. Continuing through the list for the rest of the construction period, there are four other major areas where two or more activities may be carried on at the same time. Following the longest path on the diagram, there are forty-two days required to finish the project.

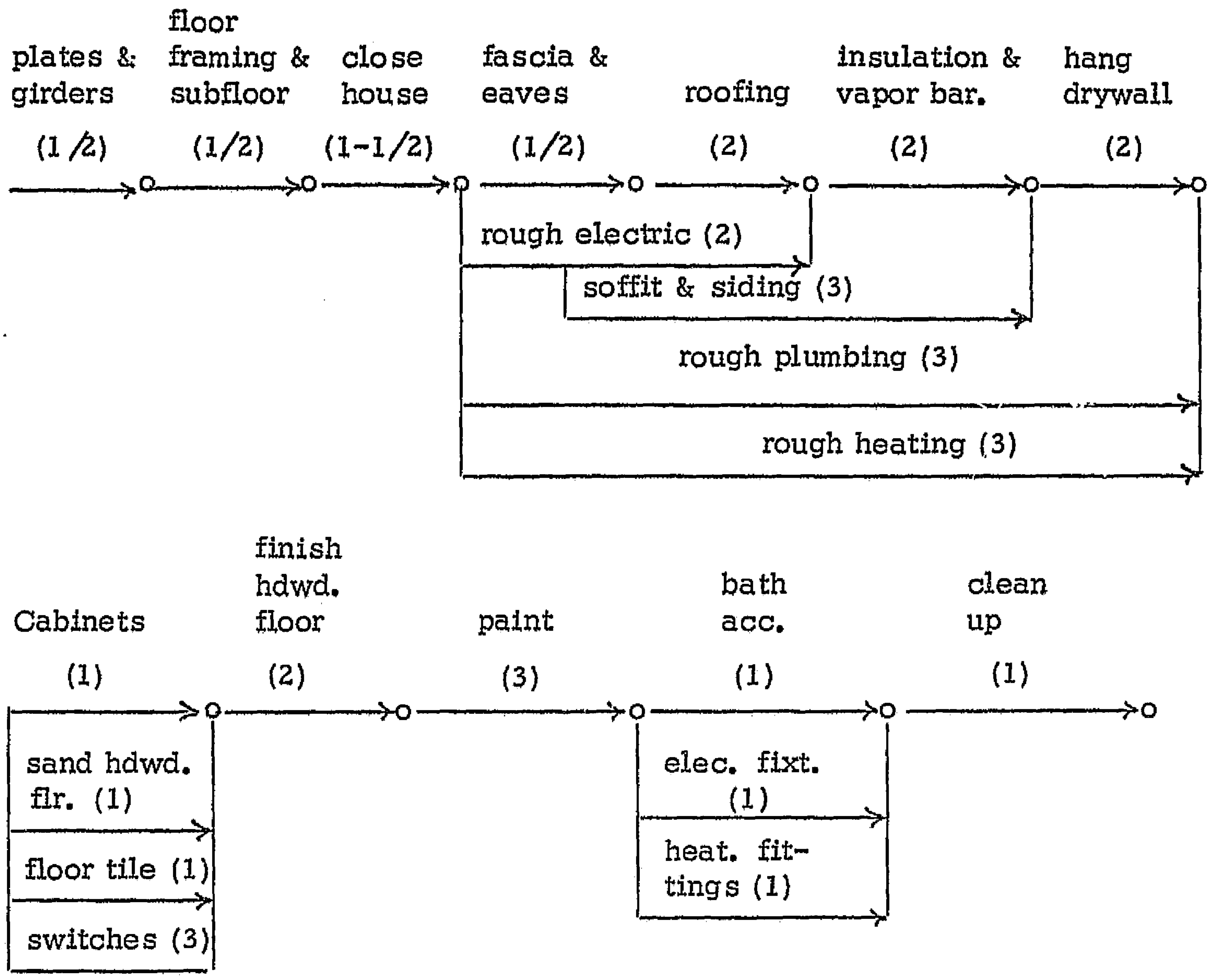
Now that the major steps in the critical path have been identified, those weather-sensitive areas may be specified. An examination of Figure 1 reveals that there are twelve days which are particularly sensitive to weather. Twelve vulnerable days out of a total of forty-two represents approximately thirty percent of the process time.

The first four steps are particularly vulnerable to precipitation and temperatures below fifteen degrees. Pouring the garage and house foundation, and the next five steps from installing plates and girders through roofing would be similarly hindered by precipitation and temperatures below fifteen degrees.

Critical Path Network for a Medium-Priced



Single-Family Home



Significance of float. Obviously, there are three other areas which would be sensitive to adverse weather conditions: grading and graveling the drive and enclosing the garage; soffitt and siding; and painting the exterior. These have been eliminated from this discussion since they do not lie on the critical path. These areas would become significant if the weather involved were to become severe enough and of sufficient duration to shift the critical path to this event. Here, the concept of "float" would be an important consideration. For example, the soffitt and siding activity has one day of float time since it requires only three days, while the roofing and insulation require four days. Thus, if the weather were to become severe enough to cost two days work on this activity, the critical path would shift to reflect the extra day required to complete it before the dry wall could be hung. As mentioned earlier, however, those activities with "float" time will be ignored from the standpoint of vulnerability to weather. It would be very difficult in this discussion to determine from past weather data the probability of such a weather-caused shift in the network flow diagram.

Severity of adverse weather. For the twelve days that lie on the critical path, another dimension should be added at this point to the weather items which have been found to affect these activities. As outlined above, the first five activities are affected by similar aspects of the weather. However, the severity of the weather in most cases determines to what extent the events are hampered. For example, layout is moderately affected by precipitation. The extent to which this operation is affected depends on how much precipitation falls and over how long a period of time. If the precipitation is light, say one-tenth of an inch over the period of an hour, operations may be delayed while it is falling and continued when it stops. On the other hand, if more than two-tenths of an inch falls over the period of an entire work day, operations may be cancelled completely for that day. If this happens, of course, the critical path of the project has been extended by one day.

The same thing is true in the case of temperature in conjunction with precipitation. A trace of precipitation throughout the workday would not affect operations significantly; however, in conjunction with temperatures below freezing, it may cause work stoppage. Even a short period of freezing rain may extend the time required to complete this activity. Ice is difficult to clear away so that activity may be continued. Temperature below fifteen degrees may hinder operations during the layout period depending on the local union regulations in the area.

Earthmoving and excavation. Bulldozer operations and footing excavation would be affected in approximately the same way by precipitation and temperature. Ground freeze has traditionally been a factor which has significantly affected this activity; however, the evolution of new heavier equipment has reduced vulnerability somewhat. In northern climates most of this work is done before the ground freezes during the winter months. Failure to accomplish this may mean cessation of operations until the spring thaw. Staking out footing grades and placing footing concrete would be affected in the same way as layout. Therefore, for the first five events, heavy precipitation within a two or three-day time period, moderate precipitation throughout the workday, light precipitation in conjunction with freezing temperatures, or temperatures below fifteen degrees would significantly affect operations.

Foundation work. In pouring the garage and house foundations, varying degrees of precipitation and temperatures hinder work. Precipitation as long as it is falling, even though light, will probably preclude pouring of any concrete. Freezing rain or temperatures, and ground freeze, preclude concrete activities. Freezing of the subgrade is prevented by spreading a layer of straw, covering this with a tarpaulin or waterproof paper. The Portland Cement Association recommends a number of techniques for pouring concrete in cold weather, one of which is the heating of mixing water. Water heaters for this purpose are available. If necessary, the aggregate may also be heated with sanddrier units, and stockpiles may be heated with live steam. However, the expense of these operations may prohibit any but the larger homebuilders' use of them. If the temperature is not too severe, the injection of a hot flame from an oil-burning heater into the miser drum may be sufficient to obtain the desired temperature. High-early-strength concrete may also be used to reduce the amount of time required for protection against cold temperatures. The poured concrete can be protected from subsequent freezing by insulating it with straw, insulating blankets or bat insulation. Thus pouring concrete may be continued through winter months provided protective equipment is used.

Closing in the house structure. The final category of events that are influenced by the weather are plates and girder, floor framing and subflooring, closing the house, finishing the fascia and eaves, and roofing. Light precipitation will have some effect on labor efficiency, but may not halt operations unless union regulations specify it. However, even a light freezing rain can be catastrophic in terms of lost time on this activity. The ice must be chipped away before the activity can be completed, an expensive and time consuming job. Low temperatures will have a detrimental effect on labor efficiency as on prior operations, but will probably not cause suspension until the thermometer approaches fifteen degrees. Experimental programs have been carried out to provide better temperature and weather control by enclosing building sites in the winter. To a certain extent, contractors have had success with temporary enclosures constructed from such materials as canvas, building board, waterproof paper and plastic. Plastic is usually favored since it lets in natural light and solar heat.

Canada has taken the lead in the way of enclosed building sites. The Canadian government encourages such advances in winter construction. For example, a government incentive program has been introduced which pays five hundred dollars to individual purchasers of homes built during the winter months. Recently, they have enacted other measures to accomplish this end. Homebuilding is receiving particular encouragement in Canada's government programs.[6]

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[6] Myers, Robert J. and Sol Swerdloff, "Seasonality and Construction," Construction Craftsman, October-December, 1967, p. 8.

Vulnerability of Weather Interference

The construction process in the homebuilding industry has been described using the critical path method. It provides the opportunity for a step-by-step analysis of the activities involved in the production cycle and pictorially portrays these steps in a network to facilitate understanding of the successive links in a single chain of events through the project. CPM offers a systematic approach for breaking out activities which, when exposed to adverse weather factors, may result in an increase in production time, thereby increasing costs.

Examination of these successive steps via CPM has revealed that the first twelve days are significantly sensitive to weather. A report by the Environmental Science Services Administration confirms that approximately one-third of the residential construction process is affected by weather.[7.] Analysis of these areas indicates that precipitation and temperature in varying combinations may cause work stoppage in any of these first twelve activities.

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[7] U. S. Department of Commerce, Environmental Science Services Administration, "Operational and Economic Impact of Weather on the Construction Industry of the United States" (National Bureau of Standards, Clearinghouse for Scientific and Technical Reports, Springfield, Virginia).

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Chapter III—A Test of the Weather Risk Factor: Frequency and Severity Estimates for Milwaukee SMSA in 1968

To restate the objectives of this research effort, knowledge is sought of potential net savings that might accrue from a better weather forecasting system. Having measured the frequency of exposure to loss during the construction cycle using critical path method, the severity of loss will be measured. Any attempt to estimate potential savings must start with a determination of the losses from adverse weather. Due to the extreme diversities of seasonal patterns throughout the United States and the voluminous data which would be involved in researching the entire country, a specific urban area has been selected for a preliminary analysis. A city in the East North Central region (Illinois, Indiana, Michigan, Ohio and Wisconsin) would product most typical results for several reasons. This area is subject to considerable weather-related interference to construction in the winter. It is also a relatively small and climatically homogeneous region; thus an urban area in this region could be construed to be relatively characteristic of the entire region in terms of weather. Finally, the research effort is centered in Madison, Wisconsin. Field investigation and communication with firms in the home-building industry, being local in character, would be facilitated by working with an urban area in close proximity. If weather conditions significantly affect construction activity in this region, then a more generalized research effort could be launched to estimate potential benefits throughout the country. Conversely, if losses are not significant in this area, research may not be rewarding in the milder regions of the South and West.

Analysis of Homebuilding Activity in Milwaukee, Wisconsin, 1968

Milwaukee, Wisconsin was selected as a representative urban area in the East North Central region. It presents a city with enough homebuilding activity to be representative of the region. Milwaukee includes the broad range of homebuilders, both large and small. Finally, the weather experienced throughout the year is felt to approximate fairly the entire region.

Vulnerability: Housing starts and recorded weather. To estimate the severity of losses due to weather in Milwaukee, it is first necessary to establish the vulnerability, that is, the number of houses under construction at any given time matched with the historical weather at that time. Construction activity for an entire year should be examined to assess the effect on day-to-day operations in all four seasons.

Bureau of Census data provide housing starts per month throughout 1968 by regions—Northeast, Northcentral, South and West. A housing start is defined as the start of construction, beginning excavation, on a residential building. Unfortunately, housing starts are not available from the Bureau of Census for urban areas. Building permit data are available for Milwaukee. A building permit is required in order to start construction on a single-family residence. However, use of these data is severely limited for this research in that the issuance of a permit tells nothing about the time construction is started. A permit may be issued in January, but construction may not start until April.

The Bureau of the Census is able to provide seasonal adjustments of permits issued and is able, using formulas based on historical housing start data, to provide estimates of housing starts for a current period by geographic area and by type of structure, such as single-family residential. These seasonal indexes provide a fairly accurate and realistic measurement of seasonal movements in private housing starts, since they were calculated directly from the housing series whose seasonal movements they are intended to identify and measure. These techniques were introduced in 1960 and were limited at first since consistent historical data were available only back to 1959. It was felt that satisfactory seasonal indexes should be derived from a minimum of six years data. With nine years of data upon which to base the 1968 seasonal indexes, they are felt to be realistic.[1]

Again the severe limitation of data, available only for the Northcentral region, is encountered. Fortunately, data were available for single-family housing starts in the Milwaukee SMSA from a local manufacturing firm, Badger Meter. The marketing department of this firm, using the same techniques developed by the Census Bureau, has been able to accurately predict housing starts on a monthly basis. The firm utilizes this informa-

[1] Seasonal adjustment factors were introduced in the Census Bureau's "Construction Reports: Housing Starts," Series C20-50. A full description of the methodology used for this purpose appears in the Bureau's "Construction Reports: Housing Starts," Series C20-11, Supplement.

tion to predict its monthly sales figures. Mr. Nelson of the marketing department provided this researcher with monthly housing start data for 1968.[2]

In comparing the housing starts for Milwaukee with data on the North-central region, it was found that seasonal patterns of starts are roughly coincident. Figures in Table 2 indicate that housing starts tend to be concentrated in the months from April to October—the months of more favorable weather. A characteristic noted in both the region and Milwaukee is the drop in starts during August followed by a pickup in October, and then by a steady decline during late fall. Apparently factors other than weather play a causal role in monthly fluctuations in homebuilding in August and September. One explanation may be the tendency of homebuilders to concentrate on completions in September in order to meet traditional occupancy deadlines in early October, and then to speed up starts in October in order to put in foundations before the onset of colder weather.[3]

Due to the impossibility of obtaining accurate data on housing starts by working day, total starts for the month were divided by working days in that month to get an average housing start per working day. Any remainder was lumped in the first working day of the month (see Table 2). The intro-

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[2]The National Association of Homebuilders publishes "Metropolitan Housing Markets Forecast," which forecasts housing starts for major metropolitan areas. It lists participating manufacturers such as Badger Meter in Milwaukee.

[3]These general characteristics tend to be found not only in the North-central region but the Northeast region as well, due to the more severe winters associated with these areas. A general discussion of patterns throughout the U. S. may be found in "Seasonal Adjustment of Private Housing Starts," Construction Review, January, 1964, p. 7.

Table 2

Housing Starts for Milwaukee in 1968

Work Day	
1-22	January (22 work days, 200 starts) 9 per day for first 22 days with extra 2 on 1st day
23-43	February (21 work days, 190 starts) 9 per day for days 23-43 with extra 2 on 23rd day
44-64	March (21 work days, 287 starts) 13 per day for days 44-64 with extra 14 on 44th day
65-86	April (22 work days with 396 starts) 18 per day for days 65-86
87-108	May (22 work days with 525 starts) 23 per day for days 87-108 with extra 19 on 87th day
109-128	June (20 work days with 459 starts) 22 per day for days 109-128 with extra 19 on 109th day
129-150	July (22 work days with 375 starts) 17 per day for days 129-150 with extra 1 on 129th day
151-172	August (22 work days with 319 starts) 14 per day for days 129-150 with extra 11 on 151st day
173-192	September (20 work days with 303 starts) 15 per day for days 173-192 with extra 3 on 173rd day
193-215	October (23 work days with 364 starts) 15 per day for days 193-215 with extra 19 on 193rd day
216-235	November (20 work days with 311 starts) 15 per day for days 216-235 with extra 11 on 216th day
236-254	December (19 work days with 261 starts) 13 per day for days 236-254 with extra 14 on 236th day

duction of this statistical average housing starts per work day was necessary to compare day-to-day weather with construction activity over the period of a month. This abstraction is intended to produce a practical method of estimating day-to-day losses due to weather.

Computer model of relationships of weather and the building process. A computer program was designed with the cooperation and aid of the University of Wisconsin, School of Business Computer Center, in order to provide an economic model of the significant relationships of weather and the building process. In general the source of potential weather-related losses and the exposure in terms of construction in progress is provided as input. The computer then matches weather variables on a given work day with those construction activities in progress on that day and provides as output the number of housing days lost due to weather for each workday, cumulatively, throughout the year.

The first twelve days of construction activity, which are vulnerable to adverse weather, are split into three different processes. These processes are affected by different combinations of weather as shown in Table 3. Process A consists of the excavation period. It includes layout, bulldozer operation, footing excavation, setting of footing elevations, and concrete footings. During this phase of construction, if any of the following occur, a work day is lost; more than a trace of precipitation falls throughout the work day with temperature below freezing, two-tenths of an inch of precipitation falls through the work day, three-tenths of an inch or more of precipitation occurs within twenty-four hours, five-tenths of an inch or more of

Table 3

Weather Variables

Process A	- days 1-3 in critical path
A1	More than a trace of precipitation throughout the work day with temperature below 32°
A2	.2 inches or more of precipitation throughout the work day
A3	.3 inches or more of precipitation within 24 hours
A4	.5 inches or more of precipitation the day before
A5	1.0 inches or more of precipitation 2 days before
A6	Temperature below 15°
Process B	- days 4-7 in critical path
B1	More than a trace of precipitation throughout the work day
B2	More than .2 inches of precipitation within 24 hours
B3	More than .4 inches of precipitation the day before
B4	More than .6 inches of precipitation two days before
B5	Temperature below 15°
Process C	- days 8-12 in critical path
C1	More than a trace of precipitation throughout the work day with temperature below 32°
C2	.2 inches or more of precipitation throughout the work day
C3	Temperature below 15°

rain occurs the day before, one inch or more of precipitation falls within two days before, or the average temperature for the day is 15° or below.

These variables are the result of both human limitations and requirements of the construction activity. Precipitation falling during the normal work day with temperatures below freezing and average temperatures below 15° make human activity in the process so uncomfortable as to require work stoppage. Union regulations usually reflect this factor and require cessation of activity. Precipitation of one inch or more would delay all excavation starts for two days following as it is presumed for this model that this much rain would make the ground too muddy to work. The other precipitation variables result in similar circumstances.

Process B requires four days and consists of the garage and house foundation work. Again, workers are stopped by average temperatures below 15°. Precipitation is even more critical in this construction activity since pouring of concrete is especially vulnerable to precipitation. Excavations partially filled with water or snow, or precipitation falling during the work day will generally result in a lost day.

Process C requires five days and is composed of plates and girders, floor framing and subfloors, closing the house, fascia and eaves and roofing. Since these activities are concerned primarily with the human element, they may be carried out as long as the precipitation is not too heavy. However, precipitation falling with the temperature below freezing, or average temperatures below 15° will result in work stoppage.

The historical weather was analyzed for each working day (see Appendix A) and the appropriate weather variables were provided as input to the computer program. Daily housing starts were also provided as input. The computer kept track of the number of houses in each process as they proceeded through each working day. It matched appropriate weather variables with appropriate processes and if the variable associated with the process occurred, every house in that process was moved up a day to reflect the extra day required to complete the process as a result of the lost day. For every day that was lost due to weather for a specific process, the computer provided as output housing days lost. (See Appendix C for computer program.)

For example, on the first working day of the year weather variables A6, B5, and C3 occurred (see Appendix B). In other words, temperatures were below 15°. Thus, any housing units which were in either process A, B, or C were delayed by one day. Since there were eleven houses scheduled to start process A, eleven house days were lost for process A. There were no houses in process B or C; therefore, no house days were lost for either of these two processes. The effects of weather for each work day throughout the year can be followed by comparing the input variables with the house days lost as shown on the computer print-out in Appendix B.

Backlog and deferred start assumptions. One other appropriate limitation was built into the program-backlog. This term may be explained as follows. If construction were geared to starting twenty-three houses per day, as occurred in May, and if weather were to cause postponement of scheduled starts for several days, the computer was programmed to keep track of the total number of starts that were postponed. Once the weather cleared and the houses could be started, there may have been too many houses for all to be started on that day. The computer was programmed to allow no more than seventy-five houses to be started on any given day. Thus, the computer recognized the practical limitations of homebuilders in Milwaukee.

For example, the last nine working days in June had an exceptional number of days on which heavy rains fell. Over six inches fell, resulting in variables A2, A4, A5, A3, A2, A2, A2, A4, and A5, respectively, for each of the last nine working days. Since twenty-two houses were scheduled to be started each day, this resulted in a backlog of 198 houses, all to be started on the first day of July. Obviously, with construction activity geared to starting twenty-two houses per day, homebuilders would not be able to start all 198 homes on the first of July. Thus, the computer sent these houses to a pool and held all in reserve but the seventy-five which it allowed to be started. This left 141 houses in the pool on work day 129. On work day 130, 17 houses were scheduled for starting. This brought the pool total to 158 at the start of work day 139. Only 75, however, were started on this day. The computer continued to keep track of the backlog in this manner until the pool at the start of day 132 totalled less than 75 and the backlog was eliminated.

During the period when there were more than 75 houses in the pool, the computer charged a house day lost for each house that had been scheduled to be started and was unable to be started due to backlog. In referring to the computer print-out, it will be noted that on working day 129, there were 119 houses in Process A. Since the 22 houses started on day 117 completed Process A by the end of day 119, that leaves 44 houses in Process A throughout the period of bad weather. Then, 75 houses were started on day 129, after the bad weather period, totalling now 119 in Process A.

House Days Lost Translated into Total Aggregate Loss in 1968

Having programmed into the computer the significant weather events which occurred during each work day in 1968 and the number of houses started on each day, the computer read-out provides the number of house days lost in each process. Thus, on the last work day of the year, 3,843 house days were lost in Process A, 3,523 in Process B, and 1,206 in Process C.

To translate house days lost into a monetary equivalent for 1968, Milwaukee homebuilders and subcontractors were interviewed in order to arrive at a dollar amount which would be considered lost for each work day in each process. It was found that roughly $5.00 per hour would be lost for each workman for all three phases. In talking with the Milwaukee Builder's Association, it was found that of the approximately $23,600 cost of a three-bedroom, medium quality home, about 18% would represent overhead and profit.[4] Though there is some loss in efficiency stemming from scheduling and related problems of lost workdays, it was the opinion of the technical staff of the Builder's Association that accounting values for variable and fixed overhead were not sufficiently refined to estimate an amount lost for variable overhead. Thus, total loss attributable to a lost working day has been limited to labor cost.

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[4]Information obtained during conversation with Mr. Steven Woll of the Milwaukee Builder's Association.

In Process A, the three days of total activity involved in the excavation period was based on a two-man crew. Thus, the total loss per workday would be 16 hours or $80.00. This loss per day multiplied by the total working days lost in Process A, 3,843, results in a loss for the year of approximately $307,440.

In Process B, the foundation operation, and Process C, the carpentry operation, the crew was assumed to consist of four men for a labor cost per day of $160.00. The total loss for the year amounts to an estimated $756,640.

Thus, the total loss in Milwaukee for 1968 due to weather is estimated to be $1,064,780. This loss balanced against a total value of housing constructed during the period estimated to be $94,164,000 ($23,600 estimated average per housing unit x 3,990 housing starts) or roughly 1% loss due to weather in 1968.

Frequency of loss having been estimated using critical path method and severity of loss having been estimated by matching frequency with historical weather phenomenon, this gives a rough indication of the total aggregate loss due to weather in Milwaukee. Before attempting to analyze the data in terms of avoidance of weather-related losses using weather forecasting, the organizational adaptability and planning controls characteristic of the industry will be viewed. This analysis is necessary since utilization of improved weather forecasting output to improve efficiency presumes that firms have the adaptability and controls to implement weather risk controls.

Chapter IV—Profile of Business Management Systems in the Home Construction Industry and the Capacity to Plan for Weather

The home building industry, which put in place $22.2 billion of new nonfarm housing units in 1968 and which is expected to increase that figure to $25.4 billion in 1969, is characterized by large numbers of small firms. These firms are primarily local in nature and are mostly single-proprietorships. In fact, the contract construction industry, of which homebuilding is a part, exhibits these same general traits. Only in agriculture and services is the proportion of sole proprietorships higher.

In 1965 there were in contract construction about as many reporting firms with employees subject to the Social Security program as in manufacturing. However, reflecting the higher proportion of smaller firms among contractors, the reporting contractors had 2.8 million employees as compared to 17.6 million in manufacturing. Contract construction consists of those firms primarily engaged in construction for others and includes general contractors primarily engaged in heavy nonbuilding construction, erection of buildings and special trade contractors.[1]

An examination of the figures in Table 4 indicates the prevalence of small firms in the construction industry. General contractors engaged in construction of buildings includes home builders. Those firms employing less than three employees account for over 50% of the total reporting firms.

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[1] Puglisi, Enzo A. and William R. Loftus, "Profile of the Contract Construction Industries," Construction Review, January, 1968, pp. 4-9.

Table 4

Number of Employees and Number of Reporting Units by Employment-Size Class in the Building Industry, March 1966

Industry	Total reporting units	No. of employees	Number of reporting units by employment-size class							
			1-3	4-7	8-19	20-49	50-99	100-249	250-499	500+
Gen'l Contractors Building	93,148	937,384	46,672	20,234	14,168	5,773	2,061	976	189	75
Special Trade Contractors	199,917	1,538,150	112,379	41,484	30,387	11,404	3,012	1,072	143	36
Paper and Paper Hanging	26,401	124,347	18,113	4,766	2,498	790	184	48	2	--
Masonry, Stonework Plastering	30,177	229,336	16,148	6,854	4,748	1,799	460	151	16	1
Masonry, Other Stonework	19,586	144,651	10,403	4,601	3,144	1,060	272	95	10	1
Carpentering, Wood Flooring	22,265	105,684	14,798	4,306	2,273	631	141	34	2	--
Roofing, Sheet Metal Work	12,479	105,973	6,222	2,655	2,297	995	248	59	3	--
Concrete Work	8,362	69,040	4,228	2,038	1,463	467	108	47	7	4
Excavating and Foundation	6,571	41,687	3,847	1,298	1,012	324	75	13	2	--

Source: Construction Review, January 1968, p. 7.

Firms employing in excess of fifty persons account for only approximately 3% of the total. A similar trend is found among the special trade contractors with over 90% of the firms employing twenty persons or less. In both these categories it is highly probable that even for those few firms which employ more than fifty persons are primarily engaged in heavy construction. Milwaukee exhibits these same general tendencies as shown in Table 5.

The prevalence of such a large number of small firms may be explained partially by the local nature of the industry, the ease of entry, and the low capital requirements.

With general characteristics established for the single-family construction industry, a deeper look will be taken at the specific characteristics of individual firms. For purposes of this research, the small volume homebuilder is defined as one who completes less than one hundred housing units per year. The large volume builder, on the other hand, completes in excess of one hundred units.

Small-Volume Builder

The small-volume builder has little or no need for a formal organization. At the lower end of the scale, the custom builder of approximately twenty-five units per year can survive with a combination secretary/receptionist/bookkeeper and perhaps a small crew of carpenters. The owner can personally serve as the construction superintendent. Architectural, engineering, legal and sales may be provided by outside consultants. The owner-builder in this case is actively engaged in the day-to-day detail of running his

Table 5

Number of Employees and Number of Reporting Units by Employment-Size Class in the Building Industry in Milwaukee SMSA, March 1967

Industry	Total reporting units	No. of Employees	Number of reporting units by employment-size class 1-3	4-7	8-19	20-49	50-99	100-249	250-499	500+
Contract Construction	2,123	22,372	1,124	399	342	163	67	25	2	1
Gen'l Contractors Buildings	471	5,569	402	196	89	50	28	16	-	1
Special Trade Contractors	1,484	14,040	804	278	232	118	39	12	1	-
Paint, Paper Hanging	196	1,073[1]	144	23	15	10	3	-	-	-
Masonry, Stonework, Plaster	250	1,921	129	57	40	20	4	-	-	-
Masonry and Other Stonework	157	1,186[1]	76	43	22	14	2	-	-	-
Carpenter and Wood Flooring	218	1,314	131	46	29	10	1	1	-	-
Carpentering	100	639[1]	58	24	13	4	-	1	-	-
Concrete Work	39	185	27	6	4	1	1	-	-	-
Excavation and Foundation	41	171	26	9	5	1	-	-	-	-

[1] Figure affected somewhat by disclosure

Source: Data compiled from U. S. Department of Commerce, <u>County Business Patterns</u>, 1967.

operation. He makes all of the policy decisions and in addition performs most of the administrative functions. The secretary keeps the files, writes letters, answers the phone, and does most of the bookkeeping. The carpentry crew may or may not be on a part-time basis. It will generally include an "all-around" craftsman capable of layout, general carpentry and finish work. If the builder has only one house scheduled, he may with the aid of his own crew frame and trim it out himself. During other periods of increased activity, he may subcontract most of the carpentry work and use his crew for layout and finish work. Other functions of this crew are to correct any discrepancies or change minor items for customer satisfaction. They also aid in checking the quantities of materials delivered to the job site and verifying quantities shown on the delivery tickets and invoices. Finally, the craftsman may act in the owner's absence as a general foreman, coordinating and directing the activity of subcontractors.

Most of the functions are performed by specialists on a contract basis. Subcontractors are used to provide the skills of painting, plumbing, electrical work, flatwork, masonry and most of the carpentry. An architect may be called in to help prepare plans and specifications or the builder may work from stock plans. The services of legal counsel, certified public accountants and, in some cases, sales, are obtained when required.

The bulk of "custom" homes are built by operatives in this category. Typically, the customer has his own lot and contracts for a home to be built on it. However, in some cases the builder may contract to deliver a total package of land and improvements. By limiting construction to a few homes at a time, the small builder is able to provide close personal attention and custom detailing specified by the customer.

At the other end of the scale of the "small" home builder is the operative who builds twenty-five to one-hundred homes per year. The organizational structure as shown in Figure 2 is much the same as the smaller builder, being just an expanded version. The owner in this case is required to delegate a part of his authority and responsibility to others; however, he remains typically in a single proprietorship position. He may employ a full-time construction superintendent, sales manager and bookkeeper. Again, some of the carpentry work may be done by the builder's own direct-hire crews. Most, however, is done by subcontract.

Large-Volume Builder

An organizational structure for the larger operative in the homebuilding industry might look like the outline in Figure 3. A builder of over one hundred homes a year would typically employ a staff to provide adequate planning, construction engineering and project management.

The owner again would be actively engaged in the entire process and would formulate policy and delegate responsibility. With the larger firms single-proprietorships may give way in some cases to partnerships. Often a partnership is the device used to obtain management talent. In some cases the very large firms may even choose the corporate form of organization.

Figure 2

Small-Volume Builder
(less than 75 homes per year)

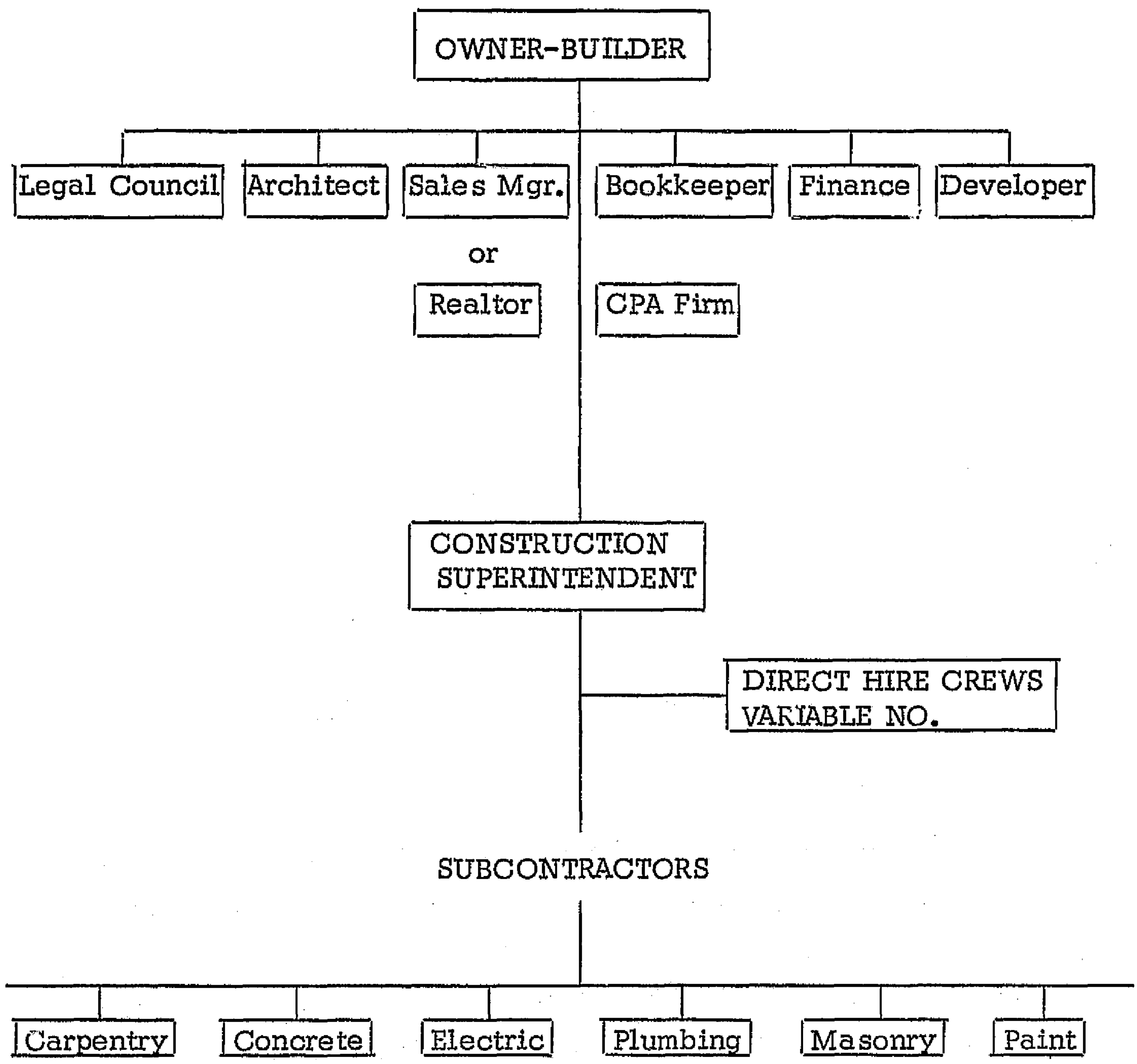
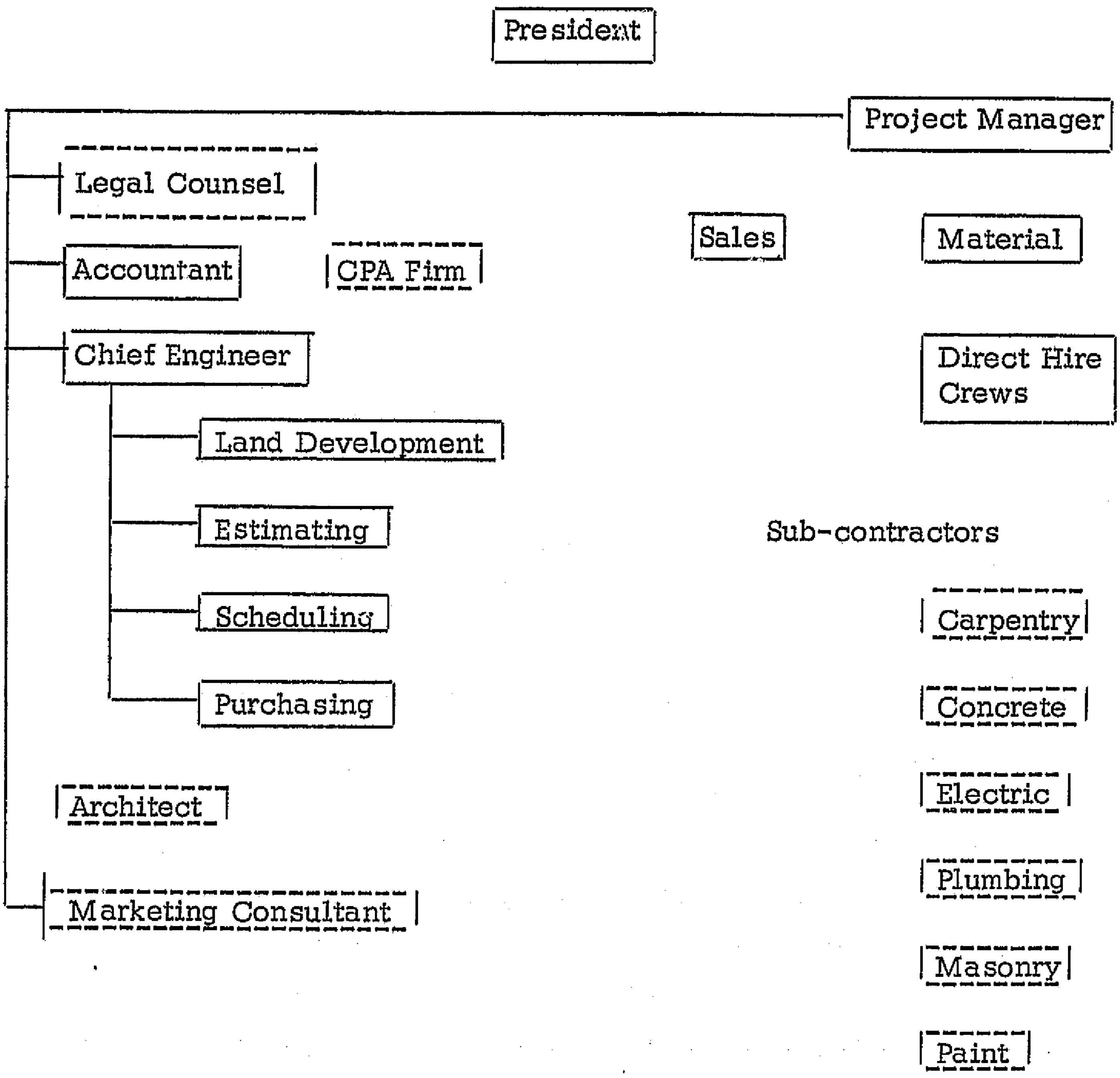


Figure 3

Large-Volume Builder
(100+ homes per year)



The chief engineer would be charged with responsibility for the development planning process including the initial estimate of construction costs. He must work closely with the architect during this phase. In addition he would prepare the overall schedule and see that material purchases and timing of subcontractors are consistent with this schedule.

The project manager assumes responsibility for implementing this plan. Unlike the construction superintendent, the project manager assumes a broader role in the home building industry in that he not only oversees the construction process, but also is directly charged with the merchandising effort. Again the bulk of the actual construction will be subcontracted to specialists. The project manager provides the management of the subcontracting effort.[2]

Though the number of large builders is relatively small compared to the smaller homebuilder, according to an NAHB estimate, the larger operative accounted for 64% of the total volume of single-family construction in 1959.[3] The tendency over the period of 1950 to 1960 has been for the large home builder to account for a larger share of total volume. For example, large-scale homebuilders accounted for approximately 24% of total volume in 1949.[4] Though the general tendency seems to have been for the larger firms to

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[2]For an extensive discussion of the management characteristics of the homebuilding industry, see Buckley, Ernest L., Residential Construction Management (New York: John Wiley and Sons, Inc., 1959).

[3]Herzog, John P., The Dynamics of Large-Scale Homebuilding (Berkeley, University of California Press, 1963), p. 20.

[4]Ibid., p. 20.

increase their share of the market, the trend has levelled out in recent years. The editors of House and Home remarked in early 1963, "The builder of 2,000 single-family homes a year on a single site has vanished with the boom of the mid '50's."[5] The tendency of the industry to move toward a more oligopolistic structure between 1950 and 1960 never materialized. The industry remains competitive as opposed to oligopolistic. The lack of scale economies beyond the 500-800 range prevented established builders from gaining sufficient advantages to keep the potential entrants out of the market and thus has prevented even most local markets from coming under the domination of a few giant firms.[6] In addition, there is the "custom home" market. The small builder with his inherent ability to provide closer supervision and attention to custom detail is unlikely to be supplanted from his market by large operatives.

One of the primary characteristics attributed to both large and small homebuilders is that both exhibit a tendency to subcontract as much as possible. More and more the homebuilder assumes the role of an agent, bringing together the various specialists to produce a finished product.

Subcontractors

Through the years these specialists have evolved as a result of benefits

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[5] "The New Housing Industry," House and Home, January, 1963, p. 64.

[6] Herzog, John P., op. cit., p. 28.

derived from this mode of operation. The builder has found that due to fluctuations in construction rate for his operation, subcontracting eliminates the need to "carry" a highly skilled work force during periods of lesser activity. The subcontractor tends to be more efficient in production, since he works on a fixed contract, than employees of the contractor who typically work on an hourly wage. Finally, competent subcontractors reduce the contractor's cost of labor supervision. The homebuilder's role is effectively reduced to that of job coordination rather than direct labor supervision.

Thus, in the final analysis the subcontractor carries out most of the actual construction activities. Typically, the majority of subcontractors are in the same category as the smaller homebuilder. Most are "small in size as most small business—i.e., a sole proprietorship with an average of only three to five employees..."[7] Because of small size and a shortage of full-time management aid, the owner must spend most of his time in the field supervision jobs, soliciting business and estimating jobs.

The tendency toward small, single-proprietorships is evidenced in Table 4. As stated earlier, over 90% of total special trade contractors employ less than twenty employees. In the carpentry sector, firms with twenty or fewer employees accounted for over 96% of the total.

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[7] Sokol, Andrew, Jr., Contractor or Manipulator (Coral Gables: University of Miami Press, 1968), p. 31.

Industry Capacity to Plan for Weather

In discussing the capability of planning in the homebuilding industry to take advantage of long-range weather forecasts, it is evident from the preceding analysis that some degree of sophistication is necessary in order to schedule construction activity to minimize weather-related losses. The builder need not be so sophisticated in his scheduling as to employ the critical path technique. There are many variations or alternate methods of scheduling that are acceptable if the essential elements are provided for:[8]

a) Orderly completion of each house as the basis.

b) Maximization of efficiency in use of labor for each activity.

c) Provision for effective supervision to correct discrepancies which might cause serious delay.

Interviews with homebuilders throughout the research period indicate the percentage of small to medium-size builders who operate without effective scheduling may be quite high. Many operate by "feel" without any plan on paper. It is highly unlikely that they would be able to utilize long-range forecasting in their scheduling process. This holds true for the average small subcontractor also. Even if the smaller builder did operate with efficient scheduling procedures, he would be hampered in his maximization of labor by the very fact of small size. He does not have enough houses in varying stages of completion to shift his carpenter crew to an inside job if adverse weather were to hamper outside activities. Due to union rules in

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[8]Buckley, Ernest L., op. cit., p. 77.

most localities, working overtime to finish vulnerable construction activities before the onset of bad weather is also limited.

The larger homebuilder with a larger and more varied management staff utilizing skillful scheduling might be able to shift labor and possibly start times to avoid labor losses due to weather. However, most of the larger builders employ subcontractors who work on a fixed bid. Therefore, if there are weather losses in employment of labor, the subcontractor absorbs these and not the large builder. Thus, the same problem of small size and inability to schedule for weather is encountered as was found in the small builder's operations.

The main problem in avoiding weather losses is due to the very nature of the industry. It is primarily a local industry with firms operating usually in one metropolitan area. If a builder were to know in advance that a freezing rain were going to fall in Milwaukee within the next two weeks, he would not be able to shift his crews to Madison since he works exclusively in Milwaukee. The next section will be concerned with a more thorough analysis of the variables that might be manipulated in order to mitigate the effects of adverse weather.

Chapter V—Potential for Weather Risk Control: Preliminary Observations

The risk management function has been defined as a process involving identification of loss exposure, measurement of economic loss potential, definition of alternative risk-control methods and execution of a loss reduction program consistent with the marginal profit objective of the firm. Loss exposure (frequency) and loss potential (severity) have been estimated in the first two sections of the report. The capabilities of individual firms' executing a loss reduction program were explored in the preceding section. This final section will concern itself with a discussion of alternative risk control methods and with the likelihood of the homebuilding industry utilizing them in a loss reduction program. Various weather data and services available will be investigated with an eye toward potential use by the homebuilder. In addition, the major variables—personnel, equipment, and material and design—will be reviewed in terms of their role in weather risk control. Finally, an estimate of "avoidable" weather losses will be attempted and the place of weather forecasting in reducing losses will be explored.

Weather Data and Services

A homebuilder might begin in an attempt to plan for weather by utilizing a detailed history of past weather conditions in his area entitled "Local Climatological Data." This document is available from the National Weather Records Center and provides an accurate picture of:[1]

[1]"How to Save a Million (Theoretically)," Constructor, January, 1967, p. 25.

1) How many lost days to expect from adverse weather.

2) When concrete can be poured and cured properly.

3) When to expect work stoppages due to union chill factor clauses.

These data are useful not only in long-range planning of manpower and equipment, but are also useful in making a realistic and profitable bid. The most useful information can be gained from analyzing each of the weather-sensitive activities on a "rough" daily schedule based on this historical data. For example, knowing that concrete is scheduled to be poured on a day when average temperatures have been near the critical point would call for special precautions. Information at this point might save lost time in getting the proper equipment to the site.

This type of planning can theoretically be implemented by any home-builder with no special knowledge and minimum expense. However, direct interviews tended to confirm the fact that very few, if any, homebuilders make use of this information.[2]

In most cities a local contractor can have a direct-line teletype giving hourly updated forecasts. Radar is used to predict movement of local rain showers. The contractor pays only for the lease of a teleprinter and connecting line to the nearest telephone exchange where circuits are available. Charges normally run $40 per month.

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[2]"Local Climatological Data" is available for $1.00 from the National Weather Records Center in Ashville, North Carolina.

The Environmental Science Services Administration is expanding UHF continuous radio transmission of local weather to most major metropolitan areas. Updates of local weather are transmitted on a frequency of 162.55 megahertz.

An alternative to interpretation of available information by the contractor's staff is the professional consultant. The services, including information tailored to a particular job requirement, can run from $100 to $1,000 per month. However, it is possible to use such services on a time-sharing arrangement much the same as computer time-sharing. An advantage in addition to the "tailored" information is the opportunity to speak directly with the consultant, to ask questions and learn more about information that might aid him in his operations.[3]

The major drawback for a small homebuilder in using present weather information systems is the lack of knowledge to interpret the information directly and the lack of funds to employ a weather consultant. Therefore, very few homebuilders are making use of anything other than the daily forecasts transmitted via television or radio.[4]

Operational Variables: Personnel, Equipment, and Material and Design

Personnel. As mentioned earlier, any advantages accruing from advance

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[3] A list of reputable consultants, who are members of the American Meteorological Society, can be obtained by writing 45 Beacon Street, Boston, Massachusetts.

[4] "How to Save a Million (Theoretically)," op. cit., p. 27.

knowledge of adverse weather would necessitate an activity planning level not evidenced by the typical homebuilder. However, even given this capability, advance knowledge of the likelihood of a freezing rain on a given day ten days hence would be useful if the homebuilder was able to reschedule men to work on an inside job that day, or he was able to speed up operations to the degree that any critical activities would be completed before the advent of the weather.

As for rescheduling men to work inside on a day of harsh weather, the degree of specialization of the building trades prohibits it except in the case of carpentry. Earthmovers and concrete personnel are forbidden to do inside carpentry work in many cases by union regulations. In addition they may lack the skills necessary for carpentry work. Rescheduling of carpenters, given inside work available, could be done just as easily in the morning of the day of harsh weather. The requisite here is for accurate one-day forecasts.

Speeding up operations, on the other hand, would require advanced knowledge. However, most homebuilders are unable to speed up the process significantly due to institutional factors. Union regulations in most areas have stiff overtime clauses, and weekend work is often prohibited. In addition, neighboring residences, though tolerating the noise associated with homebuilding during the regular work-day, are highly intolerant of night or weekend work.

Thus, work planners having benefit of long-term forecasts have limited alternatives in terms of scheduling manpower. Overtime as a loss control device has maximum potential, but theoretical value in residential areas. On-site working hours are narrowly defined by the eight-to-five schedules of residents rather than daylight hours or round-the-clock operational limits. The twenty-four hour day is reduced to a single eight or nine hour band of production time which is then further cut short by union work rules relative to forty-hour weeks and weekend construction. Within the remaining band of working hours, the potential to shift workers inside and outside with the weather is drastically curtailed by the craft specialty organization of construction labor.

Equipment. Weather loss reduction has been achieved to some degree with technological improvements in equipment for homebuilders. As discussed in the first section, many improvements have been made in earth-moving and concrete pouring that enable operation in freezing temperatures. There have been numerous such improvements made to mitigate the effects of weather. Perhaps the major limitation in this area is the wind-chill clause in union contracts, thus prohibiting use of manpower at below minimum temperatures.

Materials and Design. Perhaps the most significant advances in weather control have come about through prefabrication affecting both materials and design. At the present time, most prefabrication has been a matter of moving conventional on-site building, particularly the walls, roof and floors, into a factory.

The term prefabrication is in common use throughout the construction industry; yet its meaning is ambiguous to many. Confusion exists because prefabrication is a generic term used to describe a manufacturing process through which a building, component or piece is produced. Inherent in each of these operations are precutting, preassembly, prefinishing and final assembly. Thus, any company that participates in the process, regardless of the degree of involvement, can be called a "prefabber."

Prefabrication has taken four basic forms:[5]

1) Prefabricated components—The off-site assembly of specialized structural and mechanical components is the most widespread form. Components are then shipped from the plant to the site and integrated with conventional on-site building techniques.

2) Manufactured homes—The off-site construction of almost all elements of the frame and shell is another form. Walls, floors and roofs are constructed as separate items and assembled on the site, or complete rooms and dwelling units may be constructed in a factory in the form of modules.

3) Sectionalized homes—These units are manufactured homes in which the walls, floors and roofs are assembled in the plant instead of being shipped as components and assembled on the site. Two sections are usually placed together on a conventional foundation of the site to make a finished dwelling unit.

4) Mobile homes—These are a form of the sectionalized home. Since

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[5] "Industrialized Housing," Materials compiled and prepared for the Subcommittee on Urban Affairs of the Joint Economic Committee, Congress of the United States (U. S. Government Printing Office, Washington, 1969), p. 44.

mobile homes are generally considered a separate industry, they will be dealt with after this discussion.

Of the 1.3 million single-family residences started in 1967, an estimated 18.5% were manufactured homes of one type or another (not including mobile homes).[6] In fact, virtually all of the dwelling units currently being erected are using some prefabricated components. The growth rate of prefabrication is predicted to continue at a fairly constant rate. Most of the growth will stem from builders accepting existing methods rather than the development of new ones. By 1975, it is expected that 45% of the total cost of a dwelling unit will represent prefabricated materials.[7]

One form of prefabricated dwelling unit not included in the figures mentioned above is the mobile home. Within the space of a few years, it has emerged as a major source of housing. More than five million people now live in mobile homes.[8] The importance of mobile homes in the low-cost housing market, especially in the under-34 and the retirement age group, is suggested by the fact that the market has changed dramatically from one of second, or vacation homes to one of primary residences. The Mobile Home Manufacturers Association reports that the average stay in one location for

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[6] Ibid., p. 45.

[7] Guy, R. B. and Associates, "The State of the Art of Prefabrication in the Construction Industry" (Columbus, Ohio, Batelle Memorial Institute, 1967).

[8] Magid, James I., "The Mobile Home Industry," Financial Analysts Journal, September-October, 1969, p. 30.

mobile home owners is fifty-eight months. This is comparable to the average length of time spent in one home by conventional homeowners. About 70% of the mobile homes produced since World War II have been used as permanent dwellings.[9] The typical unit is 55-65 feet long and 12 feet wide, containing over 700 square feet of floor space and averages approximately $5,700 furnished.[10] Moreover, a number of manufacturers have begun producing units that can be joined with another unit, thus allowing sizes up to 1,500 square feet—comparable to a conventional home.

The mobile home industry has grown at an average annual rate of 11% from 1956 through 1968, as shown in Table 6. Shipments are expected to have risen 20% to 25% in 1969 to a level exceeding 375,000 units. It is interesting to note that mobile homes, were they included in single-family housing starts, would account for approximately one-fifth of all housing starts. This percentage can be expected to increase if projected growth rates materialize.[11]

The significance of prefabrication in terms of weather risk control is evident. An increasing percentage of housing units is being constructed off-site in an enclosed factory. Thus, the weather has been eliminated for mobile homes, and for other prefabricated units with one exception. The initial stages in the critical path as outlined in Chapter I are still vulnerable

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[9] "Industrialized Housing," op. cit., p. 53.

[10] Magid, James I., op. cit., p. 30.

[11] Ibid., p. 32.

Table 6

Shipments of Mobile Homes, 1956-1968

Period	No. of units shipped
1956	124,300
1957	119,300
1958	102,300
1959	120,500
1960	103,700
1961	90,200
1962	118,000
1963	150,840
1964	191,320
1965	216,470
1966	217,300
1967	240,360
1968	317,950

Note: Data prior to 1959 excludes Alaska and Hawaii

Source: Construction Review, September, 1969. From information supplied to the U. S. Department of Commerce by the Mobile Home Manufacturers Association.

to the weather. Foundations must still be poured on site. However, advances are being made here also. For example, Duraform, Inc. of Madison, Wisconsin manufactures prefabricated foundation forms for poured concrete residential basements. Forms are set within eight hours, walls are poured, and forms stripped the following working day. The forms require finished and leveled footings. If prefabricated footing systems were developed in the future, excavation and complete foundations might require only two working days to complete.

Conclusions: Control of Weather Losses

In recapitulation, the homebuilding industry is characterized by the following:

1) A critical path exists in which approximately one-third of home construction operations are vulnerable to adverse weather.

2) Weather losses as estimated in Milwaukee suggest that something more than one percent of the total value of housing units constructed was lost due to adverse weather.

3) The industry is characterized by large numbers of small firms, local in nature and operating generally without finite long-range planning.

4) Large homebuilders tend to subcontract most of the activities; subcontractors possess the same characteristics as the small homebuilder.

5) The bulk of the weather data and services currently available is not utilized by the majority of homebuilders.

6) Growth in prefabrication is reducing the on-site weather loss potential significantly.

Potential loss (frequency x severity). It has been estimated by the Environmental Science Services Administration (ESSA) that a minimum of $3 billion was lost in 1964 due to weather. The report concludes that with present weather data and services, a potential saving is possible of at least an estimated one-half billion dollars, 17% of the reported loss.[12]

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[12] Conclusions of report entitled "Operational and Economic Impact of Weather on the Construction Industry of the United States," (National Bureau of Standards, Clearinghouse for Scientific and Technical Reports, Springfield, Virginia).

Information upon which this report is based was collected over a five-year period, and the loss potential was quantified in 1964. At that time the loss potential represented something over 3% of total United States construction expenditures. It is felt that the 1% loss potential as estimated from the Milwaukee case study is representative of the loss potential in 1968 for three reasons: 1) Homebuilding has approximately one-third of its critical path vulnerable to adverse weather as opposed to as much as three-fourths for highway, special, and heavy construction included in the ESSA study; 2) Advances in equipment, and materials and design have reduced the on-site vulnerability to some extent in the period 1964 to 1968; 3) Sensitivity of construction costs and profit margins to weather upset is inverse to the price class of the house to be built. Lower-priced homes are being supplanted by mobile homes and sectionalized houses which have the fewest number of days of on-site weather vulnerable operations.

Avoidable weather losses. Analysis of weather losses in Milwaukee indicate that approximately 5% of the total loss potential is avoidable given the planning systems to take advantage of present weather data and services. Again, this "avoidable" loss is lower than that reported by ESSA. The same reasons apply as stated above and in addition two others can be cited: 1) the local nature of homebuilding, and 2) the tendency for large numbers of small firms among homebuilders and subcontractors. Weather phenomena such as critically low temperature are present throughout the limited geographic area in which the homebuilder operates. The major potential for mitigating the effect of the weather is to shift manpower to inside operations. It is highly improbable that any manpower other than carpentry can be shifted due to the high specialization of earthmoving and foundation personnel. In any case, due to the fact that most firms are small, it is somewhat improbable that the homebuilder would have enough "closed" homes in process to reduce carpentry labor losses significantly.

Role of weather forecasts in avoiding weather losses. Finally, the potential for avoidance of weather losses offered by an improved, long-range weather forecasting system necessitates long-range planning not generally found in homebuilding. It is felt that the major benefit would lie in the initiation of long-range planning capability. Homebuilders generally plan the next day's activities at about three in the afternoon. The decision is reviewed the next morning in the light of observed and forecasted weather conditions. Therefore, this report concludes that requirements for scheduling operations could best be met by an accurate forecast of local conditions at 6:00-7:00 A.M. and 3:00-4:00 P.M. Long-range (two to three months) planning for bidding purposes could be met by historical climatological information presently available.

Significant Areas for Future Research

The National Association of Homebuilders has various experiments in cost accounting underway. It might be possible to create a category for weather loss. NASA might want to encourage more research in this area by funding research in several different sizes of homebuilders in different regions to pinpoint the frequency and severity of weather-related losses. Conclusions reached in this report have been deductively reasoned. From a long-range research standpoint, it would be better to work inductively from within the accounting framework of selected firms within different regions. This cost information would provide a basis for predicting losses throughout the United States.

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APPENDIX A

Historical Weather Analysis: Milwaukee, 1968

January, 1968

WORKDAY	Average Temp of for day	Precipitation Total 24 hrs. Water	Snow	a.m. 8	9	10	11	12	p.m. 1	2	3	4	5
1	----												
2	16	.01	.3		T	T	.01	T	T	T			T
3	9	.06	1.2										
4	-4	0	0										
5	7	T	T							T			
6	----												
7	----												
8	2	.01	.2										
9	16	.01	.1	T	T	T	T						
10	16	T	T	T	T	T	T	T			T	T	
11	23	T	T				T	T					
12	26	T	T										
13	----												
14	----												
15	21	T	T				T	T	T				
16	17	0	0										
17	26	0	0										
18	34	0	0										
19	35	0	0										
20	----												
21	----												
22	36	T	T										
23	23	T	.2	T	T								
24	17	.01	.4	T	T	T	T	T	.01	T	T	T	T
25	24	T	T										
26	32	.04	.1	T	.01	T	.01	T	T	T	T		
27	----												
28	----												
29	40	.19	0	T	.01	.12	.01	T		.03	.02		
30	30	0	0										
31	36	.21	0		T	T	T	T	T	T	T	T	

NOTE: T Indicates Trace

Source: U.S. Department of Commerce, Environmental Science Services Administration," Local Climatological Data," Milwaukee, Wisconsin, January, 1968

February, 1968

WORKDAY	Average Temp of for day	Precipitation Total 24 hrs. Water	Snow	a.m. 8	9	10	11	12	p.m. 1	2	3	4	5
1	42	.23	0	T	T	T	T	T	T	T			
2	29	.15	1.6	T	.01	T	.01	T	T	T			
3	----------												
4	----------												
5	31	0	0										
6	34	.05	.1								T	.01	.01
7	25	.02	.4	T	T			T	T				
8	21	T	T										
9	16	T	T										
10	----------												
11	----------												
12	14	T	T										
13	18	0	0										
14	22	0	0										
15	23	0	0										
16	26	0	0										
17	----------												
18	----------												
19	17	T	T			T	T			T		T	T
20	11	0	0										
21	9	0	0										
22	17	0	0										
23	21	T	T										
24	----------												
25	----------												
26	23	.04	.4		T	T	T	T	T	T	.01	.01	.01
27	26	.03	.4						T	.01	.01	T	T
28	24	.01	.1						T	T	.01	T	T
29	19	T	T	T	T								

NOTE: T Indicates Trace

SOURCE: U.S. Department of Commerce, Environmental Science Services Administration, "Local Climatological Data," Milwuakee, Wisconsin, February, 1968

March, 1968

WORKDAY	Average Temp of for day	Precipitation Total 24 hrs. Water	Precipitation Total 24 hrs. Snow	Precipitation During Workday a.m. 8	9	10	11	12	p.m. 1	2	3	4	5
1	33	0	0										
2	----	----	----	----	----	----	----	----	----	----	----	----	----
3	----	----	----	----	----	----	----	----	----	----	----	----	----
4	42	0	0										
5	32	.05	.3			T						T	.02
6	29	T	T										
7	35	0	0										
8	40	.03							.01	.01	T	T	.01
9	----	----	----	----	----	----	----	----	----	----	----	----	----
10	----	----	----	----	----	----	----	----	----	----	----	----	----
11	34	0	.0										
12	25	T	T									T	T
13	27	0	0										
14	33	T	T		T								
15	48	T	0										
16	----	----	----	----	----	----	----	----	----	----	----	----	----
17	----	----	----	----	----	----	----	----	----	----	----	----	----
18	48	.02	0								T	T	.02
19	50	.07	0							T	T		
20	39	0	0										
21	32	.02	.2	T	T	T	T	T	T	T			
22	29	.02	.5	T	T	.01	.01	T	T	T			
23	----	----	----	----	----	----	----	----	----	----	----	----	----
24	----	----	----	----	----	----	----	----	----	----	----	----	----
25	52	.01	0										
26	58	.01	0										
27	59	.01	0										
28	62	0	0										
29	51	0	0										
30	----	----	----	----	----	----	----	----	----	----	----	----	----
31	----	----	----	----	----	----	----	----	----	----	----	----	----

NOTE: T Indicates Trace

SOURCE: U.S. Department of Commerce, Environmental Science Services Administration, "Local Climatological Dada," Milwaukee, Wisconsin, March, 1968

April, 1968

WORKDAY	Average Temp of for day	Precipitation Total 24 hrs. Water	Precipitation Total 24 hrs. Snow	Precipitation During Workday a.m. 8	9	10	11	12	p.m. 1	2	3	4	5
1	40	0	0										
2	42	0	0										
3	49	.56	0					.10	.09	.17	.17	.02	T
4	46	.02	T						T			T	.01
5	31	T	T										
6	—	—	—	—	—	—	—	—	—	—	—	—	—
7	—	—	—	—	—	—	—	—	—	—	—	—	—
8	51	0	0										
9	51	T	0										
10	45	0	0										
11	53	0	0										
12	68	0	0										
13	—	—	—	—	—	—	—	—	—	—	—	—	—
14	—	—	—	—	—	—	—	—	—	—	—	—	—
15	47	0	0										
16	52	.08	0									T	.01
17	48	.82	0	.03	.26	.28	.08	.01	.06	.01		T	
18	47	0	0										
19	43	T	0	T	T	T	T						
20	—	—	—	—	—	—	—	—	—	—	—	—	—
21	—	—	—	—	—	—	—	—	—	—	—	—	—
22	51	0	0										
23	51	.51	0	T	T	T	.02	.01					.01
24	37	.05	.4	T	T	T	T	.01	.01	.01	.01	.01	T
25	43	0	0										
26	41	0	0										
27	—	—	—	—	—	—	—	—	—	—	—	—	—
28	—	—	—	—	—	—	—	—	—	—	—	—	—
29	55	T	0										
30	51	.02	0										

NOTE: T Indicates Trace

SOURCE: U.S. Department of Commerce, Environmental Science Services Administration, "Local Climatological Data," Milwaukee, Wisconsin, April, 1968

May, 1968

WORK DAY	Average Temp of for day	Precipitation Total 24 hrs. Water	Snow	Precipitation During Workday a.m. 8	9	10	11	12	p.m. 1	2	3	4	5
1	47	0	0										
2	58	0	0										
3	51	.04	0							.03			
4													
5													
6	41	0	0										
7	53	0	0										
8	64	.02	0										
9	53	0	0										
10	50	0	0										
11													
12													
13	51	0	0										
14	63	.78	0	T									
15	70	.42	0										
16	55	.03	0	T									
17	52	0	0										
18													
19													
20	52	.08	0				T	T	.07	.01			
21	53	T	0										
22	56	.03	0						.02	.01			
23	55	.01	0	T	T								
24	54	0	0										
25													
26													
27	56	.04	0										
28	53	.02	0			T	T	T	T	T	T	T	T
29	53	.06	0										
30													
31	60	.04	0										

NOTE: T Indicates Trace

SOURCE: U.S. Department of Commerce, Environmental Science Services Administration, "Local Climatological Data," Milwaukee, Wisconsin, May, 1968

June, 1968

WORKDAY	Average Temp of for day	Precipitation Total 24 hrs. Water	Snow	Precipitation During Workday a.m. 8	9	10	11	12	p.m. 1	2	3	4	5
1	————												
2	————												
3	61	0	0										
4	64	0	0										
5	74	0	0										
6	75	0	0										
7	79	0	0										
8	————												
9	————												
10	74	T	0										
11	73	.02	0	T	T								
12	59	T	0										
13	55	0	0										
14	71	.01	0										
15	————												
16	————												
17	62	.01	0										
18	65	1.62	0	.29	.33	.12						.10	.58
19	66	0	0										
20	58	0	0										
21	72	1.32	0	.11	T						.32		
22	————												
23	————												
24	65	.30	0	T	T	T	T	.02	T				.11
25	54	.57	0	.08	.03	T	T	T	T	T	T	.02	T
26	56	2.03	0	.12	.28	.04	.05	.01					
27	57	.19	0	.01	T	T	T				T	T	.01
28	63	T	0						T	T			
29	————												
30	————												

NOTE: T Indicates Trace

SOURCE: U.S. Department of Commerce, Environmental Science Services Administration, "Local Climatological Data," Milwaukee, Wisconsin, June, 1968

July, 1968

WORK DAY	Average Temp of for day	Precipitation Toatl 24 hrs. Water	Snow	Precipitation During Workday a.m. 8	9	10	11	12	p.m. 1	2	3	4	5
1	72	T	0										
2	57	0	0										
3	59	0	0										
4	----	----	----	----	----	----	----	----	----	----	----	----	----
5	61	.03	0										
6	----	----	----	----	----	----	----	----	----	----	----	----	----
7	----	----	----	----	----	----	----	----	----	----	----	----	----
8	76	T	0	T									
9	65	.04	0										
10	56	0	0										
11	62	0	0										
12	69	0	0										
13	----	----	----	----	----	----	----	----	----	----	----	----	----
14	----	----	----	----	----	----	----	----	----	----	----	----	----
15	82	0	0										
16	81	0	0										
17	81	.56	0								.45	.04	T
18	78	.41	0	T	.01	T							
19	67	0	0										
20	----	----	----	----	----	----	----	----	----	----	----	----	----
21	----	----	----	----	----	----	----	----	----	----	----	----	----
22	71	0	0										
23	66	1.54	0			T	.30	.27	.13	T			
24	73	.43	0										
25	67	0	0										
26	68	0	0										
27	----	----	----	----	----	----	----	----	----	----	----	----	----
28	----	----	----	----	----	----	----	----	----	----	----	----	----
29	64	0	0										
30	71	0	0										
31	71	.26	0		.01	T							

NOTE: T Indicates Trace

SOURCE: U.S. Department of Commerce, Environmental Science Services Administration, "Local Climatological Data," Milwaukee, Wisconsin, July, 1968

August, 1968

WORKDAY	Average Temp of for day	Precipitation Total 24 hrs. Water	Snow	Precipitation During Workday a.m. 8	9	10	11	12	p.m. 1	2	3	4	5
1	66	0	0										
2	68	0	0										
3	----------												
4	----------												
5	80	.22	0	T	.03	T							
6	84	T	0										
7	76	.02	0										
8	72	.71	0				.12	.43	.15	.01			
9	74	.06	0										.06
10	----------												
11	----------												
12	68	0	0										
13	75	0	0										
14	66	0	0										
15	69	.01	0			T							
16	82	T	0										T
17	----------												
18	----------												
19	81	.16	0										
20	83	1.08	0										
21	85	0	0										
22	84	0	0										
23	85	0	0										
24	----------												
25	----------												
26	59	0	0										
27	59	0	0										
28	59	0	0										
29	62	0	0										
30	64	0	0										
31	----------												

NOTE: T Indicates Trace

SOURCE: U.S. Department of Commerce, Environmental Science Services Administration, "Local Climatological Data," Milwaukee, Wisconsin, August, 1968

September, 1968

WORKDAY	Average Temp of for day	Precipitation Total 24 hrs. Water	Snow	Precipitation During Workday a.m. 8	9	10	11	12	p.m. 1	2	3	4	5
1	------	------	------	------	------	------	------	------	------	------	------	------	------
2	------	------	------	------	------	------	------	------	------	------	------	------	------
3	76	0	0										
4	72	.56	0										
5	65	.02	0										
6	61	0	0										
7	------	------	------	------	------	------	------	------	------	------	------	------	------
8	------	------	------	------	------	------	------	------	------	------	------	------	------
9	65	.38	0					T		.01	.02	T	
10	61	.04	0										
11	60	0	0										
12	67	0	0										
13	66	0	0										
14	------	------	------	------	------	------	------	------	------	------	------	------	------
15	------	------	------	------	------	------	------	------	------	------	------	------	------
16	69	0	0										
17	67	.02	0		T	.01	T		T	T	T		
18	61	.35	0	.01	T	.02	.01	.05	.04	.03	.05	T	T
19	59	.46	0	T	T	.03	.08	.10	.03	.03	.05	.10	.10
20	63	0	0										
21	------	------	------	------	------	------	------	------	------	------	------	------	------
22	------	------	------	------	------	------	------	------	------	------	------	------	------
23	71	.02	0			T	T	T					
24	62	1.20	0	.02	T								
25	56	0	0										
26	54	0	0										
27	57	0	0										
28	------	------	------	------	------	------	------	------	------	------	------	------	------
29	------	------	------	------	------	------	------	------	------	------	------	------	------
30	64	0	0										

NOTE: T Indicates Trace

SOURCE: U.S. Department of Commerce, Environmental Science Services Administration, "Local Climatological Data," Milwaukee, Wisconsin September, 1968

October, 1968

WORK DAY	Average Temp of for day	Precipitation Total 24 hrs. Water	Snow	a.m. 8	9	10	11	12	p.m. 1	2	3	4	5
1	70	0	0										
2	66	.02	0										
3	47	0	0										
4	45	0	0										
5	—	—	—	—	—	—	—	—	—	—	—	—	—
6	—	—	—	—	—	—	—	—	—	—	—	—	—
7	54	0	0										
8	53	0	0										
9	55	.10	0				.01	.02	.01	T	.02	.03	.01
10	51	0	0										
11	51	0	0										
12	—	—	—	—	—	—	—	—	—	—	—	—	—
13	—	—	—	—	—	—	—	—	—	—	—	—	—
14	69	0	0										
15	75	0	0										
16	72	0	0										
17	62	T	0										T
18	51	0	0										
19	—	—	—	—	—	—	—	—	—	—	—	—	—
20	—	—	—	—	—	—	—	—	—	—	—	—	—
21	52	.06	0										
22	50	.31	0	T									
23	48	.01	0								T	T	T
24	43	.18	0	.02	.01	T		T	.01			T	
25	43	0	0										
26	—	—	—	—	—	—	—	—	—	—	—	—	—
27	—	—	—	—	—	—	—	—	—	—	—	—	—
28	41	.05	0										
29	37	0	0										
30	38	0	0										
31	54	0	0										

NOTE: T Indicates Trace

SOURCE: U.S. Department of Commerce, Environmental Science Services Administration, "Local Climatological Data," Milwaukee, Wisconsin, October, 1968.

November, 1968

WORKDAY	Average Temp of for day	Precipitation Total 24 hrs. Water	Snow	Precipitation During Workday a.m. 8	9	10	11	12	p.m. 1	2	3	4	5
1	59	0	0										
2	----	----	----	----	----	----	----	----	----	----	----	----	----
3	----	----	----	----	----	----	----	----	----	----	----	----	----
4	39	0	0										
5	42	.10	0										T
6	45	.41	0	.03	.02	.03	.04	.01	.02	.02	.02	.02	.04
7	40	.03	0	T	T	T	T	T					
8	34	T	T	T	T	T	T	T	T	T	T	T	T
9	----	----	----	----	----	----	----	----	----	----	----	----	----
10	----	----	----	----	----	----	----	----	----	----	----	----	----
11	36	0	0										
12	35	0	0										
13	37	0	0										
14	44	.19	0										
15	43	.23	0	T	T								
16	----	----	----	----	----	----	----	----	----	----	----	----	----
17	----	----	----	----	----	----	----	----	----	----	----	----	----
18	35	T	T										
19	28	0	0										
20	26	T	T	T	T	T							
21	42	0	0										
22	42	0	0										
23	----	----	----	----	----	----	----	----	----	----	----	----	----
24	----	----	----	----	----	----	----	----	----	----	----	----	----
25	32	.02	T										
26	41	0	0										
27	32	0	0										
28	----	----	----	----	----	----	----	----	----	----	----	----	----
29	32	T	T										
30	----	----	----	----	----	----	----	----	----	----	----	----	----

NOTE: T Indicates Trace

SOURCE: U.S. Department of Commerce, Environmental Science Services Administration, "Local Climatological Data," Milwaukee, Wisconsin November, 1968

December, 1968

WORKDAY	Average Temp of for day	Precipitation Total 24 hrs. Water	Snow	Precipitation During Workday a.m. 8	9	10	11	12	p.m. 1	2	3	4	5
1	----	----	----	----	----	----	----	----	----	----	----	----	----
2	36	.01	T	T	T								T
3	36	0	0										
4	36	T	T										
5	26	.01	.1	T	T								
6	19	0	0										
7	----	----	----	----	----	----	----	----	----	----	----	----	----
8	----	----	----	----	----	----	----	----	----	----	----	----	----
9	27	T	T								T		
10	31	0	0										
11	36	0	0										
12	50	T	0						T		T		
13	33	.01	.1			T	T	T	T	T	T	T	.01
14	----	----	----	----	----	----	----	----	----	----	----	----	----
15	----	----	----	----	----	----	----	----	----	----	----	----	----
16	20	0	0										
17	23	0	0										
18	29	.18	T			T	T	T					
19	36	.66	.5			.01	T	T	T	.01	T	T	T
20	26	T	T		T								
21	----	----	----	----	----	----	----	----	----	----	----	----	----
22	----	----	----	----	----	----	----	----	----	----	----	----	----
23	23	.01	.1										
24	----	----	----	----	----	----	----	----	----	----	----	----	----
25	----	----	----	----	----	----	----	----	----	----	----	----	----
26	24	.04	.5	T		T	T						T
27	36	.40	0	.04	.02	.04	.02	.04	T	T	T	T	T
28	----	----	----	----	----	----	----	----	----	----	----	----	----
29	----	----	----	----	----	----	----	----	----	----	----	----	----
30	21	.13	2.7		T	.01	T	T	T	.01	.02	.02	.01
31	----	----	----	----	----	----	----	----	----	----	----	----	----

NOTE: T Indicates Trace

SOURCE: U.S. Department of Commerce, Environmental Science Services Administration, "Local Climatological Data," Milwaukee, Wisconsin December, 1968

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APPENDIX B

Computer Print-Out: House Days Lost: Milwaukee, 1968

DAY	START	A	B	C		ALOST	BLOST	CLOST	PROA	PROB	PROC
1	11	1	1	1	A6 B5 C3	11	0	0	0	0	0
2	9	1	1	1	A6 B5 C3	31	0	0	0	0	0
3	9	1	1	1	A6 B5 C3	60	0	0	0	0	0
4	9	1	1	1	A6 35 C3	98	0	0	0	0	0
5	9	1	1	1	A6 B5 C3	145	0	0	0	0	0
6	9	0	0	0		145	0	0	56	0	0
7	9	0	0	0		145	0	0	65	0	0
8	9	0	0	0		145	0	0	74	0	0
9	9	0	0	0		145	0	0	27	56	0
10	9	0	0	0		145	0	0	27	65	0
11	9	0	0	0		145	0	0	27	74	0
12	9	0	0	0		145	0	0	27	83	0
13	9	0	0	0		145	0	0	27	36	56
14	9	0	0	0		145	0	0	27	36	65
15	9	0	0	0		145	0	0	27	36	74
16	9	0	0	0		145	0	0	27	36	83
17	9	1	1	1	A1 B1 C1	181	36	83	27	36	83
18	9	0	0	0		181	36	83	36	36	92
19	9	0	1	0	B1	181	72	83	36	45	36
20	9	0	1	0	B1	181	117	83	36	54	27
21	9	0	0	0		181	117	83	27	63	27
22	9	0	0	0		181	117	83	27	63	27
23	11	0	1	0	B1	181	180	83	29	72	18
24	9	0	1	0	B1	181	252	83	29	81	18
25	9	0	0	0		181	252	83	29	81	27
26	9	0	0	0		181	252	83	27	65	45
27	9	0	0	0		181	252	83	27	56	54
28	9	0	0	0		181	252	83	27	38	81
29	9	0	0	0		181	252	83	27	38	90
30	9	1	1	1	A6 B5 C3	217	290	173	27	38	90
31	9	0	0	0		217	290	173	36	36	92
32	9	0	0	0		217	290	173	36	36	74
33	9	0	0	0		217	290	173	36	36	65
34	9	0	0	0		217	290	173	27	45	47
35	9	0	0	0		217	290	173	27	45	47
36	9	0	0	0		217	290	173	27	45	45
37	9	1	1	1	A6 B5 C3	253	335	218	27	45	45
38	9	0	0	0		253	335	218	36	45	45
39	9	0	0	0		253	335	218	36	36	54
40	9	1	1	1	A1 B1 C1	298	371	272	36	36	54
41	9	0	0	0		298	371	272	45	36	54
42	9	0	0	0		298	371	272	36	45	54
43	9	0	0	0		298	371	272	36	45	54
44	27	0	0	0		298	371	272	45	54	54
45	13	0	0	0		298	371	272	49	54	45
46	13	0	0	0		298	371	272	53	45	54
47	13	0	0	0		298	371	272	39	63	54
48	13	0	0	0		298	371	272	39	58	63
49	13	0	0	0		298	371	272	39	62	63
50	13	0	0	0		298	371	272	39	66	63
51	13	0	0	0		298	371	272	39	52	72

DAY	START	A	B	C		ALOST	BLOST	CLOST	PROA	PROB	PROC
52	13	0	0	0		298	371	272	39	52	76
53	13	0	0	0		298	371	272	39	52	71
54	13	0	0	0		298	371	272	39	52	75
55	13	0	0	0		298	371	272	39	52	79
56	13	0	0	0		298	371	272	39	52	65
57	13	0	0	0		298	371	272	39	52	65
58	13	0	0	0		298	371	272	39	52	65
59	13	1	1	1	A1 B1 C1	350	423	337	39	52	65
60	13	0	0	0		350	423	337	52	52	65
61	13	0	0	0		350	423	337	52	52	65
62	13	0	0	0		350	423	337	52	52	65
63	13	0	0	0		350	423	337	39	65	65
64	13	0	0	0		350	423	337	39	65	65
65	18	0	0	0		350	423	337	44	65	65
66	18	0	0	0		350	423	337	49	65	65
67	18	1	1	1	A1 B1 C2	417	488	402	49	65	65
68	18	1	1	0	A4 B3	502	553	402	49	65	52
69	18	0	0	0		502	553	402	90	52	65
70	18	0	0	0		502	553	402	90	57	65
71	18	0	0	0		502	553	402	90	62	65
72	18	0	0	0		502	553	402	54	103	65
73	18	0	0	0		502	553	402	54	108	78
74	18	0	0	0		502	553	402	54	108	70
75	18	0	0	0		502	553	402	54	108	75
76	18	0	0	0		502	553	402	54	72	116
77	18	1	1	0	A2 B1 C2	574	625	402	54	72	103
78	18	1	1	0	A4 B3	664	697	402	54	72	90
79	18	0	0	0		664	697	402	90	72	90
80	18	0	0	0		664	697	402	90	72	90
81	18	1	1	1	A2 B1 C2	772	769	492	90	72	90
82	18	1	1	0	A4 B1	898	841	492	90	72	36
83	18	0	0	0		898	841	492	126	72	54
84	18	0	0	0		898	841	492	90	108	72
85	18	0	0	0		898	841	492	90	108	72
86	18	0	0	0		898	841	492	54	144	72
87	42	0	0	0		898	841	492	78	144	90
88	23	0	0	0		898	841	492	83	108	126
89	23	0	0	0		898	841	492	88	108	126
90	23	0	0	0		898	841	492	69	96	162
91	23	0	0	0		898	841	492	69	101	162
92	23	0	0	0		898	841	492	69	106	162
93	23	0	0	0		898	841	492	69	111	126
94	23	0	0	0		898	841	492	69	92	150
95	23	0	0	0		898	841	492	69	92	119
96	23	0	0	0		898	841	492	69	92	124
97	23	0	0	0		898	841	492	69	92	129
98	23	0	0	0		898	841	492	69	92	134
99	23	0	0	0		898	841	492	69	92	115
100	23	0	0	0		898	841	492	69	92	115
101	23	0	0	0		898	841	492	69	92	115
102	23	0	0	0		898	841	492	69	92	115

DAY	START	A	B	C		ALOST	BLOST	CLOST	PROA	PROB	PROC
103	23	0	0	0		898	841	492	69	92	115
104	23	0	0	0		898	841	492	69	92	115
105	23	0	0	0		898	841	492	69	92	115
106	23	0	0	0		898	841	492	69	92	115
107	23	0	0	0		898	841	492	69	92	115
108	23	0	0	0		898	841	492	69	92	115
109	41	0	0	0		898	841	492	87	92	115
110	22	0	0	0		898	841	492	86	92	115
111	22	0	0	0		898	841	492	85	92	115
112	22	0	0	0		898	841	492	66	110	115
113	22	0	0	0		898	841	492	66	109	115
114	22	0	0	0		898	841	492	66	108	115
115	22	0	0	0		898	841	492	66	107	115
116	22	0	0	0		898	841	492	66	88	133
117	22	0	0	0		898	841	492	66	88	132
118	22	0	0	0		898	841	492	66	88	131
119	22	0	0	0		898	841	492	66	88	130
120	22	1	1	1	A2 B1 C2	986	929	622	66	88	130
121	22	1	1	0	A4 B3	1096	1017	622	66	88	107
122	22	1	1	0	A5 B4	1228	1105	622	66	88	66
123	22	1	1	0	A3 B2	1382	1193	622	66	88	44
124	22	1	1	1	A2 B1 C2	1558	1281	666	66	88	44
125	22	1	1	1	A2 B1 C2	1756	1369	710	66	88	44
126	22	1	1	1	A2 B1 C1	1976	1457	754	66	88	44
127	22	1	1	0	A4 B3	2218	1545	754	66	88	22
128	22	1	1	0	A5 B4	2482	1633	754	66	88	0
129	18	0	0	0		2482	1633	754	119	88	22
130	17	0	0	0		2482	1633	754	172	88	44
131	17	0	0	0		2482	1633	754	225	88	66
132	17	0	0	0		2482	1633	754	192	141	88
133	17	0	0	0		2482	1633	754	134	194	110
134	17	0	0	0		2482	1633	754	76	247	110
135	17	0	0	0		2482	1633	754	51	267	110
136	17	0	0	0		2482	1633	754	51	209	163
137	17	0	0	0		2482	1633	754	51	151	216
138	17	0	0	0		2482	1633	754	51	93	269
139	17	0	0	0		2482	1633	754	51	68	289
140	17	0	0	0		2482	1633	754	51	68	284
141	17	1	1	0	A3 B2	2550	1701	754	51	68	209
142	17	0	1	0	B3	2550	1769	754	68	85	134
143	17	0	0	0		2550	1769	754	68	85	76
144	17	0	0	0	A2 B1 C2	2550	1769	754	68	85	51
145	17	1	1	0	A3 B2	2635	1854	754	68	85	34
146	17	0	0	0		2635	1854	754	68	102	51
147	17	0	0	0		2635	1854	754	68	85	85
148	17	0	0	0		2635	1854	754	68	85	85
149	17	0	0	0		2635	1854	754	51	102	85
150	17	0	1	0	B2	2635	1956	754	51	119	85
151	25	0	0	0		2635	1956	75[illegible]	59	102	102
152	14	0	0	0		2635	1956	754	56	102	85
153	14	0	0	0		2635	1956	754	53	102	85

DAY	START	A	B	C		ALOST	BLOST	CLOST	PROA	PROB	PROC
154	14	0	0	0		2635	1956	754	42	76	119
155	14	0	0	0		2635	1956	754	42	73	136
156	14	1	1	1	A2 B1 C2	2691	2029	890	42	73	136
157	14	1	1	0	A4 B3	2761	2102	890	42	73	102
158	14	0	0	0		2761	2102	890	70	70	102
159	14	0	0	0		2761	2102	890	70	67	102
160	14	0	0	0		2761	2102	890	70	56	76
161	14	0	0	0		2761	2102	890	42	84	73
162	14	0	0	0		2761	2102	890	42	84	87
163	14	0	0	0		2761	2102	890	42	84	84
164	14	1	1	0	A3 B2	2817	2186	890	42	84	67
165	14	1	1	0	A4 B3	2887	2270	890	42	84	42
166	14	1	1	0	A5 B4	2971	2354	890	42	84	28
167	14	0	0	0		2971	2354	890	84	84	28
168	14	0	0	0		2971	2354	890	84	56	56
169	14	0	0	0		2971	2354	890	84	56	70
170	14	0	0	0		2971	2354	890	42	98	84
171	14	0	0	0		2971	2354	890	42	98	98
172	14	0	0	0		2971	2354	890	42	98	98
173	18	0	0	0		2971	2354	890	46	98	70
174	15	1	1	0	A3 B2	3032	2452	890	46	98	56
175	15	1	1	0	A4 B3	3108	2550	890	46	98	42
176	15	0	0	0		3108	2550	890	77	56	84
177	15	1	1	0	A3 B2	3200	2606	890	77	56	70
178	15	0	0	0		3200	2606	890	93	56	70
179	15	0	0	0		3200	2606	890	90	60	84
180	15	0	0	0		3200	2606	890	60	91	98
181	15	0	0	0		3200	2606	890	45	107	56
182	15	0	0	0		3200	2606	890	45	108	70
183	15	0	0	0		3200	2606	890	45	105	74
184	15	1	1	1	A2 B1 C2	3260	2711	964	45	105	74
185	15	1	1	1	A2 B1 C2	3335	2816	1038	45	105	74
186	15	1	1	0	A3 B3	3425	2921	1038	45	105	60
187	15	0	0	0		3425	2921	1038	90	75	91
188	15	0	0	0		3425	2921	1038	90	60	107
189	15	0	0	0		3425	2921	1038	90	60	108
190	15	0	0	0		3425	2921	1038	45	105	105
191	15	0	0	0		3425	2921	1038	45	105	120
192	15	0	0	0		3425	2921	1038	45	105	90
193	34	0	0	0		3425	2921	1038	64	105	75
194	15	0	0	0		3425	2921	1038	64	60	120
195	15	0	0	0		3425	2921	1038	64	60	120
196	15	0	0	0		3425	2921	1038	45	79	120
197	15	0	0	0		3425	2921	1038	45	79	120
198	15	0	0	0		3425	2921	1038	45	79	120
199	15	0	1	0	B1	3425	3000	1038	45	94	60
200	15	0	0	0		3425	3000	1038	45	94	60
201	15	0	0	0		3425	3000	1038	45	75	79
202	15	0	0	0		3425	3000	1038	45	75	79
203	15	0	0	0		3425	3000	1038	45	60	94
204	15	0	0	0		3425	3000	1038	45	60	109

DAY	START	A	B	C		ALOST	BLOST	CLOST	PROA	PROB	PROC
205	15	0	0	0		3425	3000	1038	45	60	109
206	15	0	0	0		3425	3000	1038	45	60	90
207	15	0	0	0		3425	3000	1038	45	60	90
208	15	1	1	0	A3 B2	3485	3060	1038	45	60	60
209	15	0	1	0	B1	3485	3120	1038	60	75	45
210	15	0	0	0		3485	3120	1038	60	75	45
211	15	0	0	0		3485	3120	1038	60	75	45
212	15	0	0	0		3485	3120	1038	45	90	45
213	15	0	0	0		3485	3120	1038	45	75	75
214	15	0	0	0		3485	3120	1038	45	75	90
215	15	0	0	0		3485	3120	1038	45	75	90
216	26	0	0	0		3485	3120	1038	56	60	105
217	15	0	0	0		3485	3120	1038	56	60	105
218	15	0	0	0		3485	3120	1038	56	60	90
219	15	1	1	1	A2 B1 C2	3556	3180	1128	56	60	90
220	15	0	1	0	B2	3556	3240	1128	60	86	75
221	15	0	0	0		3556	3240	1128	60	86	75
222	15	0	0	0		3556	3240	1128	60	86	60
223	15	0	0	0		3556	3240	1128	45	101	60
224	15	0	0	0		3556	3240	1128	45	75	86
225	15	0	0	0		3556	3240	1128	45	75	101
226	15	0	1	0	B2	3556	3315	1128	45	90	86
227	15	0	0	0		3556	3315	1128	45	90	86
228	15	0	0	0		3556	3315	1128	45	75	101
229	15	0	0	0		3556	3315	1128	45	75	75
230	15	0	0	0		3556	3315	1128	45	60	90
231	15	0	0	0		3556	3315	1128	45	60	105
232	15	0	0	0		3556	3315	1128	45	60	105
233	15	0	0	0		3556	3315	1128	45	60	90
234	15	0	0	0		3556	3315	1128	45	60	90
235	15	0	0	0		3556	3315	1128	45	60	75
236	27	0	0	0		3556	3315	1128	57	60	75
237	13	0	0	0		3556	3315	1128	55	60	75
238	13	0	0	0		3556	3315	1128	53	60	75
239	13	0	0	0		3556	3315	1128	39	72	75
240	13	0	0	0		3556	3315	1128	39	70	75
241	13	0	0	0		3556	3315	1128	39	68	75
242	13	0	0	0		3556	3315	1128	39	66	75
243	13	0	0	0		3556	3315	1128	39	52	87
244	13	0	0	0		3556	3315	1128	39	52	85
245	13	0	0	0		3556	3315	1128	39	52	83
246	13	0	0	0		3556	3315	1128	39	52	81
247	13	0	0	0		3556	3315	1128	39	52	79
248	13	0	0	0		3556	3315	1128	39	52	65
249	13	1	1	0	A2 B2	3608	3367	1128	39	52	52
250	13	1	1	0	A4 B3	3673	3419	1128	39	52	39
251	13	0	0	0		3673	3419	1128	65	52	39
252	13	0	0	0		3673	3419	1128	65	52	39
253	13	1	1	1	A2 B2 C3	3751	3471	1167	65	52	39
254	13	1	1	1	A1 B1 C1	3842	3523	1206	65	52	39

APPENDIX C

Computer Program: House Days Lost

```
MON$$     JOB   J00-0001 U391-46-5428  B.C. FOR NASA
MON$$     ASGN MJB,12
MON$$     ASGN MDM
MON$$     MODE GO,TEST
MON$$     ASGN MGO,14
MON$$     EXEQ FORTRAN,,,,,,,WEATHER
      INTEGER ALOST,BLOST,CLOST,DSTART,A,B,C,PROA,PROB,PROC
      DIMENSION IARR(13),LABEL(15)
  100 FORMAT(1H1,5X,3HDAY,2X,5HSTART,1X,5HA B C,
     160X,32HALOST BLOST CLOST PROA PROB PROC /)
  101 FORMAT(13(10H----------)/)
  102 FORMAT(I3,2X,I2,2X,I1,4X,I1,4X,I1,15A4)
  608 FORMAT(5X,I3,2X,I2,2X,I1,1X,I1,1X,I1,15A4,3(I5,1X),3(I5,1X))
      ALOST=0
      BLOST=0
      CLOST=0
      DO 105 I=1,13
  105 IARR(I)=0
  104 LINE=0
      WRITE(3,100)
      WRITE(3,101)
  200 READ(1,102) IDAY,DSTART,A,B,C,LABEL
      IARR(1)=IARR(1)+DSTART
      PROA=IARR(2)+IARR(3)+IARR(4)
      PROB=IARR(5)+IARR(6)+IARR(7)+IARR(8)
```

```
      PROC=IARR(9)+IARR(10)+IARR(11)+IARR(12)+IARR(13)
      IF(C.NE.1) GO TO 300
      CLOST=CLOST+PROC
      GO TO 301
  300 IARR(13)=IARR(12)
      IARR(12)=IARR(11)
      IARR(11)=IARR(10)
      IARR(10)=IARR(9)
      IARR(9)=0
  301 CONTINUE
      IF(B.NE.1) GO TO 400
      BLOST=BLOST+PROB
      GO TO 401
  400 IARR(9)=IARR(9)+IARR(8)
      IARR(8)=IARR(7)
      IARR(7)=IARR(6)
      IARR(6)=IARR(5)
      IARR(5)=0
  401 CONTINUE
      IF(A.NE.1) GO TO 500
      ALOST=ALOST+PROA+IARR(1)
      GO TO 800
  500 IARR(5)=IARR(5)+IARR(4)
```

```
      IARR(4)=IARR(3)
      IARR(3)=IARR(2)
      IARR(2)=0
      IF(IARR(1).GT.75) GO TO 600
      ISTRT=IARR(1)
      IARR(1)=0
      GO TO 601
  600 ISTRT=75
      IARR(1)=IARR(1)-75
  601 IARR(2)=IARR(2)+ISTRT
  800 CONTINUE
      PROA=IARR(2)+IARR(3)+IARR(4)
      PROB=IARR(5)+IARR(6)+IARR(7)+IARR(8)
      PROC=IARR(9)+IARR(10)+IARR(11)+IARR(12)+IARR(13)


      WRITE(3,608) IDAY,DSTART,A,B,C,LABEL,ALOST,BLOST,CLOST,PROA,
     1PROB,PROC
      LINE=LINE+1
      IF(LINE.GT.50) GO TO 104
      IF(IDAY.LT.254) GO TO 200
      STOP
      END
     MON$$     EXEQ LINKLOAD
               PHASEWEATHER
               CALL WEATHER
     MON$$     EXEQ WEATHER,MJB
```

THE IMPACT OF IMPROVED SATELLITE WEATHER PREDICTION INFORMATION ON THE OPERATIONS OF A COMMON CARRIER TRUCKING COMPANY

Brad Alfrey*

ORGANIZATION

The purpose of this study is to explore the effect of weather on a common carrier trucking operation in order to determine the value to a trucker of improved weather prediction information.

The effect of weather on common carrier trucking will be analyzed by means of a case study. The subject of this case study is the Gateway Transportation Company—a large, general freight common carrier. Much of the data included in the following chapters were taken directly from internal records of the Gateway Company. Much of the analysis concerns operations in 1968; both the weather and Gateway's operations were fairly typical in that year.

There are a number of functions or activities in which a common carrier must engage to operate, and this study will look at those functions that are affected by weather. In each case, the operational function will be described with special emphasis on the way weather conditions affect the efficiency or organization of the function. Then the costs of the effect of weather and of attempts to avoid the effect of weather will be explored. Once the costs of

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adverse weather have been determined, the possibility of avoiding these costs will be discussed and the potential savings determined. The conclusion to each discussion will be a description of the potential savings due to improved weather prediction information, the probable savings Gateway would realize due to expected management reaction with improved information, and an explanation of any difference between the probable and potential savings. Where it is possible to combine parts of the discussion without obscuring important points, this will be done.

Chapter II is a descriptive discussion of the operations of a common carrier trucker, followed by a brief description of the Gateway Transportation Company. Chapter III concerns itself with sales activities, the first step in any commercial venture. Chapter IV begins the discussion of the transportation function with a coverage of pick-up and delivery operations. Chapter V continues this discussion with a coverage of terminal dock operations. The transportation function is completed in Chapter VI where line haul is discussed. The safety function, which is closely allied with the transportation function is covered in Chapter VII. The cost of claims, which may arise in a number of functions, is the subject of Chapter VIII. Chapter IX discusses freezable service, an aspect of operations that is particularly affected by weather. Then Chapter X combines the results of the previous Chapters to show the total value of improved weather prediction information in all aspects of operations.

INTRODUCTION

Common Carrier Operations

Common carriers are not able to operate as freely as would be ideal to minimize operating costs. Each common carrier has a certificate of convenience and necessity from the Interstate Commerce Commission that states explicitly what points the carrier may serve, the routes it may use to reach these points, and the commodities it may carry. Common carriers must serve all customers demanding their service and may not engage in "undue" discrimination in pricing.

In the case of a trucking company, these restrictions infringe on potential operating efficiency in several ways. Most importantly, a carrier may not alter his route to avoid adverse weather unless his certificate allows him to use an alternate route, and this is not often the case. Furthermore, a carrier may not abandon service to a location where adverse weather problems are chronic unless there is another carrier available to maintain the service. The issuance of certificates limits the number of carriers that may serve any one point. This certificating of carriers affects operating efficiency indirectly in that it encourages service competition rather than price competition. The service competition problem will receive further attention in the discussion of sales in Chapter III.

Trucking operations do not display an annual pattern of activities in the same sense that agricultural activities do. A more relevant way to describe typical trucking operations is to examine the movement of a shipment from origin to destination.

Shipments originate with the decision of a shipper to move goods. In most cases, the shipper has previously sent many other shipments so he knows how long it should take from the time this shipment leaves his plant until it arrives at the destination. He also knows when he wants the shipment to arrive. To determine when the shipment must be ready to leave, he simply subtracts the movement time from the desired arrival time. As long as the carrier is able to maintain this normal movement time, the shipper is satisfied.

Carriers attempt to normalize pickup procedures by scheduling stops on a regular basis, but shippers often request that pickups be made at a particular time for their convenience. In either case, the carrier and shipper agree on a time for the shipment to be picked up by the carrier. The carrier's local or city equipment is used for deliveries in the morning and for pickups in the afternoon. Each truck makes a number of pickups on each trip as nearly all shipments are less than truckload size. When the pickup vehicles are full or when the pickup period ends, these trucks return to the terminal with their loads. In order to maintain the carrier's promised pickup schedule these trucks must realize at least the expected average speed of movement between stops and the expected rate of loading and unloading at the stops.

As the pickup and delivery equipment returns to the terminal it is unloaded and the individual shipments are moved to line haul vehicles that are destined for the appropriate destination terminals. Shipments from one local unit generally go into a number of line haul trailers, and shipments to one line haul trailer generally come from a number of local units. Drivers are called in to take the line haul units out as loads are completed late in the evening.

The line haul portion of the trip is the movement between origin and destination terminals. Line haul may be interrupted if a truck contains shipments for several terminals, either because the truck stops off at intermediate points to leave freight or, more commonly, because the shipments in the truck are consolidated with shipments from other such mixed loads at a central terminal along the route.

As the line haul vehicles arrive at destination terminals they are unloaded and the shipments are reloaded in local vehicles to be delivered to the shippers' customers. This operation is exactly the inverse of the pickup and line haul loading operation described above. Each shipment is then delivered to the appropriate location, emptying the local equipment to begin pickup operations again.

The preceding paragraphs have given a very brief description of four trucking functions that may be affected by weather. These functions are sales, pickup and delivery, dock handling of freight, and line haul movement. The effect of weather will be discussed in later chapters.

Movements of freight in a terminal, within a city, or over the highway expose the carrier to accident risk. Any time shipments are lost or damaged tne carrier is exposed to possible claim liabilities. The effect of weather on these two somewhat cross functional activities will be examined in detail later.

A program of special precautions to protect commodities from freezing during the cold winter months is regularly instituted. The cost of freezable service will also be examined in a later chapter.

Gateway Transportation Co.

Gateway Transportation Co. is a large common carrier of general commodities. Operations in 1968 extended from St. Louis, Missouri, to Buffalo, New York and from Minneapolis, Minnesota to Miami, Florida. During 1968 Gateway trucks traveled more than 60 million miles intercity, moving a total of over 850 million ton-miles of freight. Operating revenues were $868, 431, 000 and net income was $2, 586, 000.

Gateway provides a particularly useful case study example. Nearly every available type of freight is carried by Gateway. Since the demand for service dictates the relative importance of individual items in total movement, Gateway approximates the industry in terms of relative ton-mile carriage by commodity as well. Gateway is a large enough company to feel the effect of weather wherever it is significant, but there is no reason to believe that Gateway responds any differently to weather than do other carriers. And, finally, Gateway routes over both northern and southern geographical areas with a relative intensity of usage approximating that of general trucking activities.

On a more essential, although mundane, level, Gateway management and employees down to the clerical level cooperated most fully with this research effort. Important people gave willingly many hours of their time, files were opened to extensive and intensive scrutiny, and office facilities were made available where needed. Certainly Gateway deserves much credit for the success of this study.

SALES

Effect of Weather

Trucking is an extremely competitive business. There is strong intra-industry competition coming from railroads, barges and ships, and, in some cases, from air freight. Interindustry competition comes from other trucking companies and from private trucking where a shipper has adequate freight to make this alternative practical. Where service is being handled by common carrier truckers, price tends to be uniform between companies, and competition takes the form of consistency and level of quality of service. Uniform pricing is a direct consequence of industry regulation.

Shippers are extremely aware of poor quality service, and they do not hesitate to react to quality variations. Since most shippers move freight as a part of a business operation, poor service represents a real cost to them. Typically, shippers worry only about preparing the product for shipment and hold the carrier responsible for maintaining reasonable service levels.

Weather affects service directly by delaying pickup and delivery and line haul movements. Where pickup and delivery operations are delayed by bad weather, the shipper is as aware of these conditions as is the carrier; the snipper normally does not hold the carrier responsible for these delays. In the case of line haul delay, the shipper is not always aware of the bad weather, but if in inquiring about delays in his shipments discovers they are due to bad weather, he usually accepts this cause as reasonable. Carriers compete to give the best level of service possible (at a profit) so that there is little advantage to the shipper to change carriers for a delay caused by weather. Since all carriers operate under the same weather conditions, the shipper's only alternative is to use another mode. It is intuitively obvious that the effect of weather varies substantially between modes.

Weather affects service indirectly whenever it contributes to a service deterioration whose primary cause lies elsewhere. Examples of this type of service deterioration include freight lost or damaged in accidents where weather is involved, freight delayed in terminal handling where cold weather contributes to backups, or freight frozen due to poor handling by terminal personnel. Putting this argument in broader terms, where weather indirectly causes performance of trucking functions to be less than optimally efficient, any resulting service deterioration will tend to cause the shipper to change carriers. But any other factor that causes service to deteriorate will also have this effect so that it is impossible to tell to what extent weather causes accounts to be lost by any one company.

Service failures that upset customers also cost the carrier through claims or increased labor and material costs. While it is possible to avoid these cost elements by not operating when weather is adverse, to do so is to lower the level of quality of service to zero. Where service ceases to measure up to reasonably expected levels, the shipper will change to another carrier. Shippers see consistency of service as being particularly important.[1] This

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[1]For example, see "Consistency, the Carriers Ace in the Hole," by P. Ronaly Stephenson and Ronald P. Willet in Transportation Journal, Vol. VII (Spring, 1969).

means a shipper does not dare to avoid costs by suspending service unless he expects other carriers to be forced to do the same thing.

The conclusion to be drawn from this analysis is that weather has very little effect on the sales function of a trucking company, and that what little effect it does have is so mixed in with other factors as to make it impractical if not impossible to extract.

Value of Improved Information

The absence of costs attributable to adverse weather in this area eliminates any possibility of savings due to improved information. However, improved information may provide a benefit to trucking companies that they are not presently enjoying.

As was stated earlier, consistency of service is a primary measure of quality. The meaning of consistency is not merely regularity, but regularity at meeting a minimum standard. The standard to be met is delivery within an expected time period.[2] Where shippers can rely on carriers to maintain delivery schedules, it is often possible to carry inventories in the form of goods in transit with only a very small cushion at the receiving end. The size of the cushion necessary is dependent on the cost of ordering and carrying inventory, the reliability of the delivery schedule, and the cost of a stock-out. One reason why delivery schedules may not be reliable is that delays that are

[2]There is a strong theoretical basis for this argument. In addition, letters from disgruntled customers indicate consistency in maintaining schedules is of the utmost importance to shippers.

the result of adverse weather conditions occur at random intervals. If shippers could be advised of these delays long enough in advance it would be possible for them to increase the volume of their shipments in anticipation of these delays so as to temporarily increase the size of the inventory cushion. This extra cushion would then be consumed during the delay period. In this way it would be possible to maintain a lower average inventory cushion with the same level of risk. A carrier that engaged in this practice would be in a position to attract new business and insure the maintenance of accounts already held.

The possibility of advising customers of impending delays was discussed with a number of sales personnel in the Gateway organization, and a variety of reactions was received. Some of the personnel thought the plan had great potential, while others saw little merit in it. The workability of the plan depends on the cost of running it. A system must be developed to choose those customers to whom the information is of value, and a method of informing these customers of the impending delays is necessary. Gateway salesmen already make a practice of informing customers when a plant that normally receives a large number of shipments is closed due to vacations, model changes, or a strike. This practice could possibly be expanded to warn of weather related delays.

At any rate, the consensus of top management is that some effort would be made to use improved weather information to improve customer relations. A program would probably be started after discussions with customers to see who wanted the service. Possibly the program would be started in a single market to test its effectiveness before expanding it to the whole system.

The value of such a service is incapable of measurement. Any program that gives the shipper more for his money or lowers his costs will attract business to the originator of the program, but the final effect is buried in a myriad of causes that cannot be separated. Eventually, one would expect the shippers themselves to watch the weather in scheduling their shipments. But until they do, carriers can realize a benefit by doing this for them.

PICKUP AND DELIVERY

A functional aspect where Gateway personnel expect substantial weather related costs is that of pickup and delivery. The extent of the cost in this area is primarily based on the dramatic effect adverse weather has on urban traffic flows. Snow covered, icy, or even wet streets can be expected to slow delivery vehicle speed enough to substantially limit normal capacity for this service. On a typical day during which this effect is experienced, the volume of freight handled should show a noticeable drop.

Terminal managers attempt to avoid this weather related cost in several ways. As delays develop, an extended period is necessary to complete delivery of the previous day's freight. Where possible, the subsequent pickup operations will be extended until a later than normal hour in an attempt to maintain the normal quantity of service, although there is usually little opportunity for extending operations. Freight for outgoing shipments must be assembled in the terminal soon enough to load the units and move them out as the line haul drivers come on to their next shifts.[1] Rather than delay shipments and incur layover costs, managers more often call in their city trucks before pickup operations are complete.

Whenever pickups are curtailed, customer demand for improved service results. Where the curtailment of pickups goes on for several days, this demand for improved service can become quite strong; it is often alleviated only when customers switch their business to another carrier. For this reason, the terminal manager attempts to balance the service deterioration between the shipping and receiving groups by holding back on deliveries and making extra pickups. There are economies of utilization to be had through extending service in this way as it becomes possible to consolidate several pickups or deliveries to one customer and to work in more geographically concentrated areas. There are, however, two cost elements that result from consolidation of pickup and delivery services. The first cost factor is due to terminal congestion. As deliveries are delayed, freight piles up in the terminal and gets in the way of efficient freight handling. The other cost factor is an additional service deterioration due to congestion. When congestion occurs, freight is more easily lost, loading and unloading takes longer, and personnel are taken from their regular duties to aid in tracing.[2] All of these problems cause

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[1]Drivers who are not in their home terminals are given a maximum of fifteen hours off between driving shifts. If there is no work for them at the end of this fifteen hours, they are automatically paid for layover until they begin work, for a maximum of eight hours of layover at a time. In addition, each time a driver is put on layover he receives a minimum of two hours of layover pay.

[2]Tracing refers to informing a customer of the location of his shipment. When shipments are late, customers frequently ask that they be traced.

service to further deteriorate.

Efforts to alleviate terminal congestion extend throughout the system. Other terminal managers hold back shipments to the congested terminal. If the congested terminal is a break bulk point, other terminals attempt to load full loads and send them around the congested terminal. As a last resort, an embargo will be declared on the congested terminal whereby all shipments to this terminal will be held back. Attempts to hold freight from going to a congested terminal, however, tend to spread the congestion to the other terminals. The congestion then becomes a cost to these terminals, and the problem spreads and feeds back on itself.

To put this matter in its broadest terms, pickup and delivery operations become more costly whenever conditions are such that optimum use cannot be made of equipment and driver time. This situation develops when adverse weather occurs within the area of pickup and delivery and when adverse weather that occurs elsewhere disrupts the pattern of operations at the terminal under consideration.

The situation described here is extreme, but it does occur.[3] The tendency, however, is present whenever weather conditions turn adverse and demand for service is relatively high.

A statistical study was made to test the degree to which variations in pickup and delivery efficiency are attributable to variations in weather. It was

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[3]A storm in March, 1967, that caused heavy snow in Chicago nearly paralyzed Gateway's operations there for more than a week and affected operations in other terminals for nearly a week.

expected that on days when adverse weather conditions occurred the efficiency of pickup and delivery activities would be substantially less than on days when the weather was good. The study was carried out using data on Gateway's Chicago terminal activities during 1968.

Efficiency data was available in the form of work sheets showing daily weight handled in pickup and delivery along with man-hours worked on the respective days. The data included both freight handled in city vehicles and freight loaded directly into line haul trailers spotted at customers' docks.[4]

Weather information was taken from the Local Climatological Data series of the U. S. Weather Bureau for Chicago during 1968. The weather was classified as either good, marginal, or bad. Good weather was defined as no precipitation and an average temperature above 15°F. Bad weather was defined as more than a trace of precipitation during each of at least four or more hours of the working day. Any weather that fits into neither the good nor the bad category was classified as marginal. Figure I shows the frequency distributions of efficiency (measured in pounds per man-hour) for each of these categories. The table (on the following page) shows the mean, standard deviation, and number of observations for each of the distributions.

Notice that the values of the standard deviation and the mean of the marginal weather distribution fall between the respective values of the good and

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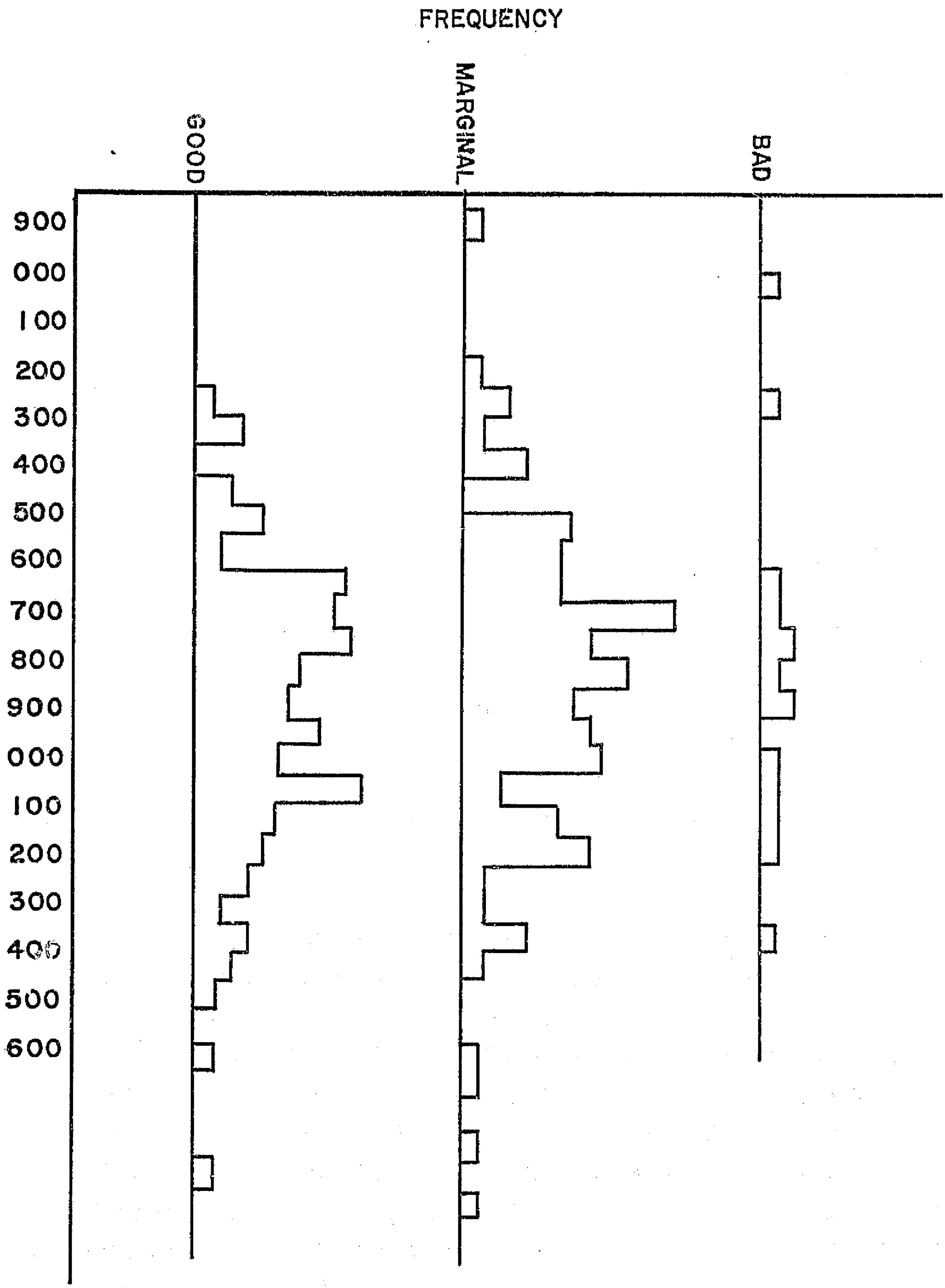
[4] Shipments that constitute full loads commonly are loaded directly into line haul trailers to avoid unnecessary terminal costs. Since relatively little time is spent driving around the city as opposed to simply loading or unloading this freight, spotted loads tend to increase the efficiency of pickup and delivery operations.


FREQUENCY
GOOD
MARGINAL
BAD
900
000
100
200
300
400
500
600
700
800
900
000
100
200
300
400
500
600

Distribution	Mean	Standard Deviation	No. of Observations
Bad weather	2646	289	14
Marginal weather	2675	270	113
Good weather	2711	239	98

bad weather distributions. The import of this fact is that if the existence of a cause and effect relationship for the good and bad weather distributions is rejected, then the possibility of a similar relationship for the marginal distribution and either of the other distributions must also be rejected.

The mean efficiency level of operations in good weather is 2711 pounds per man-hour, while the mean efficiency level in bad weather is 2646 pounds per man-hour, a drop of 2.4%. The difference between these means is of a magnitude that makes it difficult to say whether or not adverse weather conditions affect pickup and delivery operations. If adverse weather has no effect on pickup and delivery operations, then the sample taken from good weather days and the sample taken from bad weather days both come from the same distributions of efficiency levels. A statistical test employing the "t" distribution may be used to test the probability that two samples from the same population could have the means and standard deviations found in the distributions being examined here. This test shows that the probability is about .2 that the means of the same distributions would be greater than 2.4% apart if they were taken from the same population. Unfortunately, this probability level does not allow for a particularly certain conclusion.

Another way to look at this problem is to examine at what point it would be worthwhile for management to react to cost increases due to adverse weather.

This point will be measured here in terms of a percentage increase in the cost of pickup and delivery operations in bad weather as opposed to good weather, and cost will here be approximated by the level of efficiency, measured in pounds per man-hour.

Management's estimate of the minimum cost increase magnitude to which it would react is 10% of cost under normal conditions. The probability that costs actually are 10% greater under adverse conditions, based on the samples used here, is less than 0.025, an insignificantly low value.

The above argument may seem to contradict the discussion of the effects of adverse weather on pickup and delivery activities found at the beginning of this chapter. However, this is not the case. The discussion at the beginning of the chapter pointed out the way weather affects operations, while the statistical tests measured the extent of the affect of weather. These tests showed the effect of weather is minor under normally adverse weather conditions. None of the data from 1968 represents abnormally adverse weather such as a particularly bad snowstorm; the effect of this kind of weather is undoubtedly much greater than the effects measured here.

There are a number of characteristics of the data that may partially explain the small amount of cost associated with bad weather. The fact that spotted loads were included in the efficiency data was mentioned earlier. In addition, efficiency as measured here constituted an average over a period of about ten hours. Unfortunately the weather is seldom uniformly adverse over a period of this length. As a result, any effect of adverse weather is partially hidden by the results of activities during the same period when weather was not adverse.

Value of Improved Information

Improved information will have relatively little value here in that there is relatively little cost associated with adverse weather. In fact, improved information would only be used where weather was expected to be particularly adverse at a time when terminal operations are or are expected to become congested. Congestion in terminal operations is normally worked off by means of a slight increase in labor over an extended period of time. Since adverse weather could be expected to emphasize the congestion problem, it would be in management's interest to work to eliminate congestion before the adverse weather occurred. This could be done by using overtime or by hiring extra help on a temporary basis. The benefits to be gained are both a lower cost of operations in the future (due to improved efficiency with lower congestion) and improved customer relations due to a higher level of service being maintained. The magnitude of these effects, however, is likely to be quite small.

DOCK COSTS

Dock costs are the costs incurred in loading and unloading freight at a terminal and of handling freight within a terminal. These costs are nearly all labor costs, and the incremental cost due to adverse weather is the cost of extra labor time caused by decreased labor productivity.[1] Normally, the only relevant weather condition on a dock is temperature as this area is protected

[1] Gateway terminals in Milwaukee and St. Paul have heated enclosed docks. A cost of heating does exist at these terminals, but this cost will be ignored here.

against wind and precipitation. The Gateway terminal in Chicago, however, does suffer some wind effect.

The labor needed to complete a given amount of work increases as the productivity of labor falls. Unless there is excess labor on hand, the labor must be made up by using either overtime or casual labor.[2] Both of these types of labor are relatively inefficient. Casual and overtime labor is thought to be from 70% to 75% as productive as normal labor, so that if this type of labor is a!l that is available to handle the extra work, labor costs actually increase by about one-third more than the amounts shown above. In addition to this, overtime pay is 50% higher than straight time pay.

The actual labor cost borne will depend on the weather. There is undoubtedly some tendency for the work force to become acclimated to low temperatures overtime, but even this depends on the pattern of temperature movement. It would be possible to get a rough estimate of the incremental labor cost due to cold in a single terminal by using long-run average daily temperatures and making assumptions about the length of the work week, the amount of overtime and casual labor, the number of regular employees in the terminal, and the cost level associated with low temperatures. This estimate could then be expanded to cover the whole Gateway system. However, this measure would be quite rough. A far more refined measure may be possible using multiple correlation analysis, comparing productivity experienced with actual temperatures.

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[2] Casual labor is labor hired on a temporary basis, labor not regularly employed by the carrier. Casual workers are usually the least desirable workers in the regularly employed market, although some are regularly employed men moonlighting for extra income.

Gateway personnel estimated that the effect of high temperatures is quite small. The effect of low temperatures, on the other hand, was hypothesized to be quite large. The effect of temperature was thought to become noticeable at 15° by both the corporate operations manager and by terminal personnel. Estimates of the extent of the effect of cold, however, varied from 10% to 60% of normal labor efficiency.

The problem of measuring the extent of effect of cold weather on dock labor performances appeared to be one that could be solved by means of multivariate regression and correlation analysis. There are a large number of variables that can be expected to affect labor performance. If labor productivity is measured in pounds per man-hour (as was done here), the most obvious variable is the amount of freight handled. With this aspect in mind, it was hypothesized that variations in labor productivity are caused primarily by variations in weight handled and secondarily by variations in temperature when temperature varies throughout the relevant range (mean 15° F). Data showing hours worked and pounds handled on each of the three inbound and the three outbound shifts from Gateway's Chicago terminal for the first three months of 1969 were employed as these were the best data available.

Eight different regression equations were used in an attempt to explain productivity variations. The analysis indicated that weight was a significant explanatory variable, but very little effect of temperature was noted. This does not mean that the effect of weather is small. It could well be that there are other important explanatory variables that were left out of the analysis. Some obvious candidates are the size of the backlog of freight on the dock, variations in demand for equipment in other parts of the Gateway system, and worker attitudes. Unfortunately, none of these variables was measurable. As a result, this technique was abandoned.

Variations in labor productivity were not great enough that temperature could cause a 60% variation and not be statistically significant causal variable. However, it is possible that labor productivity could vary by 10% as temperatures drop from 15°F down to 0°F or below. If this magnitude of cost is assumed to exist, the total annual cost for 1968 operations can be computed, given operating and temperature data for the period.

Just such a measurement was made using Chicago terminal operations as a basis for predicting total system costs. Local Climatological Data Reports from the U. S. Weather Bureau provided information on hourly temperatures, and company records provided information from which hours worked during the corresponding periods could be approximated. This information showed total hours worked, and it was possible to break this down on the basis of average hours per shift experienced over a period of time.[3]

Finally a function was defined that related temperature to percent cost increase. This function showed an increasing marginal effect of temperature at ever lower temperatures.

The cost of cold weather was determined by multiplying the percent cost

[3]The shifts showed remarkable stability of proportion of total hours worked per day over a period of time. This proportion was applied to daily cumulative man-hours and then divided by the hours in the shift for the hourly man-hours worked. Overtime hours were also broken down by average per shift, and these were placed at the end of the shift which incurred them. Overtime constituted only 1.5% of total hours worked.

Date	Dollar Cost
Jan. 3	$ 47.64
Jan. 4	221.62
Jan. 5	118.68
Jan. 6	14.41
Jan. 8	169.98
Jan. 10	6.49
Jan. 24	.60
Feb. 9	57.15
Feb. 10	38.28
Feb. 12	4.05
Feb. 13	8.47
Feb. 14	1.65
Feb. 17	41.27
Feb. 20	9.19
Feb. 21	60.38
Feb. 23	.16
Feb. 29	.16
Dec. 14	.36
Dec. 24	23.35
Dec. 31	563.20
Total	$1,406.79

increase by the hours worked per period by the dock wage rate ($3.68 per hour straight time). These dollar costs are shown above. This total cost of $1,406.79 is relatively small. If one compares it to a single normal day's wages in the Chicago terminal (about $8,000), it is obvious that management will not do much to avoid it. If a critical cost level above which cost increases would be considered reviewable were to be set, it would have to be at least a 5% increase. This level ($400) would have yielded only one reviewable day in 1968.

Chicago would be expected to account for the majority of Gateway's cold weather problems. Although there are other terminals that are in colder climates, the important ones are enclosed and heated. Only small terminals (except Chicago) in the north are open to the cold. Thus the total system costs would only amount to about $2, 000.

Value of Improved Information

Given that the effect of cold weather on terminal operations is too small to be measured, it is not likely that much would be done to avoid it. Gateway management mentioned no specific steps that would be taken.

There is some possibility of cost saving in this area with improved information. If decreases in labor productivity were expected, it would at times be possible to do extra work ahead of time (with overtime or temporary help). In addition, extra hours could be budgeted during the cold period in order to maintain services standards. The value of these actions, however, would be quite small.

LINE HAUL

Effect of Weather

The most intuitively obvious area to look for costs associated with adverse weather conditions is that of line haul operations. Weather related costs incurred here are attributable to time lost due to closed highways and time lost due to relatively low attainable speeds in bad weather. Other costs that can be incurred here include accidents, claims for damaged merchandise, and the costs associated with delays in receipt of freight, but these items are covered in other sections and will not receive further attention here.

Gateway collects weekly reports that include a compilation of all delays due to impassable highways along with the reason the highways were blocked.

Table I shows the total cost of lost drivers' wages incurred due to highways being made impassable by weather conditions in 1968, classified both by cause and by month. This table also shows the number of trips delayed per month and the number of days per month on which delays occurred.

Given that 1968 was a reasonably typical year both as to weather conditions and Gateway's line haul operations, some tentative conclusions can be drawn from this table.

1. Snow and ice are by far the most costly weather conditions affecting line haul operations.

2. Fog (followed by ice) is the most frequent weather condition affecting line haul operations.

3. As would be expected, there is a seasonal variation in the effect of weather both by cost and cause.

These results are in line with normal weather patterns for the area in which Gateway operates. Obviously, snow occurs only during the winter, and heavy rain occurs during the summer, with ice accompanying winter rains. Fog is a year around phenomenon, occurring in scattered patches during the warmer weather, but covering wide areas during the fall and winter. Snow tends to last longer than rain so that a single snowstorm affects traffic for a number of days.[1]

It is logical to expect that weather conditions often occur that are not adverse enough to make highways impassable, but that nevertheless are sufficiently bad to cause the average speed of line haul operations to fall. A study

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[1] Snow and ice or combinations of both caused delays for three or more days in a row on seven different occasions during 1968. The comparable figure for rain and ice or combinations of both is two times during 1968.

TABLE I

Cost[1] of driver time lost due to roads made impassable by adverse weather conditions*

	Snow	Snow, ice	Ice	Ice, Rain	Rain	Fog	Flood	No. of trips	No. of days	Total Cost
January	241.04		405.01			157.82		87	20	$ 803.87
February	5.52		54.08	9.20		3.68		11	4	72.68
March	268.24	81.88	37.72			103.96		60	10	491.80
April	1.84				42.32			7	3	44.16
May					18.40	32.20	3.68	9	8	54.28
June					28.52	4.60		7	5	33.12
July						7.36	64.54	9	4	71.90
August					6.44	59.44	41.40	13	7	107.29
September						29.44		7	4	29.44
October						23.00		3	3	23.00
November			3.68					1	1	3.68
December	665.84	184.00	70.84	25.88		7.36		88	9	963.92
TOTAL	1,202.44	265.88	566.35	48.76	53.39	454.48	55.78	302	78	$2,607.08
No. of days occurring	17	5	29	3	7	35	5			

[1] Dollar cost figures were arrived at by multiplying driver waiting time wage ($3.68 per hour) by time delayed.

*in dollars.

was conducted to investigate this possibility. Adverse weather conditions were defined to be at least 0.10 inches of rain per hour, at least 0.01 inches of snow per hour, heavy fog, ice, or sleet, or any combination of these elements. Good weather was defined as mostly clear skies, normal seasonal temperatures (or above normal winter temperatures in the north) and no trace of precipitation of any kind.

Three routes were chosen for this study. One was Interstate Highway 90-94 from Chicago to Minneapolis and St. Paul, a northern route that is relatively lightly traveled. Another was U. S. Highway 6 from Chicago to Cleveland, a heavily traveled two-lane, undivided highway. These two routes were chosen to show the effect of weather on two types of highways where weather is particularly bad by the standards of the entire Gateway system. The third route chosen was Interstate Highway 75 from Atlanta to Orlando, Florida. This route was chosen to contrast the effect of weather on northern and southern routes.

Using Local Climatological Data reports published by the U. S. Department of Commerce, days when bad weather or good weather (as defined above) occurred were chosen for major cities along the routes chosen. The cities used were:

Route	Local Climatological Cities
Chicago to St. Paul	1. Chicago 2. Madison, Wis. 3. St. Paul, Minn.
Chicago to Cleveland	1. Chicago 2. Fort Wayne, Ind. 3. Cleveland

Atlanta to Orlando

1. Atlanta
2. Macon, Ga.
3. Orlando

Where data for a particular time period were found to be similar at all locations on a given route, these periods were retained. Data from the remaining time periods were dropped at this time. Then the consistency of the remaining periods was checked against data for all reporting stations at intermediate points, taken from monthly Climatological Data reports published by the U. S. Department of Commerce. Only periods that were consistent with respect to all stations were retained.

Once the periods of bad weather and good weather had been chosen, the next step was to monitor movements on these days. Since all the sources of information stated movements in terms of time elapsed in transit, transit time rather than speed was used in the study. Time and speed are, of course, directly related; the use of speed would have been an unnecessary complication. The results of this study are shown in Table II.

The first measure of results used was the percentage increase in the simple average elapsed time of travelling in bad weather as opposed to good weather. This measure showed the greatest effect occurring on the southern route, with a 4.9% increase, while the effects on the northern routes were lower and nearly equal at 3.5% for the Cleveland route and 3.7% for the St. Paul route. The relationship of these changes is exactly the opposite and their magnitude is far smaller than what had been expected. A possible explanation of this result is that some delays not accounted for by weather are included in the good weather data, and some trips made during the bad

Table II

Percent Increase in Time, Bad Weather over Good Weather, for Three Selected Routes

Route	Number of Observations		Measures of increases in time for bad weather over good weather			
	Good weather	Bad weather	Simple Average	Median	Average of middle half of items	Average of all three method results
Atlanta to Orlando	170	68	4.9%	3.8%	2.9%	3.9%
Cleveland to Chicago	166	97	3.5	6.3	5.2	5.0
St. Paul to Chicago	235	75	3.7	3.2	6.7	4.5

weather periods probably were fortunate enough to avoid most of the bad weather.[2] If these nonrepresentative items are relatively few in number, they should have no noticeable effect on the median value items. For this reason, the percentage increase in the median times of bad weather as compared to good weather was computed. Here the greatest increase was for the Cleveland trip, as was expected, but the Atlanta route stayed ahead of the St. Paul route. The magnitudes of the changes remained small.

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[2]Weather is seldom entirely consistent over a period of time and space. While the statistics used indicated consistency, they covered only cumulative results (an hour at a time at best) and only at specific points in space. There is not data available that will permit choosing routes and times where weather is completely consistent.

A third measurement was made by dropping the top quartile and the bottom quartile[3] from each of the six categories of data and calculating the percent increase in transit time in bad weather as opposed to good weather for the simple average of the remaining values. This measure gave the widest variation in values, with the St. Paul route the highest, the Cleveland route close behind, and the Atlanta route far behind that.

The magnitude of the changes using the three different measures varied for each route, and the ranking of the routes varied as the method of measurement was changed. This phenomenon is reflected in the last column of the table which gives the average of the values for each route for the three methods. These values are relatively close together and they are quite small.

In each case, the initial data displayed a wide variation from the shortest to the longest elapsed time, and none of the six categories of data displayed a good approximation of a normal distribution. The average time for each category and the variations from the average are shown below:

Route	Simple Average time	Range below	Range above
Atlanta, Bad	10.30 hrs.	1.63 hrs.	3.63 hrs.
Atlanta, Good	9.81	1.98	2.99
Cleveland, Bad	10.19	2.52	3.48
Cleveland, Good	9.85	2.85	2.98
St. Paul, Bad	11.57	1.66	4.60
St. Paul, Good	11.16	1.66	5.33

[3] A quartile is 1/4 of the items in a list ranked by magnitude. Here the top quartile is the largest 1/4 of the values (and the bottom quartile is the smallest 1/4 of the values), for each list of good and bad weather for each route.

This tabulation shows that the variations from the mean were quite wide, especially on the upward side.[4] Where the variations are wide and the means of the pairs of distributions are close together, it is not surprising that the percentage difference varies substantially as different measures are applied. The data in this table also show that the measure for the Cleveland to Chicago route is particularly weak. The explanation of this phenomenon is that there is a station at Kendallville, Indiana, along this route, where the trucks regularly stop to refuel and change drivers. The length of this stop undoubtedly varies. The data covering the Atlanta to Orlando route also contains a biasing factor. Whereas the times for the northern routes had been punched into the records by clocks, the times on the Atlanta route were written in by hand. Rather than giving the exact time, the approximate hour was often used. This resulted in a disproportionately large number of readings on the quarter hour and the half hour.

There is one other important reason for the very small difference in average times between good and bad weather trips. These routes are relatively long, and consequently the drivers are paid by the mile rather than by the hour.[5] If it should happen that a driver is forced to drive more slowly than normal under this system, he receives a substantially lower hourly rate of pay. It is in his interest, therefore, to stop his vehicle (tie up, as it is known) and

[4]The frequency distributions are sharply skewed to the right. This result is reasonable as it is easier to stretch out a trip than to shorten one.

[5]These distances are all nearly 400 miles. Gateway drivers are paid by the mile for distances in excess of 251 miles.

collect an hourly wage for waiting time until conditions improve to the point where it is once again economically worth it for him to drive.

The possibility that one type of adverse weather (for example snow) has a great effect on speed while another type (rain) has little effect presents another analytical problem. If this were the case, this factor could conceivably explain the small variations in trip time for good and bad weather. However, this possibility must be rejected on several grounds. First, the data used simply did not exhibit this characteristic; delays due to snow were not noticeably greater than delays due to rain. Second, the result for the southern route, where snow was not a factor, is not out of line with that of the northern routes. And, third, it follows from the reasoning above that the drivers would tie up rather than allow their average hourly wages to reach low levels in those cases where the effect of weather was substantial.

The fact that drivers are paid the same amount per trip regardless of the time the trip takes indicates that increased time does not increase operating cost to the firm. A significant increase in time per trip would, however, increase the investment necessary to maintain service levels during adverse weather, or alternatively, decrease the amount of service possible at these times. The increased investment would exist as excess capacity during good weather conditions that would increase flexibility and service potential beyond optimum levels, or the decreased level of service in bad weather would manifest itself as decreased flexibility or bottlenecks of inadequate capacity.

For these arguments to apply, the firm must be operating at capacity at the time the adverse weather arrives, and the difference in transit times between good and bad weather must be significant. As was discussed at length above, the difference in transit times is quite small. The following discussion will explain why the firm seldom operates at capacity.

Table III shows weekly volume handled by Gateway during 1968. There are two indications here that operations were not always at capacity. One is the frequently large variations in tonnage from week to week. The other is the large increase in tonnage during the year. Changes like these cannot occur unless some excess capacity exists at least part of the time.

On the other hand, with a given level of capacity in terms of trucks, terminal and labor, possible output may vary with the specific demand for service. Varying combinations of the elements of capacity may yield varying levels of output. What this mounts to is saying that capacity is really the attainable output level rather than the available inputs. Although it does not seem likely that the variations in output observed could be completely explained by this argument, this result is a logical possibility.

The actual historical experience of the company serves to refute the above argument. Tonnage handled typically follows a pattern with high points in the spring and fall and low points in the winter and summer. Over the course of this cycle, the mix of service stays fairly constant. Logically, then, over capacity exists during the slack seasons.[6] In addition, the aggregate data are made up of data from a number of terminals whose variations are greater

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[6] Notice also that the winter, when the effect of weather is greatest, is a slack tonnage season.

TABLE III

Weekly Tonnage Handled (1968)*

Week	Tonnage (Millions of pounds)	Week	Tonnage (Millions of pounds)
1	152	25	160
2	158	26	157
3	163	27	156
4	160	28	161
5	153	29	159
6	152	30	196
7	182	31	191
8	157	32	199
9	160	33	172
10	155	34	213
11	161	35	214
12	167	36	219
13	161	37	222
14	151	38	212
15	157	39	216
16	161	40	213
17	168	41	219
18	162	42	211
19	166	43	214
20	169	44	214
21	165	45	203
22	160	46	203
23	170	47	196
24	177		

*Weeks containing holidays (and so only four working days) are not included

individually than the total variation, indicating that capacity must be excess at some locations and full at other locations at any one time. The reason for this variety in the degree of fulfillment of capacity at any one time is that some capacity is fixed (terminals) and while other capacity may be moved to meet demand, variations in demand cannot be predicted such that the capacity can be made available to meet it.

The above arguments are based on quite a bit of deductive reasoning which may seem somewhat out of place in a study such as this one, but they are here for a reason. These arguments lend credibility to the conclusion that probably seemed logical to most readers sometime ago; lost transit time due to adverse weather is an insignificant cost to the company. This point has been given particularly minute attention because it seemed ahead of time very obvious that the opposite result would obtain and because the opposite result seems so very important from an a priori point of view. An attempt to prove the unimportance of the lost-transit time by examining capacity utilization and service levels, which is really looking at the same question from the opposite direction, would have been far more tedious.

Value of Improved Information

Given that time lost through slower than normal average speed due to adverse weather conditions is insignificant, the cost of driver time lost due to highways being made impassable by weather is the only remaining line haul cost.[7] This cost for 1968 was shown in Table I.

There are several reasons to believe that at least a part of this cost would be avoidable with improved information. The most important of these reasons is that the costs are concentrated both temporally and geographically.[8] A

[7]Actually, there is also a small cost due to the unavailability of equipment tied up by these impassable highways that need not be included there.

[8]The geographic concentration is not apparent from the table, but it is both logically and actually the case.

related factor is the seasonal variation in cost level. And, finally, nearly all the cost is accounted for by relatively few causes.

But on the other hand, there are two important restrictions to the use of improved weather prediction information in avoiding these costs. Even if precisely accurate weather information is known, management cannot be sure of exactly where a truck will be at any given time in order to avoid the weather. And, secondly, management cannot be certain of the effect of any level of predicted adversity on any given vehicle. To put this factor in a simple example, sometimes four inches of snow is sufficient to block highways while at other times a foot or more may be necessary. An additional factor is that where the delay is less than two hours in length and where the drivers involved are about to go on layover, it is actually cheaper for the company to bear the cost of waiting time due to weather than it is to bear the layover cost due to avoiding the weather.

Given the restrictions outlined above, a level of possible savings due to improved weather can be determined. The only months where costs are great enough to justify examination (in this case) are January, March, and December. The important weather variables in these months are snow, ice (and ice and snow) and fog. The cost of lost time for these variables during these months in 1968 is shown below:

	Snow	Snow + ice	Ice	Fog	Total
January	$241.05	-	$405.01	$157.82	$803.87
March	268.24	$ 81.88	37.72	103.96	491.80
December	665.84	184.00	70.84	7.36	928.04

These costs are not evenly distributed throughout the month. The number of days each type of cost occurred during each month is shown below:

	Snow	Snow + Ice	Ice	Fog
January	4	-	14	8
March	5	2	4	4
December	5	3	6	1

Some of the days included above account for relatively minor costs. A program of cost avoidance must concern itself with costs that are significant enough to justify the cost of running the program. However, the point at which costs become relevant cannot be determined precisely without a knowledge of the cost of administering the program. For the sake of simplicity, a relevant cost level of $50 per day will be used here. Variations in this figure would yield variations in the resultant savings.

Occurrences of snow, ice and snow, and ice often come in conjunction with one another. For this reason, the days on which relevant costs in these categories occurred will be determined by taking the sum of these cost elements for individual days. The number of days significant costs occurred in each cost category in each month is shown below:

	Snow, ice, Snow and ice	Fog
January	3	-
March	3	1
December	5	-

The following table shows the monthly costs corresponding to these days:

	Snow, ice Snow and ice	Fog
January	$ 397.15	
March	329.36	$56.12
December	727.51	
Total	$1,454.02	$56.12

These costs are only avoidable insofar as it is possible to avoid paying drivers for layover if they are held in the terminal to avoid impassable highways. Since the fifteen-hour period between arrival at a terminal and the beginning of layover pay is short relative to the capability of a terminal to prepare an outgoing load, drivers at terminals other than their home terminals can be assumed to be ready to go on layover at the time the outbound load is ready. Given that drivers normally drive back and forth between two points (so that they are away from home two nights per week), it is reasonable to decrease the avoidable portion of the above costs by 40%. This operation results in a potential line haul saving due to improved weather prediction of $906.

Gateway management places a substantially smaller value on the possibility of improved information. While the operational savings shown are not unrealistic, they do not reflect the total cost of using the information. Chapter III discussed the importance of consistency of service in maintaining accounts. The use of weather prediction information depends on management's ability to determine in advance which loads actually will be stopped by the weather if they are sent out. The actual effect of weather conditions on the ability of trucks to keep moving is only one of a number of factors that will determine if a given driver will tie up. The other factors included such intangible qualities as driver ability and driver attitude and the effect of the weather on road conditions at the particular moment the driver happens to meet them. Precise weather prediction information increases the probability that management will be able to predict impassable highway conditions, but in all but the most extreme cases the risk of customer dissatisfaction outweighs the gains made possible by this improved information. Only in those cases where extremely adverse weather could be predicted highly accurately would savings be possible, and it is doubtful that these savings would amount to more than $100 per year. Ice and snow are the only weather conditions that would apply.

SAFETY

Effect of Weather

Accidents may occur within a terminal, maneuvering for pickup or delivery, and on the open road within an urban area or between urban areas. Accidents within terminals are rarely related to adverse weather. Accidents in maneuvering for pickup or delivery at shipping and receiving docks are more often related to weather, but these accidents tend to be minor because of the slow speeds involved, and injury rarely results. Examples found in this area are cases of poor visibility contributing to collision, ice or snow causing trucks to skid, and even cases of wind blowing doors against other objects. The highest frequency of accidents occurs in driving on city streets where damage tends to be minor because of the slow speeds traveled, although injuries frequently result. Line haul accidents are relatively rare on a per-mile of driving basis, but these accidents tend to be the most serious in terms of both damage to property and injury or loss of life.

Each accident involving company equipment is reported on a standard form. The accidents are investigated by Gateway's safety department and are judged as either preventable or nonpreventable. Since the driver is often the only company personnel at the scene of the accident, he is responsible for the initial report. This report contains two elements that indicate the extent to which adverse weather conditions are at fault. The report asks specifically for the weather conditions at the time of the accident, and the driver must make a statement describing the accident and its causes. From this information it is possible to obtain a very rough measure of the role of adverse weather in causing accidents.

Gateway experienced 979 accidents in 1968, from simple broken mirrors to destructive multiple vehicle fatalities. About 19% of these occurred during periods of adverse weather conditions. Of these 187 accidents in bad weather, there were 91 (or 49%) in which the driver indicated that the adverse weather contributed to the cause of the accident. This means that 9.4% of all accidents were at least partially caused by weather. The total time lost by line haul drivers because they were involved in accidents was 192 hours, and the total cost of this time came to about $680. Applying 9.4% to this figure gives a cost of $70 for time lost by line haul drivers due to weather related accidents. Using the relative frequency developed in the following paragraphs, the value of time lost by city drivers would be about $60.

The table below shows the percentage of all accidents involving road drivers and the percentage involving city drivers. The data for road drivers includes those accidents these men have while driving in cities, and the city driver category includes those that occur while maneuvering for pickup and delivery. As this table shows, while road drivers were involved in only 27% of all accidents, they were involved in 55% of the accidents where adverse weather was indicated to be a contributing cause. Using driver estimates of property damage for these accidents, over the road drivers were involved in accidents where bad weather was a contributing cause worth $35, 398, while the dollar cost for this type of accident for city drivers was $7, 582.

	Road Drivers	City Drivers
% total accidents	27%	73%
% of accidents in bad weather	39	61
% of accidents where bad weather was a contributing cause	55	45

Not all of this cost is borne by Gateway. Gateway theoretically only pays where the company-owned vehicle is at fault. During 1968, Gateway paid out on a total of 348 accidents, 35% of the accidents reported. This factor yields cost of $12, 400 for line haul accidents and $2, 800 for city accidents. The average paid per accident for damage to property including the company-owned vehicle was $472, as compared to an average driver's estimate of $488. Using the ratio of these two numbers as a correction factor,[1] the final cost of weather-related accidents for road drivers is $12, 200 and

[1] The use of this ratio is based on the assumption that the average accident cost is the same whether the accident is caused by Gateway or by another party, or, to put it another way, the frequency of accidents caused by Gateway as opposed to those caused by others is constant as other factors (such as weather) vary. It also assumes that the ratio applies equally well to either the sub-groups of road or city drivers.

and for city drivers $2, 750.

The question still remains as to how many of these accidents would have occurred if weather had not been adverse, the measure of the cost due to weather. These accidents have been regularly referred to as those where weather was a part of the cause. It seems reasonable to say that if weather had not contributed to the cause of these accidents, some of them would not have occurred in the first place. Just how many would have occurred or what the difference in total damage would have been can only be approximated. The best estimate of the Gateway safety director is 50%. Using the figure, the 1968 cost of property damage in accidents due to weather turns out to be $7, 500.

Gateway also paid $100, 000 in damages for personal injury due to accidents in 1968. Some portion of this figure must be attributed to accidents caused by weather. As indicated earlier, accidents occurring during line haul account for the greatest number of injuries. Approximately $75, 000 is attributable to line haul accidents and $25, 000 to city accidents. Using the measures developed earlier, a rough measure of personal injury damages due to weather can be calculated. The result is a cost of $5, 000. This estimate may not apply in any given year; a cost of far greater magnitude could easily result from a single accident. But it does give an idea of the long-run average cost of personal injury due to adverse weather.

Gateway has a program of driver training and continuous checking of driver habits, especially of drivers with poor accident records, but there is no special attention given to weather-related accidents. Drivers are expected to know how to handle their vehicles under adverse conditions. Certainly pointers for driving in the rain or snow are given, but it would not be possible to separate out the cost of training for bad weather from other training costs.

The total cost in the area of safety due to adverse weather is summarized below.

Cost Category	City Drivers	Road Drivers	Total
Driver time lost	$ 60	$ 70	$ 130
Property damage	1,400	6,100	7,500
Personal injury	1,250	3,750	5,000
	$2,710	$9,920	$12,630

Value of Improved Information

An incremental cost of the safety function due to adverse weather, as shown above, is certain to occur, but the magnitude of this cost may vary greatly. The likelihood of accidents occurring increases as drivers find they are less able to control their vehicles. An important cause of this loss of control is the development of adverse weather conditions. The knowledge that these conditions will occur is of little value to a driver already on the road, but this information may help to avoid accident exposure by allowing the elimination of trips where accident exposure is one of a number of factors that argue against the decision to make a trip. Stated quite simply, in a situation where weather conditions are bad enough to cause consideration of a suspension of service, the knowledge that accidents are relatively likely to occur under these conditions helps persuade the decision-maker to suspend service. There may be cases where this decision would not be reached without the safety factor entering the picture.

The safety department does not, of course, act as a consultant on sending out individual trips when weather is adverse. Truck dispatching is a continuous operation that cannot be held up by jurisdictional disputes. But the safety department does function to remind the operations department that customer service goals must be harmonized with other corporate as well as social goals concerning highway safety. It follows, therefore, that the influence of the safety department's access to improved weather prediction information would be a general one, not traceable to specific instances of cost saving.

Decisions to suspend service due to weather conditions are necessarily made only when conditions warranting the suspension actually exist or are about to develop. For this reason accurate short-range prediction and reporting of present conditions is needed for this function.

CLAIMS

Effect of Weather

Another possible source of weather-related cost is in the area of claims. Motor carriers (and all other common carriers) have arbitrarily extensive liability for loss or damage of merchandise in their possession. This liability is unavoidable as it is defined by law. The carrier is liable for all losses except those due to: 1) acts of God,[1] 2) acts of enemy aliens, 3) exercises of public authority, 4) inherent defects in the commodities, and 5) negligence of the shipper.

To aid in the control of claims motor carriers define them by cause. There is a standard classification of claims, originating with the ATA,[2] that is in use throughout the industry. This classification is shown down the side of Table IV.

The commodities that suffer loss or damage are also classified systematically by the ATA. This makes possible a classification of losses by cause and commodity, a valuable aid in discovering the origin of losses.

To discover the cost of weather on claims it is necessary first to pick out those types of claims that may be caused by weather. Table IV shows costs by cause for claims received by Gateway during 1968. The two most obvious candidates are claims due to heat or freezing and claims due to wetness. Together these items make up 6.3% of all claim costs for Gateway. Other, less obvious, possibilities are claims due to fires or wrecks and claims due to theft or pilferage. In these cases claims would be the indirect result of weather where weather is a contributing cause of the claim. Examples include

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[1] An act of God is an unavoidable uncontrollable act of nature. This is something more than "adverse" weather.

[2] The ATA is the American Trucking Associations, Inc., a group made up of motor carriers that lobbies in its members' interest and administers programs to benefit its members.

damage to merchandise being carried in a truck that is involved in an accident where weather is a contributing cause of the accident, theft of merchandise from a truck that is made more than normally vulnerable by being stuck in snow, or merchandise handled carelessly due to uncomfortably cold weather. A third and more direct possibility (under category G) is the damaging of merchandise in a terminal during a violent storm. All these examples are relatively rare occurrences, and while they are partially caused by weather, weather is not in itself a sufficient cause for these claims to occur. The delay category also looks like a potential source of weather-related cost, but this classification is ruled out by its definition. To collect on a delay claim, the shipper must show that the delay was unreasonably long, and delays due to adverse weather are considered reasonable. It is possible for some weather effect to exist in any of the categories remaining. The claims are classified by clerical employees whose judgment may not always be consistent. A good example of this is a claim for $333 for steel that was allowed to become frosted, classified as visible damage.

On the other hand, losses due to heat or freezing and losses due to wetness need not be caused by adverse weather conditions. It is possible for wetness claims to arise out of accidents involving the dumping of some liquid material on a commodity where weather is irrelevant. But this is a minor point and can easily be ignored. Loss due to temperature is a more complicated case. To begin with, in order to call adverse weather the cause of a claim, adverse weather needs to be defined. Being adverse should mean more than being different than the temperature deemed ideal for the commodity. For

TABLE IV

Gateway Cost of Claims, 1968

		Cost	Average cost	% total* items	% total cost	% total cost (industry)**
A	Shortage	$280,460	$ 40.83	40.99%	32.27%	34.13%
B	Theft	104,149	289.78	1.82	11.99	7.67
C	Visible damage (improper handling)	342,787	51.79	44.59	39.45	34.98
D	Concealed damage	71,584	69.00	9.69	8.34	13.04
E	Delay	4,873	231.89	.20	.56	.91
G	Fire, wreck	10,381	179.93	.36	1.19	4.73
H	Heat, freezing	15,689	68.86	.61	1.81	.95
I	Water damage	38,974	53.81	1.74	4.49	3.59
	TOTAL	$868,899		100.00	100.00	100.00

*Based on a 10% sample of all claims received by Gateway during the fourteen-month period from February 1, 1968 to March 30, 1969.

**ATA, "Loss and Damage Claims Statistics for 1968," ATA standard from F. C. S. 1.

example, if the refrigerator unit on a trailer breaks down on a warm day and a load of fresh meat is ruined, is it meaningful to attribute this loss to adverse weather conditions? Since meat is refrigerated regardless of outside temperatures, it seems rather that this loss is due to a mechanical failure. But losses of this type are included in the heat and freezing claim category just the same. Adverse weather must be considered weather for which special arrangements are necessary. Items that must be kept cold are refrigerated regardless of outside weather. Items that must be kept warm, however, receive special treatment when cold weather threatens. Nearly all items must be kept dry. This is why covers are put over open top trailers and why holes in trailers are supposed to be repaired immediately.[3]

The collection of items vulnerable to cold is known by the general term of freezables. Motor carriers run special service for freezable commodities during the cold weather months. The extent of this service is limited by extremely cold temperatures, available heating units, location, and time. When temperatures reach too low a level it is not possible to keep some trailers warm enough to carry freezables.[4] Carrying freezables is a special service, and where inadequate heated capacity exists, this service must be denied. Since

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[3]The chief of maintenance at Gateway's Chicago terminal said all trailers are checked for holes when they arrive (and, indeed, all do go through the check land). Any holes discovered are to be repaired before the trailer is allowed back on the road. But in looking over trailers parked for loading, the author observed a number with large and often old holes in them.

[4]This is not true in the case of insulated trailers with built-in heating units, but most trailers are not of this type.

the supply of heated capacity is limited, some points (where demand for freezable service is small) will have no service of this kind at all. Since there is extra cost and risk involved in handling freezables, truckers avoid offering the service unless it can be completed without delay.[5]

Freezable service is carefully organized to avoid losses. A detailed set of directions is issued from the office of the vice president for operations advising terminal managers of their responsibilities in handling freezables and attempting to organize a balanced flow of heated capacity. But it is inevitable that this system will break down from time to time. The factors involved where freezable claims result are equipment failure, limited capacity, and human error. When heaters fail to function properly, freezable commodities have no protection. Since heated capacity is limited, variations in demand for freezable service result at times in an undersupply of heated capacity. It is then a matter of judgment whether to ship commodities unprotected or to hold them for future shipment. Where the choice is made to ship and a loss results, the company must pay a freezable claim. Human error enters from other directions as well. Freezables are shipped without notation of their vulnerability, freezables are left on unheated trailers or docks overnight, and heaters are allowed to run out of fuel.

If carriers are to avoid claims they must be able to predict when claims will occur. Claims caused by adverse weather will occur only when the ad-

[5]For example, at one terminal, the manager said he avoided picking up freezables on Fridays because he didn't want to keep them warm all weekend.

verse weather occurs, but they may not always result when weather conditions are adverse. Some particular conditions would be expected to be more important than others, and the degree of intensity of the adverse conditions would also be expected to help explain claim occurrence. To match occurrence to particular weather conditions, it is necessary to know the exact point in time and space that the damage occurs. Very few companies attempt to do this[6] as claims do not come into existence until delivery of freight is refused, at which time it is necessary to backtrack to find the origin of the damage. Unless there is reason to believe this information will be useful, it is not worth the cost of collection.

Value of the Improved Information

It is the opinion of the claims control manager of Gateway that the origin of damage in nearly all cases is human error or human negligence. In the case of freezables, careful adherence to stated policy would eliminate all freezable claims except those due to mechanical failure of heating equipment. By the same token, there is no excuse for freight suffering water damage if maintenance policy is followed. But as those who ignore these policies seldom bear the costs of the resultant claims, there is strong pressure to take the easy way out. Thus there seems to be little potential for avoiding claims cost through the use of improved weather prediction information.

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[6]The author was told of only one company that attempts to pinpoint damage, and that with very little success.

FREEZABLES

Effect of Weather

The definition of freezable commodities was given in the previous chapter. The handling of freezables is an activity that covers a number of normally distinct trucking functions and so is being covered separately in this chapter.

The handling of freezables involves the most thorough and well-organized use of weather prediction information that Gateway engages in. Because by nature the freezable classification is only relevant during the winter, the use of this information is restricted to only the cold months—November through April at most. Company policy is to accept for delivery all freezable commodities offered[1] and to make deliveries as fast as is practical. To maintain this level of service, it is necessary to have heated capacity available for both movement and storage. Information on extremely cold weather and on highway conditions that may cause delays must be available also.

Gateway has a complex telephone communications system that allows any and all terminals to talk to any and all other terminals, one at a time or in groups, at no incremental cost. This is what they call their long line system. During the freezable season, this system is used to collect weather information for the planning of freezable service. Central Operations Control, whose responsibility it is to dispatch and keep track of all line haul equipment, acts as the focus of the information collecting and movement planning process. At 9:00 A. M. each operating day, all the terminals in the Gateway system are

[1]Commodities not already normally carried may not be accepted.

tied together on the long line to trade weather information. Each station reports the low temperature predicted for the coming twenty-four-hour period, the low temperature for the twenty-four-hour period following that, and any existing or predicted snowfall in its area. In addition, each station is responsible for notifying Central Operations Control whenever significant weather developments occur in its area. Central Operations Control and individual terminal managers or dispatchers use this information in deciding when and where to send freezables. There are no precisely defined rules for the use of this information. A number of factors such as the capacity of heated storage and movement facilities available,[2] the freezable freight on hand, the expected demand for freezable service, and expected as compared to present weather conditions are weighed, and a decision is made.

The source of weather prediction information is also left up to individual terminal managers. Presumably if all comes from the U. S. Weather Bureau, but individual managers may collect their information from newspapers, television, radio, and/or weather bureau offices. The reason the long-line hookup occurs at 9:00 A. M. is that this is the most convenient hour for personnel in all the terminals to set aside. The information is used to aid in dispatching line haul movements which do not get started in any significant number until late in the evening, so it may make more sense from the point of view of effectiveness of the information to trade information at a later hour.

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[2] Gas heated, insulated trailers are safe for almost any relevant conditions of cold, but the freight must be moved out of them in the adverse weather.

Each terminal in cold weather areas is built with what is known as a warm room.[3] A warm room is a heated area of the dock space where freezable commodities may be stored to protect them from the cold. Since this space is needed only when freezable commodities are in the possession of the terminal and temperatures are very low, the size of warm rooms is kept as small as possible. The dock space devoted to warm room use would normally be built even if warm rooms were not necessary. This space is used as extra storage space during periods of peak freight movement and these periods do not normally coincide with periods of cold weather. There is, however, an investment relevant to this study in equipment to heat warm room areas.

On those occasions where warm room capacity is not adequate to hold all the freezables needing storage it is not uncommon for office, garage and other heated areas to be used as warm rooms. The cost in these cases is the decreased efficiency of garage and office operations due to crowding, as well as the cost of moving the freezables in and out of these less accessible areas.

The use of a warm room imposes a cost due to the labor necessary to move freight in and out of it. In some cases there is only one extra move, as the freight would normally be moved across the dock anyway. But at other times, freight is moved that would normally be left if it were not threatened by cold. This is what happens when freight must be removed from a trailer over a

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[3]Warm rooms are not necessary where the entire dock is enclosed and heated.

weekend and then be replaced the following Monday. In Chicago, freezable freight is always placed in the warm room over weekends during the freezable protection period. Forecasts of warm temperatures are ignored as they are not considered to be reliable enough to justify the high risk. The cost of this movement is forty-eight man hours per week at $3.68 (1968) prices, or a total of about $175.00. If it is necessary to use overtime to carry out this function, the cost becomes $260 per week. The value of the freight being protected may be many thousands of dollars.

The trucks that Gateway uses for carrying commodities that must be kept cold are insulated and carry gas-fired refrigeration units. The refrigeration units may also be used to heat these trailers when freezables are being carried. Since this capacity is supplied for the purpose of refrigeration, only the operating cost of the heaters used for freezable service can properly be attributed to adverse weather. Since the demand for freezable service outstrips the supply of heater equipped units, it is also necessary to use charcoal heaters that may be placed in trailers where heat is needed. Gateway is presently not replacing these heaters as they wear out, but rather is changing over to the exclusive use of gas-fired heaters. This may restrict freezable handling capacity in the future, but it is the investment policy being pursued presently. Thus the present cost of providing freezable protection in trailers is the cost of operating and maintaining heating units.

There are several operating problems that develop as a direct result of freezable service. The first of these is achieving balance in movement of heated line haul equipment. This problem is solved by having individual pairs of terminals agree on regularly scheduled movements of this equipment back and forth, the level of capacity being determined by the anticipated level of demand. The system breaks down, however, where one terminal uses capacity destined for another to send its own freezable load to a third location. Keeping track of charcoal heaters involves additional office work as a company bill must accompany each heater. There is also additional labor in typing a freezable sticker on the bill, placing freezable stickers on the manifests of loads carrying freezables, and placing freezable stickers on the envelopes carrying the manifests of these trips. Additional costs are incurred in handling this additional paperwork during the movement process.

In developing a measure of cost of freezable service, Gateway's Chicago terminal will frequently be used as a starting point. This terminal handles approximately 20% of Gateway's freezable service either as an overhead terminal[4] or as an origin or destination terminal. This 20% ratio will be used to expand Chicago costs to cover the whole Gateway system. While this simple operation depends on the unrealistic assumption that cost levels are proportional throughout the system, it does eliminate the very complicated task of establishing separate measures throughout the Gateway system.

The length of the freezable period varies with the temperatures that occur at the beginning and end of the period. The average length of the period is about twenty-two weeks.

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[4]An overhead terminal is one that handles overhead freight. Overhead freight that is unloaded from incoming trucks to be reloaded into outbound trucks that will take it to its final destination.

The cost of warm room heating equipment depends on the size of the terminal, the climate of the terminal location, and the type of equipment used. Gateway's Chicago terminal uses infrared lights to heat its warm room in order to avoid closing off this space with walls to hold the heat in. This space could be heated at a lower cost by conventional methods if it were walled in, but the result would be to make the warm room area less useful at other times. Thus a part of the expansion of the heating equipment cost in Chicago corresponds to higher movement costs in terminals with conventionally heated, walled-in, warm room areas during nonfreezable operating periods. The cost of the heating equipment in Chicago was $11, 800 (1968 price). Assuming a twenty-year life and straight line depreciation, the annual cost of terminal heating equipment for the Gateway system is $2, 950.

The cost of operating the terminal heating equipment in Chicago is $550 per month. This figure yields an annual heating cost for the entire system of $12, 375.

The cost of handling freezable freight in Chicago on weekends was given earlier as from $175 to $260 per week. Since overtime is necessary in most weeks, the higher figure will be used. Some cost should probably be included to cover costs incurred for moving freight in and out of the warm room during the week, but no measure is available. As a result, it will be necessary to ignore that cost here. Using the $260 per week cost given above, the annual labor cost for the entire system becomes $28, 600.

The remaining costs will be computed directly on a company-wide basis. They are based on the 1968 level of 150 freezable loads moved per day, with

100 of these loads heated by charcoal heaters. In addition, a five-day work week is assumed.

Gateway uses 80, 000 pounds of charcoal per year for heating trailers. The total 1969 cost is $3, 520. Adjusting this price by 5% to reflect 1968 costs gives a figure of $3, 330.

The cost of heating with gas-fired units is more elusive. The average line haul distance in 1968 was 350 miles; this distance takes eight hours at an average speed of forty-five miles per hour. In addition, an hour is lost due to meal periods and other rest breaks during the trip. An average outbound delay of 3. 25 hours and an average inbound delay of 6 hours[5] must also be added in, resulting in a total heated period per trip of 18. 25 hours: The total annual number of these trips is 5, 500, resulting in a total of 100, 375 hours per year of gas fired heater use. The operating cost of heating with these units as measured by Gateway is $. 30 per hour. This results in a total cost per year for operating these heaters of $30, 100.

Additional costs (cost of billing) are primarily the cost of dock labor time lost due to handling of extra billing. This cost is given as $1. 00 per trailer, or a total of $16, 500 per year. There is no incremental office billing cost.

The table on the following page summarizes annual freezable handling costs computed to this point.

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[5] The outbound and inbound delay time are rough estimates made by the vice president for operations. They are meant to account for the priority given to heated trailers and the fact that heaters on trailers that will soon be unloaded are often turned off if current temperatures are warm.

Terminal costs	
Heating equipment investment	$ 2,950
Heating equipment operation	12,375
Labor costs	28,600
Transportation costs	
Charcoal	3,330
Gas fired heater operation	30,100
Billing cost	16,500
Total annual cost	$93,855

The costs shown in the table above overstate the costs actually borne by Gateway in handling freezable commodities. These costs were determined on the assumption that freezable protection is provided continuously during the twenty-two-week period from the beginning of November to the end of March. In reality, some of these costs are avoided during November and March if temperatures are expected to be above freezing with a reasonable degree of certainty.

A statistical study was carried out to determine what portion of the above costs are avoided. As in the past, Chicago was used in this study as a model upon which a generalization about experience in the entire Gateway system could be formulated.

Gateway management bases the decision as to whether or not protection of freezable commodities is necessary during November and March on predicted temperatures. To insure that differences between actual and predicted temperatures do not allow commodities to be exposed to freezing conditions, the critical forecast temperature used is 40°F. That is, protective measures are not used during this period only if the forecasted minimum temperature for the coming twenty-four hours is greater than or equal to 40°F. Given this rule, the problem here is to determine the frequency of forecasts at or above the critical temperature.

A statistical method was designed to measure this frequency. The validity of the method depends on the following assumptions:

1. Forecasting errors are random, so that the sum of all forecasting errors is zero.
2. The standard deviation of average daily normal temperatures is the same as the standard deviation of average daily minimum temperatures.

Although these assumptions may not be completely correct, they probably are very nearly so. As long as neither of these assumptions is grossly unrealistic, the following statistical exercise yields adequate results.

Daily normal minimum temperatures for Chicago were supplied by the U. S. Weather Bureau. Depending on the first assumption above, these were treated as daily normal forecasted minimum temperatures. Since the variation of actual temperatures from normal temperatures is closely approximated by a normal distribution, it follows that a normal distribution describes the variation of actual forecasted temperatures from normal forecasted temperatures. To determine the frequency of forecasted temperatures at or above the critical level, the only other information necessary is the standard deviation of the distribution of actual forecasts from normal forecasts.

Standard deviations of monthly average temperatures were available from the U. S. Weather Bureau,[6] and these were converted to standard deviations of daily average temperatures by means of a conversion factor taken from research by A. F. Jenkinson completed in 1957.[7] Then, using the second assumption above, these results were considered to be the standard deviations of the daily forecasted minimum temperatures for the period in question. Using these standard deviations to normalize the difference between the critical temperature and the normal daily temperatures, the probability that the forecasted temperature for each day was equal to or above the critical temperature was taken from a standard normal distribution table. The resulting probabilities were then added together and divided by the number of days to determine the probability (that is, the relative frequency) of active low temperatures equal to or greater than 40°F. during November and March. The resulting probability was 0.1768.

Since freezable handling costs are not presently avoidable during December, January and February, the probability of avoiding freezable handling costs during the whole period is 9/22 of 0.1768, or .0748. The figure is the degree to which avoidable freezable handling costs must be decreased. The avoidable costs are the costs of transportation, labor, and heating equipment operation. The appropriate adjustments yield the freezable handling costs shown below.

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[6] Standard Deviation of Monthly Average Temperature, by H. C. S. Thom, Climatolo-Services Division, U. S. Weather Bureau.

[7] A. F. Jenkinson, "Relations Between Standard Deviations of Daily, 5-day, 10-day and 30-Day Mean Temperatures," in Meteorological Magazine (Vol. 86, 1957), pp. 169-176.

Terminal Costs	
Heating Equipment investment	$ 2,950
Heating Equipment operation	11,450
Labor costs	26,460
Transportation Costs	
Charcoal	3,080
Gas fired heater operation	27,850
Billing Costs	16,500
Total annual cost	$88,290

Value of Improved Information

Very little attempt is presently made to avoid freezable handling costs due to the high value risked compared to the savings possible. The average freezable handling cost per trip is less than $6.00, but the value of the commodities being protected can easily be a thousand times as much. For this reason, freezable protection is often given when temperatures stay above the critical level throughout the trip. If management could be certain that temperature would remain high enough, it would avoid freezable costs. This is essentially what happens during the period of April through October. But weather prediction is not presently reliable enough during the winter months to warrant risking the large values involved against the small savings possible. If management could be certain of the future temperatures at each point in time and space that each load will pass through, a substantial part of the freezable cost would be avoidable.

There are, however, two other important restrictions on management's ability to avoid these costs. One is its refusal to accept the predicted weather information as reliable. It would take relatively few incorrectly predicted temperatures to wipe out any savings gained by using the improved information. Some progress can be made, however, by setting the new critical predicted temperature level somewhat above the freezing temperature. The other restriction is management's inability to precisely predict the point in space that a load will occupy at a given point in time. This location can, however, be approximated fairly accurately. A range of space for each moment in time can be used here to protect against loss.

If improved weather prediction information became available, Gateway management would use it to avoid freezable handling costs. Before the information was used, however, the company would make a careful study of the reliability of this information. Assuming the information proved reliable to within 2°F over 95% of the time, Gateway would drop its critical forecasted temperature from 40°F to 35°F.

The same statistical method as used above was used to measure the cost avoidable with a 35°F critical temperature. The only change in the analysis was that the critical temperature was allowed to operate throughout the period rather than just during the beginning and ending months. This change was in line with expected Gateway operations changes.

The probability of avoiding costs yielded by this analysis was 0.2458. Applying this factor to the avoidable freezable handling costs yields the expected cost levels shown below:

Terminal costs	
Heating equipment investment	$ 2,950
Heating equipment operation	9,325
Labor costs	21,155
Transportation costs	
Charcoal	2,510
Gas-fired heater operation	22,700
Billing costs	16,500
Total costs	$75,140

The total cost in the table above is a $13,150 incremental cost saving over the present operating situation.

The 35°F critical temperature is probably higher than is necessary. This temperature is based on the assumption that freezing will occur when the temperature reaches 32°F. However, there are a number of reasons why freezing will usually not occur at this level. One obvious reason is that many liquids, although having a water base, have a freezing temperature below 32°F because of their chemical composition, as is the case with salt water. For another thing, shipments being moved within the terminal or in a truck will have lower freezing points than shipments not being moved, just as flowing water in a river does not freeze as readily as does stagnant water nearby. Furthermore, shipments that are not being moved but that are in trailers or in terminals do have some protection from the cold. And, finally, the lowest temperature reached on a particular day rarely is the actual temperature for very long. As a result, liquids would not often have time to cool off enough to freeze if the temperature just reached 32°F. For these reasons, a critical temperature of 32°F was chosen for the examination of potential cost savings. This critical temperature level results in a lower range of actual temperature of 29°F.

The 32°F critical temperature level yields a probability of avoiding freezable handling costs of 0.3117. The resulting costs are shown below.

Terminal costs	
Heating equipment investment	$ 2,950
Heating equipment operation	8,260
Labor costs	19,100
Transportation costs	
Charcoal	2,200
Gas-fired heater operation	20,100
Billing costs	16,500
Total cost	$69,110

The total operating cost in this table is an incremental cost saving over the present method of $19,180, and an incremental cost saving over the method Gateway expects to use of $6,030.

The cost of operating either system would be about the same. This cost has been approximated here as ten hours per week for twenty-two weeks of the time of an employee earning $8,000 per year. The cost of this labor is $850 per year. With this information, the net cost savings possible with improved information can be calculated. The results are shown below:

	Cost	Net savings possible
Present method	$88,290	0
Expected method	75,140	$12,300
Potential method	69,110	18,330

Both the potential and the expected cost saving methods depend on complete, accurate forecasted temperatures for the entire area of operations. Probably the best method of presentation of these data is in the form of maps showing isobars for predicted minimum temperatures.

CONCLUSIONS

Results

Gateway Transportation Company has been found to bear significant costs due to adverse weather conditions, but only a very small portion of these costs would be avoidable with improved weather prediction information. There are three central factors that explain much of the inflexibility that makes these costs unavoidable. The most important of these factors is the strong service competition that exists in the common carrier trucking industry. Another factor is the strict definition of allowable routing found in Gateway's certificate of convenience and necessity. Both of these factors result from government regulation of trucking activities. The third factor is the lack of flexibility in driver assignments and pay scales due to both union pressure and company policy.

Although there are no significant sales costs due to adverse weather, the possibility of benefiting from improved prediction does exist. This benefit would take the form of improved service to attract new customers and to retain old ones. However, it is not known what the potential or expected value of this possibility is.

Weather affects transportation costs during pickup and delivery, during terminal dock operations, and during line haul. Pickup and delivery operations are affected as traffic is slowed due to adverse weather, but the size of this effect defies measurement with the data presently available. Furthermore, there is no reasonable statistical evidence that the effect of adverse weather on pickup and delivery operations is great enough to warrant managerial efforts to avoid it.

Cold weather is believed to affect the efficiency of dock labor, but no measure of this effect was found in the data available. However, using a measure determined subjectively by management, a total system cost of about $2,000 per year was established. Although this cost is so small that management would take no action to avoid it, a small part of the cost is theoretically avoidable.

Linehaul operations are affected by weather where precipitation causes deterioration in highway driving conditions. The incremental cost due to weather incurred during linehaul for 1968 was found to be $2,607.08. The potential savings under 1968 conditions was determined to be $906, but the expected savings by Gateway was no more than $100.

Adverse weather caused Gateway to incur an incremental safety department cost of $12,630 in 1968. While this figure may not provide a reliable guide for any particular period, it does serve as a good long-run average annual measure. Improved prediction of adverse weather conditions may have some value here, but the value would seldom be realized and its magnitude would be incapable of being measured.

Claims costs due to weather exist only where company policy is violated. For this reason weather related claims are not considered a cost of adverse weather.

The cost of providing freezable service is directly attributable to adverse (cold) weather. The total cost incurred here in 1968 was $88,290. Since this cost is incurred at a fairly constant rate during the freezable period while temperatures vary above and below the critical level, a portion of this cost is avoidable. Gateway would have avoided $12, 300 of this cost with improved weather information, and a reasonably safe policy could have saved $18, 330.

The costs and savings summarized in the preceding paragraphs are accumulated in the table below. An X mark indicates that a dollar value belongs in that space, but that no estimate of the right amount was found.

Functional Activity	Cost	Potential Savings	Probable Savings
Sales	0	X[a]	X[a]
Pickup and Delivery	X	0	0
Terminal	$ 2, 000	X	0
Linehaul	2, 607	906	100
Safety	12, 630	X	X
Claims	0	0	0
Freezables	88, 290	18, 330	12, 300
Total	$105, 527	$19, 236	$12, 400

[a]Although there are no possible savings in the sales function (since there are no costs) improved weather information does promise possible benefits not now realized.

This summarization shows the total incremental cost due to adverse weather for Gateway for 1968 as $105, 527, plus an unknown amount due to decreased customer service on pickup and delivery operations. During the same period, Gateway's total operating expenses (not including taxes, licenses, depreciation or amortization) were $54, 782, 768, so that costs due to weather were 0. 19% of total operating costs. The potential savings of $19, 236 would have been 0. 035% of operating cost, and the probable savings of $12, 400 would have been 0. 023% of total costs. The $19, 230 potential savings would have increased income from operations (before income taxes) by 0.39%, while the probable savings of $12,400 would have yielded an increase of 0.25%.

The value of improved weather prediction information seen in this light is extremely small. Even if the dollar values of improved information to the sales, terminal and safety functions were known, it is highly unlikely that improved weather information would have a significant effect on this common carrier's profits. In addition, it is somewhat doubtful that Gateway would be willing to accept the improved forecasts as being reliable enough to base policy changes upon. It would be necessary not only to provide the information in an easily usable fashion, but there would also have to be proof that the information provided was reliable. Thus these two effects—the low dollar value and the perceived unreliability of weather information—combined with institutional factors such as the regulatory framework, labor agreements, and the unsophisticated scheduling techniques presently used, result in a very low value for improved weather prediction information. Insofar as Gateway Transportation Company is typical of the common carrier trucking industry, it may be generalized that improved information would be of little dollar value to common carrier trucking.

THE POTENTIAL IMPACT OF ADVANCED SATELLITE WEATHER FORECASTING ON THE RECREATIONAL BOATING INDUSTRY: A CASE STUDY

James P. Gilligan* and David D. Gow*

INTRODUCTION

The importance of outdoor recreation in the American social and economic environment is suggested by national data collected by the President's Outdoor Recreation Resources Review Commission in 1960. In the period June, 1960 to May, 1969, 90% of all Americans participated in some form of outdoor recreation on 4.4 billion occasions. At that time the commission predicted a 50% increase in outdoor recreation participation by 1976. In 1967, however, the Bureau of Outdoor Recreation updated this figure. The data available for 1960-1965 showed that outdoor recreation participation during summer months had increased by 51%.

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*Recreation Resources Center, The University of Wisconsin, Madison. Our thanks are extended to the U. S. Army Corps of Engineers and local Chambers of Commerce who were very helpful in providing addresses of potential respondents. Our thanks are also extended to Maurice Warner and Professor William Burch, visiting professor from Yale University, who helped on several parts of this study. And, finally we wish to acknowledge the excellent cooperation of boat concession operators and resort managers in their responses to field interviews and mail questionnaires.

This growth in participation has been consistent with other changes in society at large: the increase in population, the economic boom of the sixties, the higher levels of disposable income, increasing leisure time, more formal education and increased mobility. Such variables as age, income, education, occupation, place of residence, and, to a lesser extent, sex, help to determine who will or will not participate in outdoor recreation.

Recreational boating has been no exception to this boom. The data available on the growth of recreational boating over the past decade show some variance. To avoid bias, two sets of data are presented: one prepared by the Bureau of Outdoor Recreation (U. S. Department of the Interior), and the other by the Boating Industry Association in conjunction with the National Association of Engine and Boat Manufacturers. It should be emphasized that the latter set of data is based on estimates. The data are listed in Table 1.

Despite the differences in available estimates of boating use in the United States, there is general agreement on the steady increase in what has been termed "America's top family sport." It is presently a $3 billion a year industry. The number of marinas, boat yards, and yacht clubs has increased by 15% in the period 1960-1969. There are now 4500 marinas and boat yards and 1400 yacht clubs in the United States. The Bureau of Outdoor Recreation estimated a 76% increase in boating participating, excluding canoeing and sailing, in the period 1965-1980.

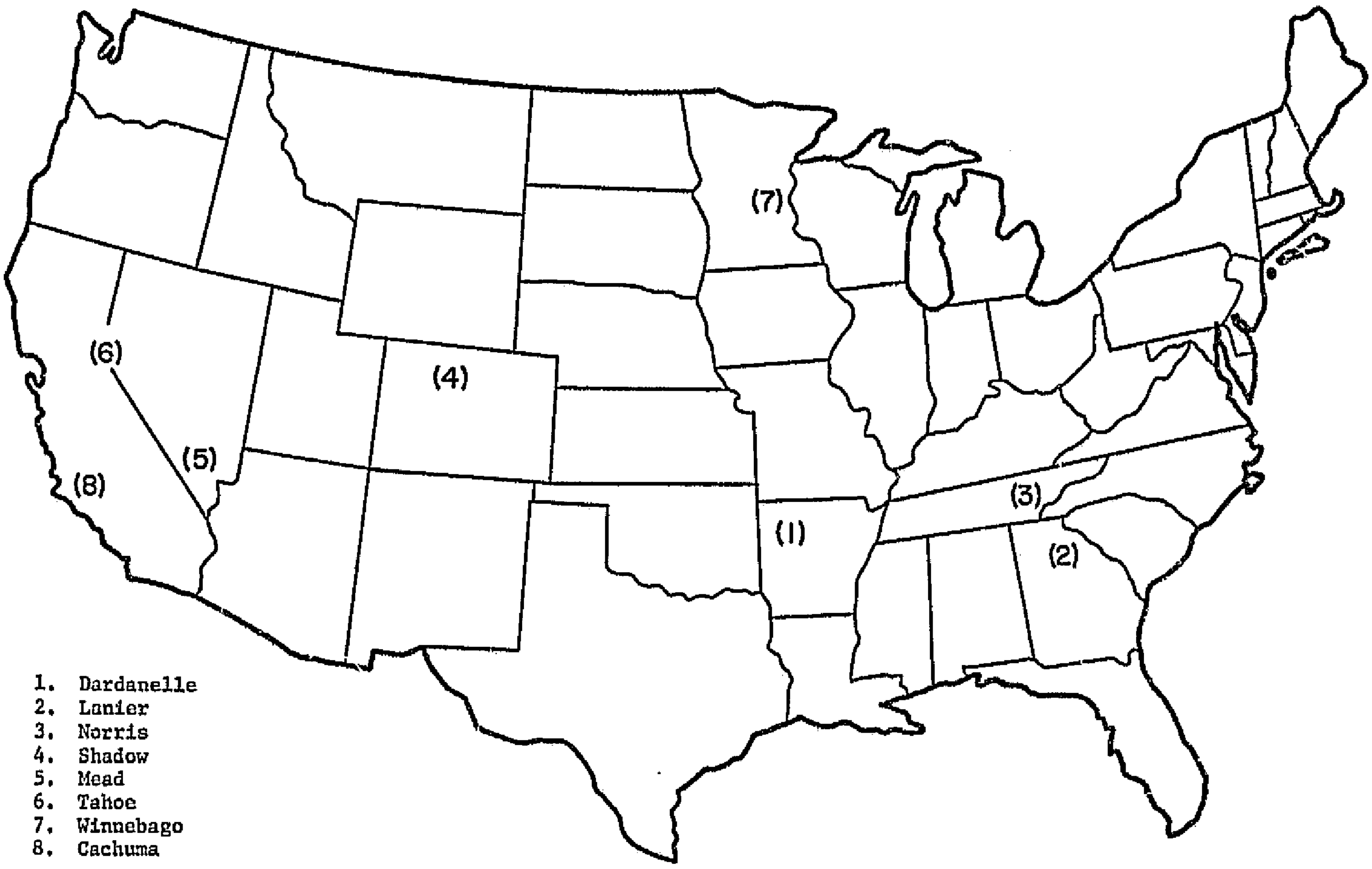

Figure 1: Geographical Distribution of Respondents

Purpose of Study

The purpose of this case study was to determine to what extent recreational boating management and planning are currently influenced by weather conditions and weather forecasting and to estimate possible changes that may result from improved weather forecasting and communication. Because of time limitations the study was confined to large inland lakes and reservoirs on which weather factors could be a significant influence on boating activities.

Methodology

Several criteria were used in selecting the regions and specific boating

Table 1. Percentage Increase in Boating Use, Ownership, and Expenditure 1960-1969.

	BOR	BIA and NAEBM		
	No. of People[a]	No. of People[b]	No. of Boats	Expenditure (millions)
1960	33,931,000	35,125,000	7,025,000	2,525
1965	42,376,000	39,325,000	7,865,000	2,683
1969	---	43,230,000	8,646,000	3,292
% increase 1960-1965	25%	12%	12%	6%
% increase 1965-1969		10%	10%	23%
% increase 1960-1969		23%	23%	30%

[a]Figures based on those individuals twelve years of age and older who participate once or more.

[b]Figures based on those using waterways more than twice a year.

areas to be sampled. Recognizing the probable differences in boating area weather conditions and management practices that exist between various sections of the United States, three regions were selected as a representative cross section of major boating area zones. The regions were the West (California, Nevada and Colorado), the South (Arkansas, Georgia and Tennessee) and the Lake States (Wisconsin).

A second criterion was that all boating areas sampled should be large lakes or reservoirs within a half-day drive from major metropolitan centers. This factor was based upon preliminary field interviews that indicated the use of such areas comprised a major proportion of total United States recreational boating use and that weather forecast information and boating area management changes were more significant to one-day and weekend boating activities than to more extended boating vacations. More isolated boating areas appeared to be more heavily utilized by extended boating vacationers for whom day-to-day weather variations were not a principle determinant of time and place for vacationing.

The final criterion was the availability of daily boat use data for the areas included in the sample. Our intention was to correlate these data with correlate these data with corresponding daily weather data and subject them to a regression analysis to reveal how significant past weather factors and day of week were in determining boating use. We then intended to compare what actually happened with what boating operators said happened.

After a very intensive nationwide search, it was discovered that daily use records, particularly defining kinds and amounts of boating use, were available for only a few large inland lakes in the country; and where these use data were available, the necessary accurate weather data were not available for these lakes. Therefore, this aspect of the study had to be abandoned. All of the lakes included in the study did have some use data available, usually on a weekly or monthly summary basis which were often estimates.

Efforts were also made to distribute the sample among boating areas of differing capacities, from small limited facility operations to major boating area complexes, to determine possible differences in use of weather forecasts as related to area management.

A questionnaire was constructed and mailed to boat concession operators in the three principal sample regions guided by the criteria previously indicated. Our sample was confined to boat concession operators because we felt their knowledge, background, and records could help provide the information we were interested in. We also felt that if improved weather forecasts were available, boat concession operators would feel the impact of increased recreational boating participation and react accordingly.

As a follow-up to the questionnaire, personal observations and interviews were conducted at representative sites to check contradictions and accuracy of questionnaire responses. Response rate to the mailed questionnaire was 57.5% with a total of fifty-eight respondents. Response rate is shown in Table 2 and geographical distribution of respondents is shown in Tables 3 and 4 and Figure 1.

Mailing lists of potential respondents were obtained primarily from such sources as the U.S. Army Corps of Engineers, U.S. Bureau of Reclamation, local Chambers of Commerce, State Water Resources agencies, the T.V.A., and the yellow pages of telephone directories. Duplications of address arose when a respondent owned more than one of the resorts or concessions on our list. From the information available it was sometimes difficult to know if the questionnaire was applicable to certain respondents.

The study also included a review and analysis of existing published information related to the influence of weather and weather forecasting on recreational boating operations.

The questionnaire was designed to elicit information and data about the following aspects of recreational boating operations:

Table 2. Response to Mailed Questionnaire

Number of questionnaires sent out	129
Number of duplications of address	6
Number of potential respondents who had moved	3
Adjusted sample size	120
Number of questionnaires received	69
Response rate	57.5%
Number of questionnaires not used because respondents did not rent out boats and claimed operations were not affected by weather	9
Number of operators not yet in operation	2
Number of respondents included in this analysis	58

Table 3. Distribution of Respondents by State

Lake	State	Number	Percent of sample
Dardanelle	Arkansas	5	8.6%
Lanier	Georgia	8	13.8%
Norris	Tennessee	13	22.4%
Shadow Mt.	Colorado	5	8.6%
Mead	Nevada	4	6.9%
Tahoe	California	12	20.7%
Winnebago	Wisconsin	10	17.3%
Cachuma	California	1	1.7%
Total		58	100.0%

Table 4. Distribution of Respondents by Area

Area	Number	Percent
South (Arkansas, Tennessee, Georgia)	10	17.3%
West (Colorado, Nevada, California)	21	36.2%
Lake (Wisconsin)	26	44.8%
Other (Cachuma, California)	1	1.7%
Totals	58	100.0%

1. Background information about respondents including type of operation, size of operation and types of boats rented out.
2. Effects of present weather forecasts on recreational boating management.
3. Most important weather factors in recreational boating operations.
4. Effects that improved weather forecasts might have on present boating operations.
5. Long-term effects that improved weather forecasts might have on boating operations.

In the tables which follow results are usually given for each state, each region and totals of all regions sampled. The category "national" includes Lake Cachuma in California.

1. <u>Background Information</u>

The majority of respondents, 72.4%, operated marinas either as a single enterprise or in combination with a holiday resort and/or motel. The classification "others," 15.5% of the sample, included boat salesmen and marine suppliers and distributors. These findings are listed by region in Table 5.

Table 5. Distribution of Operation by Region

	Type							
	1	2	3	4	5	6	7	8
South (26)	65.4 (17)		7.7 (3)		3.8 (1)		3.8 (1)	19.2 (5)
West (21)	42.8 (9)	4.8 (1)		4.8 (1)	9.5 (2)	19.0 (4)	4.8 (1)	14.3 (3)
Lake (10)	60.0 (6)	10.0 (1)	10.0 (1)	10.0 (1)				10.0 (1)
National (58)	55.2 (32)	3.4 (2)	5.2 (3)	3.4 (2)	6.9 (4)	6.9 (4)	3.4 (2)	15.5 (9)

1. Marina
2. Holiday resort
3. National, state or county park
4. Motel
5. Marina and holiday resort
6. Marina and motel
7. Marina, motel and holiday resort
8. Other (boat sales, marine distributors, etc.)

The figure in parentheses after each region is the number of respondents from that region who answered the question. The figure in the box is the percentage of respondents who answered that particular part of the question. The figure in parentheses after each percentage is the number of respondents who answered that particular part of the question. This format is used in all subsequent tables unless otherwise stated. In certain cases the row totals for each state or region will exceed 100%. This is because respondents may have checked more than one part of the question.

Of the sample, eleven respondents did not rent out boats but were involved in recreational boating in the sense that they sold boats or were suppliers of marine and fishing equipment. One respondent had a large cabin cruiser which was used exclusively for organized boat trips. These results are tabulated in Table 6.

Table 6. Number of Respondents who Rented Boats

	Number	Percent of total
Rentals	46	79.4
Number of rentals	11	18.9
Organized boat trips	1	1.7
Totals	58	100.0

The average number of boats owned by each operation was twenty. This ranged from a high of thirty-three on Lake Dardanelle to a low of ten on Lake Winnebago. These results are tabulated in Table 7.

Table 7. Average Number of Rental Boats

Area	Number
Dardanelle (5)	33
Lanier (5)	12
Norris (13)	22
Shadow (5)	12
Mead (3)	17
Tahoe (10)	25
Winnebago (4)	10
Southern States (23)	22
Western States (18)	19
Lake States (4)	10
National (45)[a]	20

[a]Lake Cachuma was omitted because the number of boats for rent, 149, was atypical of the sample.

The most popular rental boats were pleasure boats, thirteen to sixteen feet long, and rowboats. Foats fourteen feet in length were generally considered the minimum "safe" size for boating on large lakes and reservoirs. Boats were usually rented for fishing and, to a lesser extent, pleasure boating. Many were equipped with motors or capable of being equipped with motors. The only place where waterskiing and sailing were practiced to any extent was Lake Tahoe. The busiest boating months were July and August. In the South, May was the busiest month. For the majority of respondents, 63.8%, the boating season fell between April and October. One-fourth of the respondents remained open all year, the majority of them, 66.7%, in the South. The most popular time of day for renting a boat was between eight in the morning and three in the afternoon as aggregated in the variety of open-ended responses. As there was considerable variation in response to this aspect, the results are tabulated in Table 8.

Table 8. Daily Boat Rental Periods

	8 A. M.— noon	noon— 3 P. M.	3 P. M.— 6 P. M.	6 P. M. sunset	8 A. M.— 3 P. M.	6 A. M.— noon	8 A. M.— noon and 3 P. M.— 6 P. M.	8 A. M.— noon and 6 P. M.— sunset	4 A. M.— 8 A. M.
Dardanelle (5)	60.0 (3)	40.0 (2)							
Lanier (5)	100.0 (5)								
Norris (13)	42.1 (6)		7.7 (1)	30.8 (4)		15.4 (2)			
Shadow (5)	40.0 (2)				20.0 (1)		20.0 (1)	20.0 (1)	
Mead (3)	33.3 (1)				33.3 (1)	33.3 (1)			
Tahoe (10)		50.0 (5)	30.0 (3)			10.0 (1)	10.0 (1)		
Winnebago (4)	50.0 (2)				25.0 (1)				25.0 (1)
Southern States (23)	60.9 (14)	8.7 (2)	4.3 (1)	17.4 (4)		8.7 (2)			
Western States (18)	16.6 (3)	27.8 (5)	22.2 (4)		11.1 (2)	11.1 (2)	5.6 (1)	5.6 (1)	
Lake States (4)	50.0 (2)				25.0 (1)				25.0 (1)
National (46)	41.3 (19)	15.2 (7)	8.7 (4)	8.7 (4)	8.7 (4)	8.7 (4)	4.3 (2)	2.2 (1)	2.2 (1)

The majority of respondents, 81%, rented boat space to private owners. On a national level, the average number of mooring spaces rented annually was 184. There was a considerable amount of variation in the number of spaces rented at various lakes. The results are tabulated in Table 9.

Table 9. Number of Operators who Rented Mooring Space and Average Number of Spaces Rented on an Annual Basis

	Number Renting	Percent	Average number of spaces	High*	Low*
Dardanelle (5)	5	100.0	110	220	50
Lanier (8)	8	100.0	346	700	50
Norris (13)	10	76.9	95	225	50
Shadow (5)	4	80.0	47	70	30
Mead (4)	3	75.0	333	500	150
Tahoe (12)	10	83.3	154	400	25
Winnebago (10)	6	60.0	66	150	5
Southern States (26)	23	88.5	185	700	50
Southwest States (21)	17	81.0	205	500	25
Lake States (10)	6	60.0	66	150	5
National (58)	47	81.0	184	700	5

*The category "high" refers to the largest individual number of spaces rented; "low" to the lowest individual number.

The majority of respondents, 75.8%, allowed private owners to use their launching ramps. On a national level, the average number of launchings was

Table 10. Number of Operators who Allowed General Public to Use Launching Ramps and the Average Number of Launchings Annually

	Number	Percent	Average No. Launchings	High	Low
Dardanelle (5)	3	60.0	3000	5000	1000
Lanier (8)	8	100.0	2921[a]	12000	125
Norris (13)	10	76.9	1238	7300	75
Shadow (5)	5	100.0	212	700	40
Mead (4)	3	75.0	5625[b]	11000	250
Tahoe (12)	8	75.0	467	2000	15
Winnebago (10)	6	60.0	198	700	10
Southern States (26)	21	80.7	2047[c]	12000	75
Western States (21)	16	76.2	1070[d]	11000	15
Lake States (10)	6	60.0	198	700	10
National (58)	44	75.8	1539[e]	12000	10

[a]Total from 6 respondents

[b]Total from 2 respondents

[c]Total from 19 respondents

[d]Total from 15 respondents

[e]Total from 41 respondents

1,539. There was a considerable degree of variation in the number of public launchings at various lakes. The results are tabulated in Table 10.

Attempts were also made to discover the volume of business done by individual respondents on the basis of the number of boat rentals over the past three years. This proved impossible for two reasons: first, the questions relating to this information were badly worded and too amgibuous in meaning; second, many respondents had no data available on the number of daily or annual boat rentals. For the same reasons we were unable to obtain reliable data concerning most popular days of the week for renting boats.

Several unsubstantiated observations from field work can be offered. During the peak weeks or months for some operators closest to metropolitan centers, boat rentals did not vary significantly from day to day or from weekdays to weekends. All rental boats were often in constant use during these peak periods. Also, while it is commonly accepted that weekend days are peak periods for many kinds of outdoor recreational activities, we found several instances in lake boating where week days were the usual high-use periods. These occurred where there were other (non-water related) features or leisure attractions of major significance nearby.

2. Effects of Present Weather Forecasts

The majority of respondents, 85.2%, indicated that present weather forecasts do influence their planning and management in varying degrees. The number of management activities affected by weather forecast information is listed in Table 11 and kinds of activities affected are included in Table 12. However, in examining these aggregate data for each individual aspect, considerable variations appeared. Weather forecasts had little influence on planning what employees would do at Lake Mead, Shadow Lake or Lake Winnebago. The greatest influence was in the South where 73.9% of respondents answered in the affirmative. These results are listed in Table 13.

Table 11. Number of Management Activities Affected by Weather Forecast Information

	Number of Activities				
	0	1	2	3	4
Dardanelle (5)	20.0 (1)		20.0 (1)	40.0 (2)	20.0 (1)
Lanier (7)			28.6 (2)	71.4 (5)	
Norris (11)	9.1 (1)	27.3 (3)	45.4 (5)	9.1 (1)	9.1 (1)
Shadow (5)	40.0 (2)		20.0 (1)	40.0 (2)	
Mead (4)		50.0 (2)	25.0 (1)	25.0 (1)	
Tahoe (12)	8.3 (1)	50.0 (6)	25.0 (3)	16.7 (2)	
Winnebago (9)	33.3 (3)	33.3 (3)	22.2 (2)	11.1 (1)	
Southern States (23)	8.7 (2)	13.0 (3)	34.8 (8)	34.8 (8)	8.7 (2)
Western States (21)	14.3 (3)	38.1 (8)	23.8 (5)	23.8 (5)	
Lake States (9)	33.3 (3)	33.3 (3)	22.2 (2)	11.1 (1)	
National (54)	14.8 (8)	27.8 (15)	27.8 (15)	25.9 (14)	3.7(2)

Table 12. Influence of Weather Forecasts on Present Boat Rental Operations

Aspect	Percent who checked
Planning what employees will do	57.1
Planning number of employees	50.0
Stocking more gas and oil	38.3
Having more boats available	36.9

Table 13. Influence of Weather Forecast Information on Planning what Employees Would Do

	Important	Unimportant
Dardanelle (5)	60.0 (3)	40.0 (2)
Lanier (7)	85.7 (6)	14.3 (1)
Norris (11)	72.7 (8)	27.3 (3)
Shadow (5)	40.0 (2)	60.0 (3)
Mead (3)	33.3 (1)	66.7 (2)
Tahoe (8)	62.5 (5)	37.5 (3)
Winnebago (9)	33.3 (3)	66.7 (6)
Southern States (23)	73.9 (17)	26.1 (6)
Western States (16)	50.0 (8)	50.0 (8)
Lake States (9)	33.3 (3)	66.7 (6)
National (49)	57.1 (28)	42.9 (21)

Weather forecasts had little or no influence on planning number of employees at Lake Dardanelle, Shadow Lake and Lake Tahoe. The greatest influence was in the South where 65.2% of respondents answered in the affirmative. These results are listed in Table 14.

The influence of weather forecast information on stocking more gas and oil was of little or no importance at Lake Norris, Lake Mead and Lake Winnebago. In other areas it was only of some importance. These results are listed in Table 15.

Weather forecast information had little influence on having more boats

Table 14. Influence of Weather Forecast Information on Planning Number of Employees

	Important	Unimportant
Dardanelle (5)	40.0 (2)	60.0 (3)
Lanier (7)	100.0 (7)	-
Norris (11)	54.6 (6)	45.4 (5)
Shadow (5)	-	100.0 (5)
Mead (3)	100.0 (3)	-
Tahoe (9)	33.3 (3)	66.7 (6)
Winnebago (9)	33.3 (3)	66.7 (6)
Southern States (23)	65.2 (15)	34.8 (8)
Western States (17)	35.3 (6)	64.7 (11)
Lake States (9)	33.3 (3)	66.7 (6)
National (50)	50.0 (25)	50.0 (25)

Table 15. Influence of Weather Forecast Information on Stocking More Gas and Oil

	Important	Unimportant
Dardanelle (5)	80.0 (4)	20.0 (1)
Lanier (7)	57.1 (4)	42.9 (3)
Norris (9)	11.1 (1)	88.9 (8)
Shadow (5)	60.0 (3)	40.0 (2)
Mead (3)	-	100.0 (3)
Tahoe (9)	44.4 (4)	55.6 (5)
Winnebago (8)	25.0 (2)	75.0 (6)
Southern States (21)	42.9 (9)	57.1 (12)
Western States (17)	41.2 (7)	58.8 (10)
Lake States (8)	25.0 (2)	75.0 (6)
National (47)	38.3 (18)	61.7 (29)

Table 16. Influence of Weather Forecast Information on Having More Boats Available

	Important	Unimportant
Dardanelle (5)	40.0 (2)	60.0 (3)
Lanier (7)	28.6 (2)	71.4 (5)
Norris (11)	27.3 (3)	72.7 (8)
Shadow (5)	60.0 (3)	40.0 (2)
Mead (3)	66.7 (2)	33.3 (1)
Tahoe (7)	42.9 (3)	57.1 (4)
Winnebago (7)	28.6 (2)	71.4 (5)
Southern States (23)	30.4 (7)	69.6 (16)
Western States (15)	53.3 (8)	46.7 (7)
Lake States (7)	28.6 (2)	71.4 (5)
National (46)	36.9 (17)	63.1 (29)

available at Lake Lanier, Lake Norris, Lake Winnebago and in the South in general. These results are listed in Table 16.

3. Most Important Weather Factors

The most important factors in weather forecasts for boat-rental operators were wind direction, wind velocity and rain. In the South, information about rain was regarded as more important than information about wind. These results are tabulated in Table 17.

Field interviews revealed some interesting differences among boating operators located on a single lake in their reaction to weather factors. Topographic elevations (hills, ridges and mountains) close to a lake can provide extensive barriers to prevailing winds a considerable distance into large lakes

Table 17. Most Important Weather Factor in Weather Forecasts

	Rain	Wind direction	Wind velocity	Tempera-ture	Cloud cover	None
Dardanelle (4)	25.0 (1)	50.0 (2)	25.0 (1)			
Lanier (5)	20.0 (1)	40.0 (2)	20.0 (1)		20.0 (1)	
Norris (10)	40.0 (4)		20.0 (2)	20.0 (2)		20.0 (2)
Shadow (5)	60.0 (3)					40.0 (2)
Mead (2)		100.0 (2)				
Tahoe (10)		50.0 (5)	40.0 (4)		10.0 (1)	
Winnebago (8)	12.5 (1)	50.0 (4)	25.0 (2)			12.5 (1)
Southern States (19)	31.6 (6)	21.1 (4)	21.1 (4)	10.5 (2)	5.2 (1)	1 .5 (2)
Western States (17)	17.6 (3)	41.2 (7)	23.5 (4)		5.9 (1)	11.8 (2)
Lake States(8)	12.5 (1)	50.0 (4)	25.0 (2)			12.5 (1)
National (45)	24.4 (11)	33.3 (15)	22.2 (10)	4.5 (2)	4.5 (2)	11.1 (5)

with only light rippling in these portions of the lake. Whereas on the unprotected windward sides of lakes (or offshore from wind funneling canyons) influence of the same wind can build up severe wave conditions for boating. Thus, one operator could report wind direction and velocity as a major influencing factor while another operator on the same lake could report these factors as of minor influence.

The lengths of forecasts most useful for planning and management

Table 18. Length of Forecast Most Useful in Planning and Management

	Length of Forecast				
	1-Day	5-Day	30-Day	1-Day and 5-Day	No changes
Dardanelle (5)		40.0 (4)			20.0 (1)
Lanier (8)	25.0 (2)	50.0 (4)		12.5 (1)	12.5 (1)
Norris (12)	41.7 (5)	50.0 (6)			9.3 (1)
Shadow (5)		60.0 (3)	20.0 (1)		20.0 (1)
Mead (4)		75.0 (3)		25.0 (1)	
Tahoe (12)	25.0 (3)	16.7 (2)	3.[illegible] (1)	41.7 (5)	8.3 (1)
Winnebago (10)	40.0 (4)	10.0 (1)	10.0 (1)	30.0 (3)	10.0 (1)
Southern States (25)	28.0 (7)	56.0 (14)		4.0 (1)	12.0 (3)
Western States (21)	14.3 (3)	38.1 (8)	9.5 (2)	28.6 (6)	9.5 (2)
Lake States (10)	40.0 (4)	10.0 (1)	10.0 (1)	30.0 (3)	10.0 (1)
National (57)	24.6 (14)	40.3 (23)	5.3 (3)	17.5 (10)	12.3 (7)

decisions were five-day and one-day forecasts. Little interest was shown in thirty-day forecasts. These results are listed in Table 18.

Local radio and television stations were the most popular sources of weather forecast information, utilized by 79.3% of respondents. Of the remainder, 13.8% used no weather forecast information whatsoever.

Respondents were not particularly impressed by the accuracy of present weather forecasts. The majority, 71.5%, thought they were at least 50% accurate. Only 7.1% regarded them as totally unreliable. However, respondents

Table 19. Sources Utilized for Weather Forecast Information

	Sources				
	Local radio or television stations	Private weather forecasting firms	Direct weather bureau station reports	No sources utilized	Other (U. S. Coast Guard, TVA bulletin, etc.)
Dardanelle (5)	100.0 (5)				
Lanier (8)	100.0 (8)		25.0 (2)		25.0 (2)
Norris (13)	76.9 (10)			15.4 (2)	15.4 (2)
Shadow (5)	60.0 (3)			40.0 (2)	
Mead (4)	50.0 (2)	25.0 (1)	50.0 (2)		25.0 (1)
Tahoe (12)	66.7 (8)	8.3 (1)	8.3 (1)	25.0 (3)	25.0 (3)
Winnebago (10)	90.0 (9)			10.0 (1)	
Southern States (26)	88.5 (23)		7.7 (2)	7.7 (2)	15.4 (4)
Western States (21)	61.9 (13)	9.5 (2)	14.3 (3)	23.8 (5)	19.0 (4)
Lake States (10)	90.0 (9)			10.0 (1)	
National (58)	79.3 (46)	3.4 (2)	8.6 (5)	13.8 (8)	13.8 (8)

from Lake Norris and Lake Tahoe were not at all impressed by present accuracy. These results are listed in Table 20.

On several lakes a type of informal "existing or immediately pending" weather reporting system has been established via radio linkage between boats (with transmitters and receivers), marinas, sheriff's boat patrol and government agency offices in the vicinity. This system often transmits bad weather build-ups in time for boaters to reach the shelter of shore.

Table 20. Respondents' Opinions of Present Weather Forecasts

	75% Accurate	50% Accurate	25% Accurate	Totally Unreliable
Dardanelle (5)	60.0 (3)	40.0 (2)		
Lanier (8)	50.0 (4)	37.5 (3)		12.5 (1)
Norris (12)	16.7 (2)	33.3 (4)	41.7 (5)	8.3 (1)
Shadow (5)	20.0 (1)	60.0 (3)		20.0 (1)
Mead (4)	75.0 (3)		25.0 (1)	
Tahoe (12)	16.7 (2)	50.0 (6)	25.0 (3)	8.3 (1)
Winnebago (9)	33.3 (3)	44.4 (4)	22.2 (2)	
Southern States (25)	36.0 (9)	36.0 (9)	20.0 (5)	8.0 (2)
Western States (21)	28.6 (6)	42.9 (9)	19.0 (4)	9.5 (2)
Lake States (9)	33.3 (3)	44.4 (4)	22.2 (2)	
National (56)	32.2 (18)	39.3 (22)	21.4 (12)	7.1 (4)

Good weather forecasts meant more boat users than normal, according to 87% of respondents, and bad forecasts meant fewer boat users according to 64.8% of respondents. These results are tabulated in Table 21.

4. Effects of Improved Forecasts on Present Operations

If improved weather forecasts were available, 86.2% of respondents in the sample said they would make changes in specific aspects of present boating management and planning. Those aspects which would be affected are listed in order of importance in Table 22. Regionally, there were certain differences

Table 21. Effects Present Weather Forecasts Have on Boat Use

	Good forecast means more boat users than usual	Good forecast has no effect	Bad forecast means fewer boat users than usual	Bad forecast has no effect	Other
Dardanelle (5)	80.0 (4)		100.0 (5)		
Lanier (8)	87.5 (7)		62.5 (5)		
Norris (11)	81.8 (9)	9.1 (1)	45.6 (5)	9.1 (1)	
Shadow (5)	80.0 (4)		80.0 (4)	20.0 (1)	
Mead (4)	100.0 (4)		75.0 (3)		
Tahoe (12)	91.7 (11)	8.3 (1)	66.7 (8)		8.3 (1)
Winnebago (8)	87.5 (7)		50.0 (4)		
Southern States (24)	83.3 (20)	4.2 (1)	62.5 (15)	4.2 (1)	
Western States (21)	90.5 (19)	4.8 (1)	71.4 (15)	4.8 (1)	4.8 (1)
Lake States (8)	87.5 (7)		50.0 (4)		
National (54)	87.0 (47)	3.7 (2)	64.8 (35)	3.7 (2)	1.9 (1)

which are presented in Tables 23 and 24. A cross in Table 23 signifies that 40% or more of respondents said that particular aspects of boating management would be affected by improved weather forecasts. "Road and parking area maintenance" and "stocking of gas and oil" were the least important aspects. All other aspects were important. Table 24 shows the percentage response for each management aspect by state and region.

Table 22. Management Aspects Which Would be Affected by Improved Weather Forecasts

Aspect	Percent that checked
Season opening	70%
Equipment and facility maintenance	62%
Season closing	54%
Number of employees	50%
Number of boats	42%
Stocking of gas and oil	34%
Road and parking area maintenance	26%

Table 23. Management Aspects Which Would Be Affected By Improved Forecasts

	Aspect						
	A	B	C	D	E	F	G
Dardanelle	X	X	X			X	X
Lanier	X		X			X	X
Norris	X	X	X	X	X	X	
Shadow	X	X			X		X
Mead	X				X	X	
Tahoe	X	X	X		X	X	
Winnebago	X	X	X		X		
Southern States	X	X	X			X	X
Western States	X	X			X		
Lake States	X	X	X		X		
National	X	X	X		X	X	

A. Season opening
B. Season closing
C. Equipment and facilities maintenance
D. Road and parking area maintenance
E. Number of boats
F. Number of employees
G. Stocking of Gas and oil

Table 24. Percentage of Respondents Who Thought Specific Aspects of Management Would Be Affected By Improved Weather Forecasts. *

	Aspect						
	A	B	C	D	E	F	G
Dardanelle (4)	75.0 (3)	75.0 (3)	100.0 (4)	25.0 (1)	25.0 (1)	75.0 (3)	50.0 (2)
Lanier (8)	50.0 (4)	37.5 (3)	62.5 (5)	37.5 (3)	25.0 (2)	87.5 (7)	50.0 (4)
Norris (10)	60.0 (6)	40.0 (4)	90.0 (9)	40.0 (4)	40.0 (4)	50.0 (5)	30.0 (3)
Shadow (4)	100.0 (4)	100.0 (4)	25.0 (1)	25.0 (1)	50.0 (2)	-	75.0 (3)
Mead (4)	50.0 (2)	-	25.0 (1)	25.0 (1)	50.0 (2)	50.0 (2)	-
Tahoe (10)	90.0 (9)	80.0 (8)	40.0 (4)	-	40.0 (4)	40.0 (4)	30.0 (3)
Winnebago (9)	77.8 (7)	55.6 (5)	66.7 (6)	33.3 (3)	55.6 (5)	33.3 (3)	22.2 (2)
Southern States (22)	59.1 (13)	45.6 (10)	81.8 (18)	36.4 (8)	31.8 (7)	68.2 (15)	40.9 (9)
Western States (18)	83.3 (15)	66.7 (12)	33.3 (6)	11.1 (2)	44.4 (8)	33.3 (6)	33.3 (6)
Lake States (9)	77.8 (7)	55.6 (5)	66.7 (6)	33.3 (3)	55.6 (5)	33.3 (3)	22.2 (2)
National (50)	70.0 (35)	54.0 (27)	62.0 (31)	26.0 (13)	42.0 (21)	50.0 (25)	34.0 (17)

A. Season opening
B. Season closing
C. Equipment and facilities maintenance
D. Road and parking area maintenance
E. Number of boats
F. Number of employees
G. Stocking of gas and oil

*It was inaccurate to classify the eight respondents who did not answer as operators who would make no changes.

Percentages indicated are percentages of the number of respondents who answered the question. They are not percentages of the total number of respondents in the sample.

Respondents were asked to specify the length of forecast required for each management aspect that they checked off. The results are an aggregate of the responses to the seven aspects in Table 25. It was felt that one comprehensive table would be more useful than seven separate ones. When and if improved weather forecasts are introduced, it is unlikely there will be seven distinct types of forecasts for boating areas. Much more likely is one comprehensive forecast. Nationally, for boating, the most popular lengths of forecast would be five-day and one-day. Regionally, five-day and one-day forecasts were almost equally popular in the South, whereas in the West, five-day forecasts were most popular with thirty-day forecasts in second place.

Respondents were asked to specify the critical weather factors involved in each management aspect that they checked off. The results are an aggregate of the responses to the seven aspects listed in Table 24. Nationally, the critical weather factors involved are temperature, rainfall, wind and, to a lesser extent, amount of sunshine. Regionally, rainfall was the most important factor in the South while wind was of major importance in the West. In contrast to what they said about present weather forecasts, respondents regarded temperature as a critical factor in improved weather forecasts. One reason for this inconsistency may be that in the section concerning present weather forecasts, respondents had to answer an open-ended question; in the section concerning improved weather forecasts, respondents had to choose from a

Table 25. Length of Forecast Required for All Activities

	Length						
	12 hours	1 day	5 days	30 days	12 hours and 5 day	1 day and 5 day	5 day and 30 day
Dardanelle (17)*	11.8 (2)	70.6 (12)		17.6 (3)			
Lanier (28)	17.9 (5)	10.7 (3)	32.1 (9)	14.3 (4)	3.6 (1)	21.4 (6)	
Norris (35)	20.0 (7)	25.7 (9)	40.0 (14)	11.4 (4)		2.9 (1)	
Shadow (13)		15.4 (2)	46.1 (6)	38.5 (5)			
Mead (8)			62.5 (5)		12.5 (1)	25.0 (2)	
Tahoe (27)	7.4 (2)	14.8 (4)	37.0 (10)	18.5 (5)		14.8 (4)	7.4 (2)
Winnebago (30)	23.3 (7)	33.3 (10)	20.0 (6)	20.0 (6)		3.3 (1)	
Southern States (80)	17.5 (14)	30.0 (24)	28.8 (23)	13.8 (11)	1.2 (1)	8.7 (7)	
Western States (48)	4.2 (2)	12.5 (6)	43.7 (21)	20.8 (10)	2.1 (1)	12.5 (6)	4.2 (2)
Lake States (30)	23.3 (7)	33.3 (10)	20.0 (6)	20.0 (6)		3.3 (1)	
National (161)	14.3 (23)	24.9 (40)	32.3 (52)	17.4 (28)	1.2 (2)	8.7 (14)	1.2 (2)

*These figures in parentheses, which are taken from the row totals in Table 24, do not always correspond because some respondents did not specify length of forecast required.

Table 26. Critical Weather Factors in Improved Weather Forecasts

	Weather Factors			
	Temperature	Rainfall	Wind	Sunshine
Dardanelle (17)*	58.8 (10)	76.5 (13)	52.9 (9)	29.4 (5)
Lanier (28)	67.9 (19)	82.1 (23)	50.0 (14)	39.3 (11)
Norris (33)	48.5 (16)	66.7 (22)	45.5 (15)	12.1 (4)
Shadow (14)	85.7 (12)	42.9 (6)	21.4 (3)	21.4 (3)
Mead (7)	85.7 (6)	-	100.0 (7)	28.6 (2)
Tahoe (31)	87.1 (27)	38.7 (12)	61.3 (19)	25.8 (8)
Winnebago (31)	51.6 (16)	67.7 (21)	61.3 (19)	12.9 (4)
Southern States (78)	57.7 (45)	74.4 (58)	47.4 (37)	25.6 (20)
Western States (52)	86.5 (45)	34.6 (18)	55.8 (29)	25.0 (13)
Lake States (31)	51.6 (16)	67.7 (21)	61.3 (19)	12.9 (4)
National (164)	66.5 (109)	61.0 (100)	51.8 (85)	22.6 (37)

*As in Table 25, these figures in parentheses, which are taken from the row totals in Table 24, do not always correspond because some respondents did not specify length of forecast desired.

given list of weather factors. The results are tabulated in Table 26.

When asked what effects improved weather forecasts might have on boat use, 86.8% of respondents said good weather forecasts would mean more boat users than normal and 60.4% of respondents said bad weather forecasts would mean fewer boat users. These responses which are tabulated in Table 28 are almost identical to those given for the effects of present weather forecasts on boat use in Table 21.

5. Long-Term Effects

When questioned about the long-term effects of improved weather forecasts on their boating operations, 74.5% of respondents who answered this question said they would make changes. The changes listed by this 74.5% are tabulated in Table 28.

Table 27. Effects Improved Weather Forecasts Might Have on Boat Use

	1	2	3	4	5
Dardanelle (5)	80.0 (4)	20.0 (1)	80.0 (4)	20.0 (1)	
Lanier (8)	87.5 (7)		50.0 (4)		
Norris (11)	100.0 (11)		54.5 (6)		
Shadow (4)	75.0 (3)		75.0 (3)		25.0 (1)
Mead (4)	100.0 (4)		100.0 (4)		
Tahoe (11)	81.8 (9)	9.1 (1)	63.6 (7)	9.1 (1)	
Winnebago (10)	80.0 (8)		40.0 (4)		
Southern States (24)	91.7 (22)	4.2 (1)	58.3 (14)	4.2 (1)	
Western States (19)	84.2 (16)	5.3 (1)	73.7 (14)	5.3 (1)	5.3 (1)
Lake States (10)	80.0 (8)		40.0 (4)		
National (53)	86.8 (46)	3.8 (2)	60.4 (32)	3.8 (2)	1.9 (1)

1. Good forecast would mean more boat users than normal.
2. Good forecast would have no effect.
3. Bad forecast would mean fewer boat users than normal.
4. Bad forecast would have no effect.
5. Other.

Table 28. Long-Term Effects of Improved Weather Forecasts

Future Changes	Percent That Checked
Add to boating area facilities	35.3%
Make week-to-week arrangements with employees more flexible	31.4%
Increase number of boats	29.4%
Develop alternative recreation facilities on site	19.6%

Regionally, there were certain differences which are presented in Tables 29 and 30. On the one hand, respondents from lakes Tahoe and Winnebago showed the least interest in making changes; on the other, respondents from the South showed the greatest interest in making long-term changes.

The seven respondents (12% of the sample) who did not answer the question all rented out boats. Thus ownership of rental boats was not the sole factor determining response. Similarly, only three respondents of the thirteen (25.5% of sample) who said they would make no changes did not own rental boats.

SUMMARY

Background Information

The majority of respondents operated marinas which had an average of twenty rental boats at their disposal. The most popular rental boats were pleasure boats, thirteen to sixteen feet long, and rowboats which were used for fishing and, to a lesser extent, pleasure boating. For the majority, the boating season fell between April and October, with July and August the

Table 29. Long-Term Changes Which Might Result From Improved Weather Forecasts

	1	2	3	4	5
Dardanelle (5)		40.0 (2)	40.0 (2)	60.0 (3)	20.0 (1)
Lanier (7)	28.6 (2)	42.9 (3)	14.3 (1)	28.6 (2)	-
Norris (11)	36.4 (4)	27.3 (3)	36.4 (4)	45.6 (5)	-
Shadow (4)	50.0 (2)	50.0 (2)	-	25.0 (1)	25.0 (1)
Mead (4)	50.0 (2)	50.0 (2)	-	50.0 (2)	25.0 (1)
Tahoe (10)	20.0 (2)	20.0 (2)	-	20.0 (2)	60.0 (4)
Winnebago (10)	30.0 (3)	40.0 (4)	30.0 (3)	10.0 (1)	40.0 (4)
Southern States (23)	26.1 (6)	34.8 (8)	30.4 (7)	43.5 (10)	4.3 (1)
Western States (18)	33.3 (6)	33.3 (6)	-	27.8 (5)	44.4 (8)
Lake States (10)	30.0 (3)	40.0 (4)	30.0 (3)	10.0 (1)	40.0 (4)
National (51)	29.4 (15)	35.3 (18)	19.6 (10)	31.4 (16)	25.5 (13)

1. Increase number of boats
2. Add to boating area facilities
3. Develop alternative recreation facilities on site
4. Make week-to-week arrangements with employees more flexible
5. No changes

businest months in the Western and Lake States regions. May was the busiest month in the South. The most popular time of day for renting a boat was between 8:00 A. M. and 3:00 P. M. The majority of respondents rented out mooring space to private owners and allowed them to use their launching ramps.

Table 30. Percentage of Respondents Who Would Make Long-Term Changes

	Changes	No Changes
Dardanelle (5)	80.0 (4)	20.0 (1)
Lanier (7)	100.0 (7)	-
Norris (11)	100.0 (11)	-
Shadow (4)	75.0 (3)	25.0 (1)
Mead (4)	75.0 (3)	25.0 (1)
Tahoe (10)	40.0 (4)	60.0 (6)
Winnebago (10)	60.0 (6)	40.0 (4)
Southern States (23)	95.7 (22)	4.3 (1)
Western States (18)	55.6 (10)	44.4 (8)
Lake States (10)	60.0 (6)	40.0 (4)
National (51)	74.5 (38)	25.5 (13)

Effects of Present Weather Forecasts

Planning and management aspects of boating operations which were affected by present weather forecasts were, in order of importance,

1. Planning what employees would do
2. Planning number of employees
3. Stocking more gas and oil
4. Having more boats available

Most Important Weather Factors

The most important factors in weather forecasts were, in order of importance,

1. Wind direction
2. Rain
3. Wind velocity

In the South, information about rain was regarded as more important than information about wind.

The lengths of forecasts most useful for planning and management decisions in order of priority were,

1. 5-day
2. 1-day
3. 1-day and 5-day
4. 30-day

Local radio and television stations were the most popular sources of weather forecast information. The accuracy of present weather forecasts was not greatly admired; 71.5% of respondents thought they were at least 50% accurate.

<u>Effects of Improved Forecasts on Present Operations</u>

The aspects of present boating operations which would be affected by improved weather forecasts were, in order of importance,

1. Season opening
2. Equipment and facility maintenance
3. Season closing
4. Number of employees
5. Number of boats
6. Stocking of gas and oil
7. Road and parking area maintenance

These improved forecasts would have to contain information about the following factors,

1. Temperature
2. Rainfall
3. Wind

The lengths of forecast required to implement these changes are,

1. 5-day
2. 1-day
3. 30-day
4. 12-hour

Long-Term Effects

The aspects of long-term boating operations which would be affected by improved weather forecasts were, in order of importance,

1. Add to boating area facilities
2. Make week-to-week arrangements with employees more flexible
3. Increase number of boats
4. Develop alternative recreation facilities on site

Our study was concerned with the potential effects of improved weather forecasts on boating operations and individual boating operators. But what of the potential effects on the boat users themselves? When questioned on this matter, boating operators indicated that good weather forecasts would mean more boat users than normal and bad weather forecasts would mean fewer. Is this in fact the case? Three recent studies by Paul Nelson, Dr. Carrol Dowell and Dr. Melvin Crapo throw some light on this aspect of improved forecasts.

Nelson studied the potential impact of accurate one-week weather forecasts on the demand for outdoor recreation in Wisconsin. If such forecasts were available, fishermen in this sample said they would increase participation by 54.2%, canoers by 13.2%, yachtsmen by 38.3%, motorboaters by 21.7%, and waterskiers by 30.1%.[1] With the exception of the yachtsmen, the majority

[1] Nelson, Paul A., The Impact of Accurate One-Week Weather Forecasts on the Demand for Outdoor Recreation (in Wisconsin). Social Systems Research Institute, Publication ZMiE 7041 (University of Wisconsin, Madison), p. 47.

of the members of these groups defined their favorite type of weather as "warm, sunny and dry, not windy." Yachtsmen responded almost identically except, of course, that they wanted plenty of wind.[2]

It should be pointed out that a previous study of outdoor recreation in Wisconsin indicated that Wisconsin adults tend to participate more frequently in boating than adults do nationally.[3] Nelson also points out in his conclusions that among those people who currently engage in outdoor recreation of the types considered in his study, income, age and retirement are not barriers to benefiting from accurate one-week forecasts. However, he also states that such forecasts will benefit neither the rural population nor the urban poor who do not currently participate in outdoor recreation as defined in his study.[4]

Dowell conducted a year-long study of the effects of weather on pleasure boating on Lake Dardanelle, Arkansas, and arrived at the following conclusions:

1. Weekend and holiday boat launchings showed definite seasonality, irrespective of local weather conditions. Summer was the busiest boat launching season, May the busiest boat launching month and July 4 the single busiest boat launching day.

2. During the period studied, approximately 90% of the boat launchings occurred on days with a daily mean temperature range between 56°F and 86°F; 81% occurred on days with forty-five miles or less of daily total wind; 90% occurred on days with less than 0.50 of an inch of rainfall; and 87% occurred on days with barometric pressure change between -0.10 and 0.10 inches.

3. On an annual basis, mean temperature and rainfall were associated with 63.7% of the variations in boat launchings. These data inferred

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[2] Ibid., p. 36.

[3] David, Elizabeth, Outdoor Recreation in Wisconsin (Preliminary Draft), p. 1.

[4] Nelson, op. cit., p. 57.

that with a warmer day an increase in boat launchings could be expected and conversely an increasing amount of precipitation would exert a negative influence on boat launchings, especially in the spring and fall.

The importance of temperature and precipitation are substantiated in Nelson's findings for Wisconsin.

Dowell also mentions that boaters in his study showed a strong preference for boat ramps with easy access. Reservoir management was also an important factor in boat ramp use. The presence of flotsam on or near the ramps due to storm conditions meant they were considerably underutilized on such days.[5]

Crapo studied the influence of weather factors on selected recreational activities in several Michigan state parks. The activities studied were sightseeing from car, walking to scenic points, picnicking and swimming. Although he did find variations in recreation use as a result of weather factors, Crapo emphasizes that other variables in addition to those of weather must be included in order to accurately forecast recreational activity choice, e.g. characteristics of park user and park use, origin weather of recreationer.[6] We assume that these variables may also have some importance for recreational boating.

Summarizing these findings and our own, we can make the following tentative statements:

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[5] Dowell, Carrol Davis, The Relationship of Reservoir [Lake Dardanelle] Pleasure Boating to Selected Meteorological Factors (Unpublished Ph.D. Dissertation, Texas A and M University, 1970), pp. 49-53.

[6] Crapo, Douglas M, Recreational Activity Choice and Weather: The Significance of Various Weather Perceptions in Influencing Preference for Selected Recreational Activities in Michigan State Parks (Unpublished Ph.D. Dissertation, Michigan State University, 1970).

1. Boating operators would respond to improved weather forecasts by establishing better management practices and expanding their operations.

2. The public is interested in increasing its participation in recreational boating as a result of such forecasts.

3. The public and the boating operators regard information about temperature and rainfall as important in improved forecasts. Wind information is regarded as slightly less important.

4. Improved weather forecasts will not be the sole determinant of increased recreational boating participation. Such factors as the managerial aspects of lakes, the types of lakes, the personal characteristics of users, and the time of year must also be taken into consideration.

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