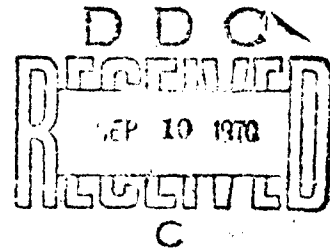


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AN ANALYSIS OF AIRPORT SNOW REMOVAL AND ICE CONTROL

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APRIL 1970

INTERIM REPORT

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<p>16. Abstract This report is divided into two major sections. The first describes an approach using modelling techniques by which airport snow removal and ice control systems may be evaluated on a cost-effectiveness basis, taking into account factors such as the following:</p> <ul style="list-style-type: none"> - airport type, size and structure - incidence of snow and/or icing conditions - volume and type of air traffic <p>As part of the study, a team visited nine representative airports in the United States to observe present day snow removal and ice control practices. The second section of the report discusses the technical characteristics of the equipment and systems observed, as well as the factors mentioned above.</p> <p>The conclusions which are drawn at this interim stage in the study fall into the following three areas:</p> <p>(a) Conclusions regarding the choice of factors which influence system design. These are enumerated and discussed in detail in the text of Section I.</p> <p>(b) Conclusions about current snow removal and ice control practice, and possible improvements which could be made. These are discussed in the text of Section II, and are summarized in Chapter 9.</p> <p>(c) Conclusions about areas where future research in the field of airport snow removal and ice control is desirable. These are also discussed in Section II and Chapter 9.</p>					
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SECTION I GENERAL

1. INTRODUCTION

1.1 Scope of the Study.

The terms of reference in this study were laid down in an Engineering Requirement originated by the Federal Aviation Administration in 1967 as follows:

"This Engineering Requirement specifies the analysis required to describe and define, preferably in quantitative form, those factors which affect designs and applications of adequate systems for removal of snow, ice, slush and standing water from civil airport surfaces. The descriptions and definitions shall treat in detail removal system(s) performance characteristics including specifying the critical and/or limiting factors and the influences, the various physical, operational and environmental factors have on system(s) designs. The removal system(s) recommended shall be applicable for use at the various civil airports throughout the United States and including Alaska. Estimates of initial equipment, maintenance, operating and training costs to implement recommended removal system(s) are also required".

The study is being performed by a consortium of two consultant firms. One, Hovey & Associates Ltd, are specialists in all aspects of equipment utilization, the second, Sores Inc, are specialists in Operational Research. This dual-disciplinary approach is dictated by the nature of the study, essentially a cost effectiveness analysis of snow removal and ice control systems within a total airport/traffic/climatic environment. Such a study requires knowledge both of mathematical modelling techniques and technical characteristics, including costs, equipment performances, and system effectiveness.

The program is jointly sponsored by the Canadian and United States Governments, and its findings will be applied by the following agencies:

Federal Aviation Administration (U S)

Preceding Page Blank

Department of Industry, Trade & Commerce (Canada)

Department of Transport (Canada)

The study was begun in late 1969, and is scheduled for completion in October 1970. The work encompasses the following stages, which are discussed in greater detail in succeeding chapters:

- a) Isolate, define and measure the factors which influence the snow removal and ice control task.
- b) Evaluate cost/performance parameters of equipment for snow removal and ice control.
- c) Design a set of alternative systems and derive cost/effectiveness functions.
- d) Obtain measures of traffic delay costs under alternative airport service level and traffic conditions.
- e) By analysis, determine a set of alternative systems which are optimal.
- f) Establish commonalities to enable generalization to all United States airports.
- g) Submit suggestions by which these systems may be successfully implemented.

1.2 Objective of the Report.

In carrying out this study, the team visited a total of nine commercial airports distributed across the United States during the winter of 1969/70. They were the following:

Logan International Airport, Boston, Mass.

Greater Pittsburgh Airport, Pittsburgh, Penn.

Wold-Chamberlain Field, Minneapolis, Minn.
Greater Buffalo International Airport, Buffalo, New York
Port Columbus International Airport, Columbus, Ohio
Salt Lake City International Airport, Salt Lake City, Utah
Anchorage International Airport, Anchorage, Alaska
Logan Field, Billings, Montana
St. Joseph County Airport, South Bend, Indiana

These airports were chosen as being representative of both airport type and weather conditions existing throughout the United States.

The team was well received by all airport personnel, and given all the assistance possible. This was greatly appreciated and aided the study considerably.

The visits had a three-fold objective:

- a) To learn about existing practice.
- b) To gain an appreciation of the factors which influence their purchasing and deployment decisions.
- c) To derive an approach for analysis of alternative systems.

Having completed these visits it was decided that an interim report describing the information obtained relevant to these objectives would be timely.

1.3 Report Contents.

The structure of this report is intended to reflect the bias towards abstraction which an Operational Research study must provide. Model objectives, evaluation criteria, and a general structure are therefore defined at an early stage (Chapter 2), together with a close specification of factors considered relevant and

therefore scheduled for inclusion in future analysis. Our findings at the airports visited are outlined relative both to factor specification and to their role in future model analysis (Chapter 3, 4, 5, 6, 7, 8).

Such a structure is recognized to possess both advantages and disadvantages in that although it ensures that information noted will be fully relevant to overall study objectives, it does impose very definite constraints on discussion of technical detail. It is considered, however, that the study objectives must dominate the content of our report.

Within the report a number of preliminary conclusions are drawn. Team members are fully aware of the dangers of generalizing about more than three thousand airports after having visited nine of them. Any general statements therefore are made with the provision that the situation may be unique to the locations where it was noted. In other words, a reader may benefit from any of the conclusions if he encounters the problem to which it relates. We do not imply that he necessarily has this problem.

1.4 Future Work in this Study.

During the next six months of the study our major task will be one of quantification, in other words, measurement of factor influences, detailed statements of system cost/effectiveness parameters, and the design of the mathematical model for their analysis. Another important aspect of the work is the generalization of the chosen systems to enable us to make meaningful statements about reality, in this case, the removal needs of a given airport type in a given region, with given future traffic conditions. Thus the final output of this stage will be such a specification of snow removal and ice control systems and the applicability of each one. This will be in a final report.

1.5 Development of Study Results.

An area which must be of vital interest is the ultimate implementation, the translation into action,

of the conclusions of this study. To be avoided is an abrupt ending with the production of a report. Thus, to improve snow removal and ice control practices in airports in order to anticipate the needs of the mid 1970's, it will not be enough to simply circulate a study such as this. Attitudes must be changed. Airports should realize the relevance of this study to their special needs and problems, and should be convinced of the value, within their own context, of the suggested systems.

In this report this question will not be discussed in detail. However some general areas for future work are indicated.

- a) An investigation of possible approaches by which positive change can be shown to be beneficial at the airport level. For example, the possible development of advanced instructional devices, such as:
 - i) Gaming, using a computer simulation model. The development of a computer game as a medium for implementation of the removal systems designed during this stage of the project is a natural future development of the simulation model to be used for system design. A computer game is essentially a technique by which a snow removal controller or airport manager may take decisions regarding the purchase or development of snow removal or ice control machinery. The computer then simulates a real life situation such as a series of storms, and calculates the costs, delays and effectiveness which result from those decisions. Such an application of a simulation model differs from our present use in the following respects:

- a) The player intervenes more frequently in the computing process,
- b) A real airport, hopefully that one for which the player is responsible, can be used, rather than the generalized ones used for system design,
- c) The game can be played at a number of management levels, depending on the responsibilities of the player, and for varying time periods, ranging from one storm to many winters. The choice once again being dependent on the type of decisions taken.

In general, such an approach has proved itself as a teaching device in such varied fields as financial management, urban planning, and war gaming.

- ii) Films to illustrate advanced snow removal and ice control procedures for distribution to airports.
- b) There appears to be a need for a central system for storing information on snow removal and ice control to which individual airports could refer. At present, such information is obtained informally, at annual conferences, for example, or from equipment manufacturers. These sources may frequently contain bias.

2. METHOD OF ANALYSIS

2.1 A Statement of the Problem.

A given airport disposes of a certain amount of financial resources to be applied to the provision and operation of facilities for land and air traffic and their passengers. In general, expenditure by an airport on a particular service or facility will result in a proportionate improvement in the level of service provided. In some cases the nature and magnitude of the service improvement will be apparent. For example, increasing the number of aircraft landing gates will enable the airport to handle more aircraft at peak periods by reducing user delay.

A service which many United States airports are called on to provide is that of snow removal and ice control. It is an example of a service for which certain basic questions about the efficiency and effectiveness are not immediately apparent. For example, given that the correct level of service is provided, are we using our resources economically? The reasons for this are as follows:

- a) The measure of service quality has two dimensions, cost and safety. On the one hand, there is the delay and its associated costs which are incurred by user traffic, both aircraft and passenger, if the ability of the airports to accept traffic is impeded by either removal operations or the accumulation of snow and ice. On the other hand, there is an increasing possibility of incidents on landing or take-off due to deterioration of the runway surface.
- b) The effectiveness of expenditure on snow removal and ice control cannot be measured if we take into account only the direct effect

on airport revenues of a given snow removal strategy. In fact, as is pointed out in a study carried out for the FAA in 1964 (see reference 1) an increasing burden of the total cost of snow removal and ice control is borne by airport users, rather than by the airport itself. In other words, if a runway is closed for a period of time to permit clearing, the cost of the resulting delay to users might exceed the costs to the airport of the removal operation. Moreover, due to increasing congestion and larger and more expensive aircraft this divergence in cost has been shown to be increasing.

In general terms therefore, the problem may be formulated thus: how much should an airport spend on the purchase and utilization of snow removal and ice control equipment and methods? To answer this question, a number of others are posed. They are:

- a) What criteria should be used to define the removal task? For example:
 - i) At what accumulation of snow on airport surfaces should a removal operation commence? What quality should be achieved by the operation?
 - ii) To what extent should the removal/control process be permitted to impede the flow of user traffic? In other words, when, for how long, and to what extent should the operation be permitted to affect airport capacity?
- b) Given the criteria and level of service defined above, what equipment should be purchased and how should it be deployed?

2.2 Study Goals and Requirements.

Our objectives are essentially to answer the questions posed above. However, the approach must be constrained by the following considerations.

The results will be generally applicable to all U S commercial airports, even though the questions as phrased above apply to a hypothetical airport. Thus a higher level of analysis is introduced, in that although the study must proceed as an analysis of particular airport structures and their interactions with weather, traffic, and removal and control systems, the results must be capable of being generalized over all types, sizes, and locations of airports, with varying traffic density and composition. The final product therefore must be a set of systems for snow removal and ice control, together with a definition of the airport environment within which they may be used.

Our approach must take into account both an advancing technology in the equipment and techniques of snow removal and ice control and a changing environment within which they will perform. The systems, therefore, must be oriented toward the airport structures and air traffic of the mid-70's rather than those prevailing today.

2.3 Definition of Terms.

In discussing the approach certain technical terms are used, which, unless adequately defined, tend to cloud the exposition rather than clarify it. Those terms which are frequently used in describing systems analysis models are defined on the following pages.

2.3.1 Total System Cost.

This is the sum of two major components:

- a) The financial resources which the airport allocates during a given time period to the snow removal and ice control function.
- b) The costs which are incurred by airport users due to operating delays, resulting from removal operations.

Thus, in theory, the choice of removal system must be that which minimizes the sum of a) and b) above. Consider, for illustration, two extremes: one, if no money is spent on removal it is apparent that the surface deterioration will soon cause the airport to close. Equally obvious, delay costs increase to the maximum for this minimum expenditure on removal. Two: if a very large amount of money is spent on equipment, resulting in a minimal interference with user traffic, then the converse will apply. Hence, the optimal choice will lie between these extremes. It should be noted that the choice of system will be made subject to an externally defined criterion for safety. Thus all systems considered will be acceptable from a safety stand-point. No attempt, therefore, to trade safety against cost will be made.

It has been suggested that loss of revenue by the airport should dictate the levels of expenditures on a removal system. This criterion will not be used, for the following reasons:

- a) The objective of an airport is not to maximize revenue. At all airports visited, the stated objective was to provide air transportation service for the city or region in which it was located. Financially, their goal was merely to equalize direct revenues and expenditures in the medium to long-term. Thus service to users rather than revenue loss is indicated as a

meaningful measure of their performance.

b) Loss of revenue is not a consistent measure of service provided. For example, in the short-term, revenue from concessions will probably increase with delay, since departing passengers will spend more money while waiting. Furthermore, delays will not result in any loss in landing fees, since the aircraft must come down eventually. The only loss will be due to diversion or cancellation. In the long-term, of course, consistently poor service will result in a decrease in air traffic. This, however, is difficult to measure.

c) From the standpoint of the Federal Aviation Administration, which is concerned with all aspects of air transportation, airport user costs must be taken into account. Three recent airport studies carried out for the FAA have taken this approach (see References 5, 8 and 9). The criterion to be used for evaluation therefore, will be that system which minimizes airport and user costs.

2.3.2 Snow Removal and Ice Control System Costs

These consist essentially of the following components:

a) Fixed and variable costs of machinery, cost per ton of chemicals, etc.

b) Charges associated with the housing or storage and maintenance of machines or chemicals.

c) Labor costs incurred.

d) Costs associated with controlling snow removal and ice control operations.

These must be expressed in terms of both annual costs and costs per operating hour.

2.3.3 System Effectiveness.

Our study objective is to devise systems which will provide certain levels of security and delay to traffic. Effectiveness is the measure by which we check the extent to which our goal is achieved. In this use effectiveness will be measured by the time period which a given system requires to restore a snow or ice covered runway to full operating capacity. Thus, for example, the more rapid the clearance process the more effective the system. At the extreme a prevention system is most effective since zero time will be required for clearance. In this study optimum effectiveness is the result of a trade off between system costs and user delay.

2.3.4 Machine Performance.

Performance of a machine is its ability to do a given job within a system, where effectiveness must be ultimately a function of the performances of the various machinery of which it is composed. As an example, the performance of a snow blower is defined by its speed, width of cut, and distance of cast when working on snow of a stated range of depth and density.

2.3.5 Task.

This defines the nature and magnitude of the job to be done. The task is specified by, and is sensitive to, the criteria chosen and the service required. For example: the runway clearance task could be stated thus, to reduce snow cover on a 10,000 foot runway from a two inch depth to "blacktop" within, let us say, a thirty-five minute interval.

2.4 Detailed Approach.

Having defined the terms, the approach may be described in greater detail.

2.4.1 Definition of System Task.

An airport will generate annually a number of snow removal and ice control operations or tasks.

A statement of these tasks will depend on:

- a) Weather conditions at the airport; number of tasks per year.
- b) The structure of the airport; size of task.
- c) The safety criteria which specify the task; number of clearances within a storm.
- d) The level of service to user traffic which the airport offers; period runway is closed.

Note that the first three may be measured and specified externally, but the last one must be derived from analysis.

2.2 Definition of System Parameters.

In order to carry out the task the airport will possess a snow removal and ice control system. Many types of system are possible, each one different both in cost and effectiveness, depending on the capital cost of the equipment used, the cost of operating, the skill with which the removal strategy is planned and implemented, and the performance characteristics of the machines.

2.4.3 Derivation of Total System Cost.

The level of service, in other words, the extent to which traffic may be interrupted and delayed is also a function of the needs of aircraft and passenger traffic. Thus the busier an airport is, the higher the level of service to be provided. Here is a conflict, since the

airport must either spend more money or use existing equipment more efficiently, if it wishes to improve the service level and hence reduce the delay costs carried by aircraft and their contents. Therefore a balance must exist between the amount the airport should spend and the delay costs incurred. Our model will attempt to calculate it based on an assessment of total system cost.

2.4.4 Summary of Analysis.

Our approach therefore implies the following stages:

- a) Isolate, define and measure the factors which determine the task.
- b) Evaluate the cost/performance parameters of equipment for snow removal and ice control.
- c) Combine equipment and ways of using them into a set of possible systems and establish system cost-effectiveness.
- d) Obtain measures of traffic delay under alternative service/traffic conditions.
- e) Hence, derive that system and service level for which total system costs are a minimum.
- f) Finally, establish commonalities so that the results may be expanded for all classes of airports within the United States. In other words establish bases by which the derived removal systems can be generalized meaningful to all North American commercial airports.

2.5 The Model for Evaluation of Alternate Systems.

The questions which the model must answer have been posed in a preceding section. The need for a modelling approach to analyze alternative snow removal and ice control systems, rather than the usual approach is specified in our terms of reference. It is not felt to be necessary, therefore to justify the approach to be described in this section.

2.5.1 Stages in Model Design.

The general stages which describe the model building procedures are:

- a) The isolation, statement and measurement of all factors which affect the design and choice of snow removal and ice control systems on airports affected by snow and ice.
- b) A statement, in terms of a model or set of interacting sub-models, of the relationships between these variables.
- c) The derivation of a set of optimal systems, using these models.

It should be noted that upper and lower bounds constrain the number of systems derived. On the one hand, to derive a system for each airport in the United States would be excessively time-consuming and unrealistic. On the other hand too few alternative systems could not be realistically generalized.

d) The preparation of test procedures whereby the greater efficiency and effectiveness of the proposed system may be demonstrated, thus ensuring their acceptance and eventual implementation by commercial airports.

The "test plans" should, as their primary object, convince airport management of the usefulness to their own operation of the proposed systems. We must search for techniques by which all those responsible at both field and management levels, may learn for themselves the benefits of change, should change be necessary, in their snow removal and ice control practices. This aspect, dealing with the procedure for implementation of our findings, will be expanded upon in the final report.

2.5.2 Factor Definition and Measurement.

The factors which affect the snow removal and ice control operation on airports are:

a) Weather Conditions:

- i) Annual occurrence of snow storms and icing conditions.
- ii) Intensity of snowfall within the storm.
- iii) Ambient temperature and wind conditions.
- iv) Time of day of storm occurrence (if not uniformly distributed).
- v) Forecasting capability at location.

b) Traffic Intensity and Composition:

- i) Average hourly volumes.
- ii) Magnitudes and timing of peaks and troughs.
- iii) The composition of traffic.
- iv) Propensity of traffic to stack, divert or cancel.

c) Airport Structure.

- i) Number of runways.
- ii) Alignment of runways.
- iii) Length, width, navigational category, and aircraft usage of runways.
- iv) Number and type of turnoffs.
- v) Length of taxiways.
- vi) Area and shape of ramp.
- vii) Area of car parks and access roads.
- viii) Existence of central runway, touch-down, and turnoff lighting.
- ix) Position and height of edge lighting.

d) Characteristics of Equipment and Methods of Operation.

- i) Cost/Performance particulars of machines/chemicals.
- ii) Adaptiveness of machines to non-snow removal and ice control tasks.
- iii) Working life of equipment.
- iv) Limits imposed by tasks on machine/chemical utilization.
- v) Safety devices and technical characteristics of machines.

e) Characteristics of Removal and Control Systems.

- i) Effectiveness of machine combinations.
- ii) Manpower requirements:
 - number of men
 - shift/overtime work system
 - salary and skill levels
- iii) Definition of priority areas.
- iv) Clearance criteria.
- v) Pattern of interference of the removal or control methods with traffic movement.
- vi) Direction and nature of information flow between aircraft, traffic controllers and task co-ordinators; operators and forecasters.
- vii) Maintenance and storage policy for machines and chemicals.
- viii) Division of task responsibility between airlines, concessionaires, and the airport.
- ix) The effect of regional/state and municipal constraints on purchasing and deployment of system components.

2.5.3 Model Design.

The method of analysis of these factors is illustrated by figure 1. The procedure requires the use of three models. These are structured as a general model for system analysis

using outputs provided by two nested sub-models. The models are:

a) Model for Total System Planning:

The objective of this model is to derive a set of snow removal and ice control systems, clearance criteria, and levels of service sufficient in number to generalize realistically for all airports encountered.

i) Inputs:

Those factors which describe: weather, airport structure, traffic delay/cost functions (an output of sub-model 2) and system cost/effectiveness parameters (an output of sub-model 1).

ii) Output:

A specification of that system and service level which minimizes total system cost, assuming that clearance criteria are externally specified by safety considerations.

b) Sub-Model 1 - Cost/Effectiveness Model of Alternative Removal Systems.

The objective of this model is to specify the fixed and variable costs of a given system admissible for study; i.e.: whose effectiveness will meet the level of service requirement. In other words, if the service level demands clearance within 30 minutes, the chosen system must achieve this rate.

i) Inputs:

Characteristics of equipment and methods of deployment.

ii) Output:

Cost/Effectiveness characteristics of snow removal and ice control systems.

c) Sub-model 2 - cost model for user delays:

The objective of the model is to derive measures of waiting time and cost for reduction in the capacity of the airport which will result both from accumulation of snow and ice on surfaces and the removal operation.

i) Inputs:

Traffic intensity and composition.

Airport capacity or acceptance rate as a function of the level of service and clearance criteria.

ii) Output:

Traffic delay and associated cost.

2.5.4 Modelling Techniques to be Used.

a) The system planning model will use simulation as the analytic technique. Airport, safety and weather parameters will be externally specified, while system and user delay input parameters will be produced as outputs on the two sub-models. The model will then simulate alternative removal systems and traffic interruption patterns (service levels) until that combination is found which is optimal with respect to total system costs (removal cost plus user costs).

b) The cost/effectiveness model will not contain mathematical optimization techniques. Our experience in this area will be relied upon to construct the necessary functions, using as building-blocks the cost/performance characteristics of removal equipment and control methods.

c) The delay-cost model will be based on the techniques provided by Queueing Theory, making use, if possible, of work already carried out for the FAA in the field of airport capacity measurement (see Reference 1, 2, 9).

SYSTEM PLANNING MODEL (OBJECTIVE : TO SELECT A SYSTEM & SERVICE LEVEL FOR A

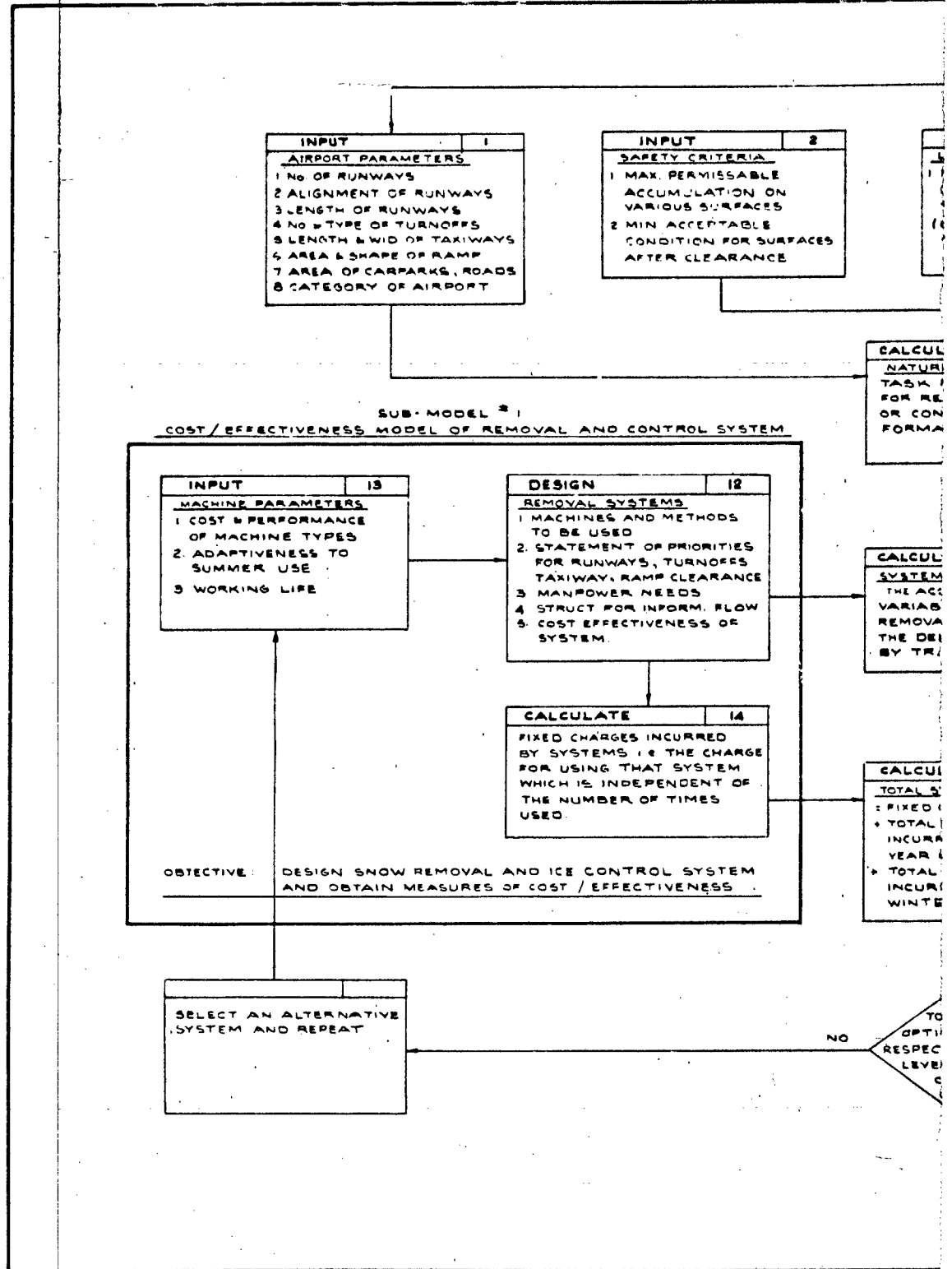


FIG. 1
 MODEL STRUCTURE FOR ANALYSIS
 FOR SNOW REMOVAL AND ICE CO

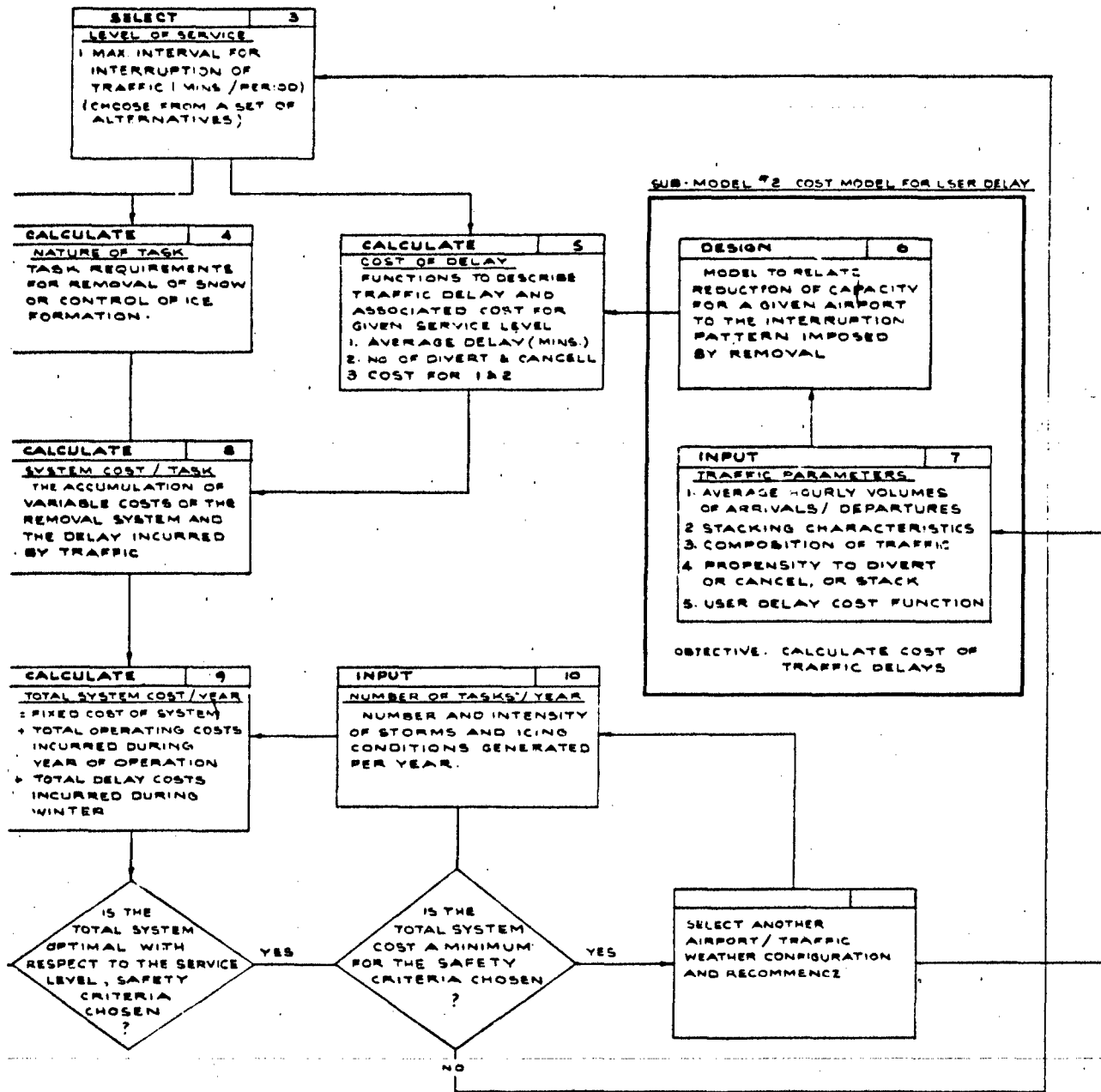


FIG. 1
ANALYSIS OF ALTERNATIVE SYSTEMS
ICE CONTROL ON AIRPORTS

SECTION II AIRPORT VISITS

3. INTRODUCTION

Nine airports in the United States were visited during a period of just over four months, during the winter season of 1969/70. These airports were, in order of decreasing hub classification:

a) Large Hub

- i) Logan International Airport, Boston, Mass.
- ii) Greater Pittsburgh Airport, Pittsburgh, Penn.
- iii) Wold-Chamberlain Field, Minneapolis, Minn.

b) Medium Hub

- i) Greater Buffalo International Airport, Buffalo, New York
- ii) Port Columbus International Airport, Columbus, Ohio.
- iii) Salt Lake City International Airport, Salt Lake City, Utah.

c) Small Hub

- i) Anchorage International Airport, Anchorage, Alaska.
- ii) Logan Field, Billings, Montana.
- iii) St. Joseph County Airport, South Bend, Indiana.

Up to two days was spent at each airport by the three-man study group. The questions asked were intended to elicit information in three areas:

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- to learn about existing snow removal and ice control methods and procedures at United States commercial airports.
- to gain an appreciation of the factors which affect purchasing policies and deployment decisions.
- to devise an approach to our analysis of alternative systems which will be realistic and which will provide results capable of implementation.

Our questions, therefore, were initially devised in order to provide a strategic appraisal of the nature and quality of information available at the airports visited. As the visits progressed our approach was modified. For example, it became clear that the information collected by the United States Weather Bureau and the Federal Aviation Administration in the area of task incidence and traffic behavior was as complete and more accessible than that tabulated at the airports. Our questions in these areas were, therefore, minimized. It was also found that the generally pragmatic approach of airports to buying and deployment decisions did not lend itself to a highly structured questionnaire approach and our technique was altered accordingly. Again, the gradual emergence of certain factors and the discarding of irrelevant ones tended to modify our approach, highlighting some problem areas and eliminating others.

What we have learned about the relevance of certain factors and their analysis is described in Chapter 2. Chapters 3 through 8 describe the knowledge we have obtained about present practices. Since these airports were intended to be representative of all United States airports it will not be necessary to refer to them individually. Each provided information which enabled us to draw certain conclusions.

As mentioned previously, the team was highly impressed with both the level of co-operation and general competence shown by all airport personnel interviewed. Such readiness to put immediate pressures aside to provide information was greatly appreciated by the study team.

The remainder of this report will discuss our findings according to a structure provided by the general factor classification given in the previous chapter (see Section 2.5.2). Thus the relevance of our findings to future analysis is emphasized. It may also be useful to cross-reference to the model description of Figure 1. It should be kept in mind that this model is intended to be a copy of the real-life situation. Thus the proposed model of the decision-making process also describes what presently happens on airports. However, it is very general and cannot incorporate all the refinements which at the operating level make each storm a unique emergency situation.

4. AIRPORT STRUCTURE

4.1 Relevance to Model Design.

The factors which describe the structure of an airport affect both the choice and the deployment of the removal system. On one side of the maximum capacity, in terms of number of operations per hour, depends primarily on such basic parameters as:

- a) Number, alignment, and length of runways.
- b) Number and type (high-speed or conventional?), of turn-offs.
- c) Area of ramp.
- d) Navigational category of airport.

A snow condition and its subsequent removal is basically evaluated from the point of view of the reduction in capacity which is engendered, and hence the accumulation of traffic delay.

Airport structure will also play an important part in the decisions associated with the purchase and utilization of equipment. For example, the existence of runway centre lighting, which in turn creates a need for certain equipment and operating methods. In other words, task definition must hinge on the extent and nature of operating surfaces. The factors to be discussed are those which best describe and measure this aspect of the snow removal and ice control task.

4.2 Structure of Airports Visited.

That section of the airport structure which essentially dictates the airport snow removal system is the layout of the landing area. Obvious factors such as the number and size of runways and taxiways contribute to the total area

to be cleared and thus have a definite bearing on the task, but other less easily defined factors must also be considered. For example the relative alignment of runways to each other plays a very important part in determining the snow removal techniques to be used.

4.2.1 Runway Alignment.

Parallel main runways, for example, result in a reasonably straight forward job of snow clearing if traffic is such that one of the parallels can be closed for clearing while all traffic uses the other. Intersecting main runways, however, result in a situation where for a definite period of time both runways are affected simultaneously by the snow removal crews. On busy airports it may be impossible to perform the intersection clearance between flights, therefore costly delays will result.

4.2.2 Location of the terminal relative to runways.

The position of the main runway(s) in relation to the terminal is also important, since this affects the length of taxiway that it is necessary to clear in conjunction with the main runway(s). It can also result in a larger number of intersections requiring clearance. For example, if the terminal is located between two parallel main runways, it can be seen that no major intersection clearance problems will arise. On the other hand if both parallels are located on the same side of the terminal building, taxiways from the outer parallel will cross the inner one, resulting in intersection clearance problems.

4.2.3 Shape and Area of Ramps.

The second main area of an airport which causes removal problems is the ramp and terminal. In the majority of cases, airport designers seem to have neglected snow removal considerations altogether when laying out terminals and ramp areas. Ramp areas on the majority of airports which

we visited, averaged 2 million square feet. With a 3" snow fall weighing 8 lbs per cu ft, this results in a half-million cubic feet of snow weighing 2,000 tons. Even considering that the snow could compress to 32 - 35 lbs per cu ft as it is handled by the removal equipment, the resulting amount would be 125,000 cubic feet, still an appreciable volume. If terminal and ramp areas are not designed with the removal and storage of these amounts of snow in mind, expensive double handling needed by hauling and melting procedures result.

Often, however, the proximity of taxiways and runways to the ramp area results in insufficient grass area for snow storage. In addition, the shape of the ramps and terminals necessitates bulldozing or hauling of snow for large distances before the storage areas are reached. This occurs where the aircraft loading gates branch out from long "fingers" which jut out from the main terminal building. U shaped areas result, and prevent the snow from being plowed progressively in one direction.

These two main problem areas, however, are a direct result of airport design, and cannot be economically remedied except in cases where a new airport or a major expansion to an existing airport is being built.

4.2.4 Runway Lighting

Lesser features affecting snow removal on airports are such things as runway centreline "flush" lighting and touchdown lights. These lights are not in fact perfectly flush with the runway surface, and therefore pose a problem. Various methods are used to cope with clearance of these lights at the airports which we visited. For example, plows equipped with rubber blades were commonly used. Runway sweepers were also considered useful for this task. One feature which proved beneficial to snow removal at a few airports was the existence of a paved area up to and outside the runway or taxiway edge lights. This was sub-paving only, not usable by aircraft, but capable of supporting the snow

removal equipment. This made the removal of snow from around the edge lights considerably easier than where the lights were set outside the paved area.

4.2.5 Condition of Surfaces.

Airport maintenance also plays a large part in snow removal, and this is an area which can be changed or improved, if required. Cracked and uneven asphalt and concrete surfaces on an airfield can result in either damage to snow removal equipment or in the slowing down of the removal to allow for the possible damage of hitting a raised section of pavement. Other slightly raised obstructions such as manhole covers are also a very real hazard that could be corrected. On one airport, we witnessed a plow strike a manhole cover at approximately twenty MPH, throwing the cover twenty feet into the air over a distance of forty feet. This occurred on a general aviation parking ramp, and the dangers of such a situation are evident.

4.2.6 Existence of Debris.

Such items, as aircraft wheel chocks, empty mail bags, construction material, and any number of different types of objects were found on the ramps of various airports. In general these were the property not of the airport but of the airport users. The danger of damage to equipment or injury to personnel when an item such as an aircraft wheel chock is inadvertently ingested by a snow blower is great.

4.2.7 Explanation of Table 1.

The adjoining table gives a comparison of the relevant structural features of the airports visited. The airports are arranged in decreasing order of the number of scheduled air carrier operations per year (using 1968 statistics).

Within each airport, the runways are listed in

order of decreasing length. On any runways with displaced thresholds, the length given is the total length of pavement, since this is critical to the effectiveness of snow removal systems.

The "Priority 1" column gives an indication of the runways considered to be of highest priority, both from the point of view of air carrier operations, and of snow removal. Similarly, the "Priority 1 length" column gives the amount of taxiway necessary for full operation of the Priority 1 runways. Where a runway has an Instrument Landing System (ILS), in one direction, that heading has been underlined. For example, the entry runway 15R-33L at Boston, shows that it is runway 33L which is equipped with the ILS.

The number of turn-offs has been calculated using the ILS or the highest priority heading for each runway. In addition, the assumption has been made that turn-offs closer than approximately 4,000 feet from the threshold will not be used except on runways used primarily for general aviation. Thus, although at Boston, runway 33L has eight turn-offs, three are too close to the threshold to be used when landing from the 33 end of the runway and the usable number of turn-offs is therefore shown as five.

AIRPORT		RUNWAYS All 150 feet wide								TURN OFFS		TAXIWAYS		RAMP	PANCAP
HUB	NAME	Number	Length (ft)	Priority 1	With ILS	Centre Lights	Touchdown Lights	Intersections with runways	High Speed	Normal	Total Length (feet)	Priority 1 Length (feet)	Area (square feet)	Practical Annual Capacity (operations per year)	
L	Boston	15R-33L	10,100	x	x			3	1	4	48,200	23,800	7,170,000	288,000	
		4R-22L	10,000	x	x	x		2	1	1					
		4L-22R	7,850					2	1	2					
		9-27	7,000					2	1	1					
		15L-33R	2,500					2	-	1					
L	Pittsburgh	10L-28R	10,500	x	x	x	x	-	4	-	50,600	23,600	1,983,000		
		10R-28L	10,000	x	x			2	1	4					
		14-32	6,700					2	-	4					
		5-23	5,800					2	-	3					
L	Minneapolis**	11R-29L	10,000	x	x	x		1	1	3	48,400	23,600	2,180,000	350,000	
		4-22	7,300	x	x			2	-	4					
		11L-29R	6,200					1	1	1					
M	Buffalo ***	5-23	8,100	x	x	x	x	1	2	1	22,200	9,800	855,000	200,000	
		13-31	5,400					1	1	2					
M	Columbus	10R-28L	10,700	x	x			3	2	2	31,100	12,000	2,186,000	350,000	
		10L-28R	6,000					-	-	2					
		13-31	5,000					3	-	2					
		5-23	4,400					3	-	2					
		1-19	3,400					3	-	1					
M	Salt Lake City	16R-34L	10,000	x	x			-	1	2	34,000	13,800	2,100,000		
		16L-34R	8,600					-	-	2					
		14-32	5,500					-	-	2					
S	Anchorage	6-24	10,600	x	x			1	-	4	25,500	14,000	2,646,000	175,000	
		13-31	5,000					1	-	2					
S	Billings	9-27	8,600	x	x			2	-	3	15,700	10,900	849,000		
		4-22	5,700					1	-	2					
		16-34	5,600					1	-	1					
S	South Bend	9-27	6,000	x				3	-	2	9,700	8,200	546,000		
		6-24	4,000					3	-	2					
		12-30	4,000					3	-	1					
		18-36	3,000					3	-	1					

* Runway 4R-22L has centreline lighting only 2500 feet up to the displaced threshold.

** Runway 11R-29L is 200 feet wide.

*** Both runway 5 and 23 are equipped with ILS and centreline lighting, however 23 is of higher priority.

TABLE 1
Aspects of Airport Structure
Relevant to Snow Removal and Ice Control

5. WEATHER

5.1 Relevance to Model Design (See Block 10).

This factor is one of the most critical descriptors of the system task. Essentially, it is the pivot about which the total system cost will revolve, since the number of snow removal and ice control tasks occurring in a year at a given location will dictate the level of investment in removal equipment, and the annual capital charge for ice control sensors, compounds, and chemicals.

There are many different measures of weather and hence a wide range of possible estimators for system task. During one of our visits it was noted, for example, that the manufacturer of a certain piece of removal equipment had used "inches of snow per year" as a basic task estimator. Such a measure in our opinion is biased towards overstatement, since it could be hypothesized that if the total snowfall occurred frequently in small quantities, then few tasks will occur, due to removal by jet blast, or by natural melting.

Our estimator for snow removal task, therefore, should allow for the following observed phenomena if it is to be realistic.

a) Accumulation at temperatures over 32°F will be slower than at lower ones, particularly if the rate of snowfall (inches per hour) is low, due to melting.

b) It was observed that jet aircraft act as quite effective removal devices during low snowfall rates and for low ambient temperatures when the snow is dry. We can conclude, therefore, that there exists a rate of fall and temperature below and above which respectively a task will not be generated.

The estimator of ice incidence, and hence the control task, is quite complex, since ice occurrence interacts strongly with both the snow removal system and the volume of traffic. Interaction with the former comes from the

fact that, if a surface is not completely cleared of residual snow and a sudden drop in temperature occurs, a serious icing problem will ensue. The latter interaction is a result of the compaction effect of aircraft, together with the melting - refreezing of residual snow caused by jet blast on take-off.

Our requirement, is for an unbiased estimator of weather conditions and hence of system task. Thus, in the next stage of our study, a number of estimators will be statistically verified and the best chosen.

The snow removal task is highly sensitive to the clearance criterion chosen, in other words, the depth at which an operation must take place. Thus the greater the accumulation permitted before clearance, the less the number of tasks generated during the year.

At this stage of our study, task criteria have not been set and we will use a commonly accepted criterion, namely that runway clearance should take place when the accumulation reaches $1\frac{1}{2}$ " of snow. Note, however, the choice is arbitrary.

The incidence of icing conditions can be measured apart from interaction phenomena, directly from Weather Bureau data. To calculate task incidence it will be assumed that a condition existed at the time when any of the following weather phenomena were noted:

- glaze
- freezing rain
- freezing drizzle
- sleet

Having derived the best estimator it will also be necessary to relate it to some easily measurable weather index for each region, since it is probably that the estimators chosen will not be readily generalized because they would be time consuming to calculate for each airport. Thus some correlation analysis will be carried out in the next stage to relate task occurrence to such indices as snowfall and average temperatures.

5.2 Weather Characteristics of Airports Visited (See Table 2)

Weather, or more specifically, the incidence of snow and ice in quantities capable of impeding aircraft operations, is highly variable both between and within locations in North America. It is, however, closely documented and, since weather conditions do not change markedly over the years, is also highly predictable in general terms. Not so predictable is the incidence of tasks for snow removal and ice control. This is due to two considerations:

- a) Task definition depends on how the task is defined, and cannot be estimated independently.
- b) The nature of the task is affected by numerous additional variables, such as:
 - i) ambient temperature: the higher the temperature the more efficient the self-removal process due to melting. The ambient also affects the density of the snow.
 - ii) strength and directions of wind determines the extent to which drifting, as opposed to normal accumulation, is encountered.
 - iii) relative humidity affects the density and hence the weight of snow to be moved.

TABLE 2

TABLE SHOWING SALIENT ASPECTS OF THE WEATHER ENVIRONMENT AT AIRPORTS VISITED

Location of Airport	No of Storms over 1.5"	Av. winter Ambient		Inches of Snowfall in '67/68 (inches)	Average Annual Snowfall (inches)	Snow Removal	Ice Control
		Max of	Min of				
Boston	10	43	29	44.8	40	27	9
Pittsburgh	10	44	26	50.5	39	26	6
Minneapolis	2	38	17	17.2	40	5	17
Columbus	7	45	27	32.2	29	17	10
Salt Lake City	17	48	31	74.2	52	50	2
Buffalo	13	36	23	80.5	109	29	13
Billings	13	44	25	48.0	55	23	4
South Bend	17	41	26	62.4	35	31	8
Anchorage	17	30	18	75.4	74	42	4

NOTE: Data based on the winter of 1967/68

Reference: Local climatological data - Environmental Data Service

iv) predictability can vary from location to location. For example, one airport located on the East coast was subject to relatively infrequent but intensive storms moving in from the sea with short advance warning.

v) number of storms: whether a given volume of snow is deposited in a small number of heavy storms or a large number of light ones is important. It was observed that the cumulative strain of a long drawn out operation can cause fatigue to both machines and operators which may ultimately result in system breakdown and airport closure.

A general set of descriptors of weather conditions existing at the Airports visited is provided in Table 2. As may be expected, considerable variation exists between airports. In addition, the danger of drawing conclusions about task incidence from one year of weather data is emphasized. For example, the snowfall in Minneapolis for the winter 1967/68 was only 17.2 inches compared with an average annual snowfall of 40.0 inches. It is possible that the size distribution of storms will be a useful general descriptor of the size of the task.

6. TRAFFIC

6.1 Relevance to Model Design.

An airport exists to provide service for aircraft and their passengers and cargo. Thus, all facilities, such as number and size of runways, number of gates, capacity of terminals, etc are designed as a function of the expected demand for service. The design choice is always constrained in the same manner: excess capacity implies a high level of service, but also a high investment requirement: under provision of facilities will result in the formation of queues for service and the accumulation of waiting-time and cost by aircraft and passenger traffic.

A completely analogous decision is posed by the design of the snow removal and ice control system at a given airport. The choice of a system implies some degree of interference with the normal flow of traffic, in other words, a reduction in the capacity of the airport. At the extreme, no system for removal would result in a rapid reduction to zero of airport capacity during the winter months. Conversely, an instantaneous system, (such as a perfectly reliable prevention method), would have no adverse effect on capacity.

To arrive at an optimal system, therefore, we must take account of the effect on traffic, specifically the changing waiting time and cost for alternative levels of service. The effect on traffic is complex, and thus requires a sub-model for analysis. For example, if the peak arrival rate at an airport exceeds a certain level, aircraft will be forced to stack. If the capacity/demand ratio is further reduced because of snow or ice closing one or more runways, the waiting time can be shown to increase dramatically, probably causing diversions. On the other hand, if an airport is operating well below capacity, partial or complete shut-down of a runway may have little or no effect on waiting-time. Thus, the objective of the model is to predict waiting-time, based on inputs describing traffic, airport capacity, and level of service.

In addition, the model must predict the cost of this delay. This cost is a function of the number and type of aircraft waiting, and the number of passengers delayed. To provide an idea of the magnitude of these costs, it has been estimated (References 5 and 8) that a large four engine jet will incur a cost of \$900.00 per hour delayed, while the cost for each of its passengers will be \$7.00 per hour.

When predicting delay patterns another factor should be noted, namely, the increasing separation between arrivals and/or departures while snow is accumulating on airport surfaces, due to both reduced visibility and reduced traction. In discussion with tower personnel it was mentioned that time spacing between operations could lengthen from about 50 seconds to 90 seconds during a storm (see also Figure 2). This implies, at full capacity, a considerable reduction in the airport acceptance rate which must be taken into account in the model.

6.2 Traffic Characteristics at Airports Visited (see Table 3).

6.2.1 Average Hourly Volume (Column 6)

As might be expected, the average hourly volume varied among the airports visited. Of more significance to our analysis was the proportion of general aviation activity, which varied between 32% and 81% of hourly operations.

6.2.2 Peaking Characteristics (Column 4)

The magnitude and time of occurrence of the peak period exerts a significant influence on the deployment of the removal system. It was observed, for example, that the removal system controller was generally reluctant to interfere with traffic during peak periods, usually occurring between 1600 - 1800 hours, preferring rather to delay cleanup until traffic activity lessened.

TABLE 3

Table showing air traffic characteristics at airports visited.*

Location of Airport	Hub Class	Annual Growth Rate %	AIR CARRIER		GENERAL AVIATION No of ops. in av. hr. hour	TOTAL Ops. in average hour	% traffic General Aviation %	% traffic Commercial Propeller %	% traffic Commercial Jet %	Calculated delay cost per minute**
			No of ops. in av. hour	No of ops. in peak hr.						
Boston	L	11	23	55	11	34	32	14	54	7.67
Pittsburgh	L		17	38	12	29	41	18	41	6.17
Minneapolis	L	8	13	30	20	33	61	2	37	5.19
Columbus	M	9	8	39	32	40	80	6	14	2.63
Salt Lake City	M	10	7	26	24	31	77	8	15	2.80
Buffalo	M	9	9	20	9	18	50	11	39	5.71
Billings	S		3	17	13	16	81	7	12	2.43
South Bend	S		3	13	12	15	80	11	9	2.18
Anchorage	S		5	17	12	17	71	14	15	3.00

* All estimates filed year 1968

** Aircraft only, passenger costs excluded

It was noticed also that general clean-ups of surfaces were often postponed to the "trough" period, between 0100 - 0500 hours, when the number of operations are negligible for all airports visited. Air carrier activity during the peak hour was frequently intense relative to the average hour, the multiplicative factor ranging between 2 and 5. General aviation peaks are even more intense. However, it was observed that these peaks occur in general during the summer and thus are irrelevant to our study. It is unlikely that, during a storm, general aviation activity during the peak period will exceed that in the average hour, since general aviation activity tends to decrease when IFR conditions prevail.

6.2.3 Composition of Air Traffic (Columns 7, 8, 9).

Jet aircraft now dominate air carrier activity. However, at many airports, general aviation operations were predominant. The composition is the major determinant of the delay cost incurred by user traffic, and hence of total system cost. An estimate of airline cost is provided in reference 8. When applied to the traffic composition at the airports visited we obtain an estimate of delay cost (see Column 10).

An interesting variation between airports is apparent, from \$2.18 per aircraft per minute delay to \$7.70. It should be kept in mind that passenger time costs, a function of aircraft capacity, load factor, and individual delay cost have not been included. These will tend to further spread the estimates. To be noticed also is the correlation between hub class and delay cost of traffic. This will help future generalization of the results.

6.2.4 Waiting Behavior.

It appears that the maximum delay which an aircraft arrival will tolerate is about 30 minutes, after which the aircraft will divert (thus incurring a cost which has been

variously estimated at from \$4,000.00 to \$20,000.00). Departures are naturally more flexible. It was observed that in many cases it was possible to predict a temporary closure sufficiently in advance to warn incoming flights before they have left the preceding airport, thus reducing delay costs and the possibility of a diversion. In the case of airports which served mainly as stop-overs on through flights, it could be hypothesized, although no quantitative evidence was obtained, that an airline will be more reluctant to accept stacking and will prefer to overfly to the next stage of its route. Finally, it was noticed that airports which view themselves as key locations will place an even greater emphasis on maintaining this service capability. An example of this was provided by Anchorage, which is an important stop-over and refuelling point for international flights between Europe and Japan.

6.2.5 Calculated delay costs at Selected Airports (see Table 4).

As mentioned previously, the extent of the delay induced at a given airport is a function both of the existing level of congestion and the level of service. A number of the airports visited were therefore evaluated from the point of view of existing congestion (obtained from reference 8) and a hypothetical closure pattern for snow removal, assumed to be 15 minutes in a one hour period. The marginal increase in average delay per aircraft was calculated (Column 5) and the cost per operation and total delay cost of the strategy derived (Columns 6 and 7).

The existing degree of congestion (and the marginal increase resulting from temporary closure) was established by comparing the annual operations at certain airports with their practical annual capacity (PANCAP), and by using the delay curves provided on page 2-6 of Reference 8.

This measure of airport capacity is highly relevant to our work. Its derivation and application are described in Reference 1, 2, 8.

TABLE 4

Table showing the accumulation of delays and the associated costs for selected airports based on the level of congestion prevailing in 1968.

Location of Airport	Annual No of Ops. (1968)	Practical Annual Cap. of Airport (PANCAP) (Ops./year)	Level of Utilization of airport (No. of Ops.) Capacity %	Level of Utilization resulting from 15 min. closure for snow removal	Approximate delay per Op. caused by snow removal (Min./aircraft)	Approximate delay costs resulting from 15 min. clearance policy
Boston	296,976	288,000	103	137	14.2	3,670
Minneapolis	290,937	350,000	83	110	4.3	726
Columbus	346,196	350,000	99	132	9.3	1,000
Buffalo	154,803	200,000	77	102	2.7	270
Anchorage	150,495	175,000	88	117	5.0	255

Within the airports selected Boston is of the greatest interest. The high cost of any traffic interference pattern such as will be caused by snow clearance results primarily from the already high demand/capacity ratio. Thus, any interference will dislocate traffic considerably. Another determinant is the high value of traffic in Boston, due to a preponderance of commercial jets. Buffalo illustrates a converse situation in that in general the airport is not over-loaded. Thus a fifteen minute closure will not cause a high additional level of delay. In addition, due to a higher proportion of general aviation, delay costs of traffic are lower in Buffalo. In conclusion, it should be noticed that the analysis described above is purely for illustration. More detailed analysis of the cost consequences of delay will be undertaken in the next stage of the study.

7. SNOW REMOVAL AND ICE CONTROL EQUIPMENT

7.1 Relevance to Model Design.

It is apparent that machines and chemicals are the building blocks of our systems. Equally important are the variables which define their applicability, i.e. cost and performance.

7.1.1 Cost should be considered in two parts, namely, fixed (capital investment) and variable costs. Fixed costs, i.e. that which will be incurred whether or not the equipment is used, play a major part in the buying decision. Variable costs, usually calculated per operating hour, influence deployment decisions.

a) Fixed costs normally include the following components:

- i) Price
- ii) Expected working life
- iii) Cost of capital invested
- iv) Adaptiveness to other work

Adaptiveness is an important factor in our study. Since snow removal and ice control tasks are only encountered for at most six months a year, whether or not the machine can be usefully employed during the summer months will determine the fraction of the capital cost charged to the snow removal tasks. For example, a fully adaptive machine will require only 50 percent of its cost to be charged to the winter job. A completely specialized one must be fully charged.

b) Variable costs include:

- i) operating costs
- ii) maintenance and repair costs

At the majority of the airports visited it was found that costs associated with their snow removal and ice control operations were not easily accessible. This was due to the fact that the normal accounting procedure allocated these costs to general centres such as "airfield maintenance". The time required to separate out the costs of interest to us would have been impractical. However, to illustrate the order of magnitude of costs presently incurred, the replacement cost of snow removal and ice control equipment at each airport has been calculated and ranked. For comparison purposes, some crude measures of major factors which influence system cost have also been noted and ranked. (The results are shown in Table 5).

Examination of the table shows that slight correlation exists between the investment of an airport in equipment and the size of the job to be done. Considerable variation exists. Boston, for example, ranks low on investment despite large surface areas and heavy traffic. Buffalo, on the other hand, leads in investment but is low on task. To be noted, is the extent with which, for all airports, investment increases with snowfall. This would seem to indicate that this factor has played a major part in past equipment purchasing decisions.

In general, by applying a simple "rank-difference test", i.e. by subtracting the rank of each factor from the corresponding investment ranking for each airport, the following tentative conclusions may be drawn:

- a) Snowfall is the major (and the only statistically significant) determinant of the level of investment in equipment.
- b) The areas of runways and ramps may have some marginal influence on the equipment purchasing decision.
- c) The level of traffic at an airport seems to have no apparent influence on the purchasing decision.

TABLE 5

Table comparing investment in equipment at airports visited
with the size of their removal task.

Name of Airport	Replacement value of equipment \$	R*	Runway Area sq ft	R*	Ramp Area sq ft	R*	Snowfall inches per annum	R*	Traffic Operations Ave hour	R*
Boston	450,000	6	5,617,500	1	7,170,000	1	40	6	34	2
Pittsburgh	521,000	2	4,950,000	2	1,982,800	6	39	7	29	5
Minneapolis	505,250	4	4,025,000	4	2,180,000	4	40	5	33	3
Buffalo	589,000	1	2,025,000	8	855,000	7	109	1	18	6
Columbus	213,000	8	4,423,500	3	2,185,875	3	29	9	40	1
Salt Lake City	452,000	5	3,615,000	5	2,100,000	5	52	4	31	4
Anchorage	507,000	3	2,340,000	7	2,645,500	2	74	2	17	7
Billings	254,700	7	3,135,000	6	848,500	8	55	3	16	8
South Bend	141,000	9	2,006,000	9	546,100	9	35	8	15	9

* Ranking by size

It appears, therefore, that the terms of reference of our study, are particularly timely. According to Reference 6, the costs incurred by airport users will exceed by a factor of five the costs of snow removal and ice control incurred by airport operators during the mid-70's. Traffic levels should influence equipment buying decisions. One of the goals of our study is to establish the extent.

7.1.2 Performance measures essentially the potential contribution of a given equipment piece or ice control material to total system effectiveness. The definition of effectiveness, therefore, dictates how performance is stated.

During the visit it was evident that at most airports a gradual transition, from the older slower, high capacity types of equipment to the newer high performance machines, was being accomplished. Older machines such as rotary snowblowers - many with over 25 years service - were being replaced by rotaries of vastly improved design and with much higher snow removal capacities and operating speeds. Similarly the older snowplow units - vehicle and plow - are being replaced by more powerful units capable of far greater speed, fitted with high performance versatile snowplow attachments. A general impression of the equipment profiles of each airport visited is provided by Table 6.

7.2 Observed Limitations on Machine Performance.

It is a truism to state that theoretical performance figures provided by manufacturers will often greatly exceed those practically obtainable. Frequently observed also is the fact that operators, due to unique conditions prevailing at their airport, or due to a misunderstanding of operating procedures, tend to utilize equipment at rates and in ways which do not conform to those recommended. It was not part of our mandate to comment exhaustively on existing snow removal and ice control practises, however,

TABLE 6

TABLE SHOWING EQUIPMENT PROFILE OF EACH AIRPORT VISITED

	Number of Snow-plows (Including special ramp plows)	Number with Rollover plow	Number with Reversible plow	One Way Plow	Number with Wings	Number of Rotary Sweepers	Number of Low Speed Rotary Snowblowers	Number of High Speed Rotary Snowblower	Number of Folding Wing Plows	Ramp Plows (Special Push Plows Mounted on front End Loader)
Boston	9	5	0	4	0	2	4	1	0	0
Pittsburgh	5	3	0	0	1(*)	4	1	3	2	0
Minneapolis	9	0	7	0	0	1	3	0	1	1
Buffalo	7	5	1	0	1	3	3	1	1	0
Columbus	10	0	10	0	0	1	2	0	0	0
Salt Lake City	12	0	7M	2	1	2	3	0	1	2
Anchorage	7	0	0	2	0	3	1	2	0	3
Billings	7	0	5	2	0	2	2	0	0	0
South Bend	4	0	2	2	0	0	2	0	0	0

M - Manual Reversible - All others Power Reversible

* - One Wing - Plow on each side

a number of situations were observed whose discussion may be of interest to people involved with snow removal and ice control.

7.3 Snowplow Carrier Vehicles.

At all airports visited it was noted that conventional dump trucks in sizes ranging from 20,000 to 54,000 GVW (Gross vehicle weight) of either 4x2 or 4x4 drive (two-wheel or four-wheel drive), are being used as snowplow carriers. The reason for their popularity is that they can be used for a multitude of purposes on an airport. In the winter, in addition to accommodating plow units, they may also be readily equipped with sand spreaders or be used as snow haulage vehicles. For the remainder of the year, with plow and/or sander removed, the carriers may be used for any number of haulage tasks. Only two other types of plow carriers were noted during the visit: the carrier for the 24 ft folding plow and the carrier for the side roto-wing plow. In the first instance the carrier is especially designed for snow removal and as such is not used for any other purpose. Similarly the carrier for the roto-wing requires a permanently installed auxilliary engine, and since this engine is mounted on the rear of the chassis in place of the dump box, the carrier is not readily convertible for summer use.

It was noted that the interior of the cabs of the newer carriers were of improved design, well appointed and comfortable. The newer cabs have adjustable well padded seats, easy to operate vehicle and plow controls, and good heating and ventilating systems. Some of the latest carriers have automatic transmissions which have proved popular and well suited for snowplow operation.

Cab position of most snowplow units used at the airports visited, are of the conventional cab-behind engine design, which somewhat hampers the operators forward visibility. For example, when equipped with a low profile plow, the engine hood of the vehicle invariably restricts the operator's view of the plow. In some cases plow flags are

used so that the operator can determine the position of his plow. On the other hand the new cab-over engine rotary snowblowers facilitate unrestricted operator visibility. The late model 24 ft folding wing snowplow unit, also has an excellent cab forward design. In this unit, even though the folding wing plow is large, it is relatively close-coupled with its carrier vehicle so that the operator has a clear view of his plow and is always aware of its position. When asked their opinion of the cab-forward design, all operators, without exception, stated that they much preferred cab-forward vehicles to the conventional cab-behind-engine carrier vehicles.

7.4 4x4 and 4x2 Snowplow Carriers.

4x4 carrier with reversible plow .. Cost \$36,000. (average)

4x2 carrier with reversible plow .. Cost \$12,000. (average)

At three of the larger airports visited it was noted that heavy duty carriers of 36,000 to 54,000 GVW 4x4 drive are being used primarily for clearing the runways and taxiways. All of these high performance machines are equipped with either a rollover or a reversible plow. For airport snow removal it was the consensus of snow removal personnel that these snowplow combinations were efficient and versatile and well suited for the task of rapidly removing newly fallen snow from the runways and taxiways.

At one medium hub airport, lighter 4x2 drive carriers of 20,000 to 30,000 GVW, fitted with reversible plows are being used mainly for high speed runway and taxiway snow clearing.

At another airport, located in the medium snowbelt it was reported that of the two types of snowplow units used for runway snow removal, the lightweight snowplows are preferred over the heavy duty plow especially for removing light snow accumulations. The reason given was that the lighter plows are easier to manoeuvre and are far more economical to use than the heavier units. When one considers that under the present runway snow removal requirement where snow should be removed progressively, rather than being permitted to build up, the concept of using lightweight,

powerful and fast snowplow combinations is thought to have considerable merit. It was noted that a number of airports were using a combination of lightweight and heavyweight snowplows with reportedly good results.

7.5 Snowplows.

7.5.1 Rollover: Cost \$4,700.00

Rollover snowplows, primarily designed for use on large carrier vehicles, are used on many airports for high speed airfield snow removal. By means of a rotating mechanism, the plow can be positioned so that it can plow snow to the right or left as desired. In operation the plow moldboard cleanly casts snow up to 30 feet. Although particularly suited for airfield work this plow design does not incorporate a safety trip feature, so it is not suited for use on other than smooth paved surfaces. At all airports where they are used, it was reported that the rollover plows are excellent performers, well suited for airfield snow removal.

7.5.2 Reversible: Cost \$1,800.00

Reversible snowplows are used extensively for airfield snow removal. There are reversible snowplows of various moldboard sizes and designs available, but those used on airports are generally 10 - 11 feet wide and from 48 to 60 inches high. The moldboard may be of the manual or power reversing design to facilitate plowing snow to the right or left. The plow may be angled up to 37 degrees to the left or right and also positioned straight across to permit the use of the plow as a bulldozer, a feature that is useful in pushing back snow piles at runway intersections, and in clearing confined ramp areas, parking lots and other areas where a straight plow is more useful than angled plows. Normally reversible plows have a safety trip device to prevent damage to the plow should the cutting edge strike an obstruction. At either the extreme right or left plowing position the 11 foot wide plow clears a path of approximately 9 feet. Most reversible plows are equipped with either a fixed or adjustable snow deflector to aid operators vision while plowing.

7.5.3 One-Way Plows: Ccst \$1,200.00

The one-way plow, designed for use on carrier vehicles of all sizes is primarily used on roads and highways. Because the plow is non-adjustable it lacks versatility and therefore is not entirely suited for airfield use. The plow is usually rigidly mounted with the moldboard positioned to plow snow only to the right. The shape of moldboard is generally rectangular but many tapered one-way plows are also being used. At one airport visited for instance, one-way tapered plows are being used for high speed runway snow removal and are mounted on a machine which also has a side wing. It was reported that this combination operates efficiently, despite the fact that it is difficult to eliminate "deadheading". (Since one-way plows are restricted to plowing to one side only, any operation which requires progressive movement of the snow in one direction results in "deadheading", or return trips on which the plows cannot operate).

7.5.4 Side Wings: Cost: One wing and main plow - \$6,900.00

With two wings - \$9,300.00

In addition to a conventional plow unit, some large carriers are equipped with either one or two side wing plows in order to achieve a greater clearing width. Although only one side wing is common, some carriers are equipped with two side wings for use in unconfined areas such as runways, taxiways and ramp areas. Side wing equipped carriers have also proved invaluable for tapering oversize snow-banks along runway and taxiway edges. (At only one airport visited is the side wing used for tapering snowbanks, even though there was evidence at other airports that the tapering of snowbanks should be employed). It is also felt that where heavy carriers are used for airfield snow removal, greater utilization of these machines could be achieved by the addition of a side wing.

At one major airport for example, a 44,000 GVW carrier equipped with a rollover plow and two side wings is

being used effectively for runway, taxiway and ramp snow removal. When used for runway snow removal, this unit clears a path approximately 20 feet wide. Considering that approximately eight such passes would, with only one wing, complete the clearing of a 150 foot wide runway, it is apparent why a wide plow unit is useful for airfield snow removal.

At another airport three heavy duty carriers with large tapered one-way plows, are also equipped with powered side (roto) wing plows which are mounted on the right side of the carrier in such a way as to be an extension of the main plow unit. In operation each unit is capable of clearing a path approximately 17 feet wide and "casting" the snow 40 to 50 feet. When used for high speed runway snow removal these units were reported to be efficient and when operated in light snowfall conditions did not require the assistance of heavy duty snowblowers to throw the snow off the runway. As a combination high-speed plow and rotary snowblower, this unit is said to be suitable for runway snow removal at this airport which is located in the medium snowbelt.

7.5.5 Folding Wing Plow: Cost \$49,000.00

Three-section, folding-wing plows, 24 to 28 feet wide mounted on special purpose heavy-duty 4x4. 50,000 GVW carriers, are currently being used at four of the nine airports visited, for clearing ramps, taxiways and runways. According to reports, these extra wide plow units are proving particularly useful for feeding snow to the rotary snowblowers, which work more efficiently when operated in other than shallow snow depths.

It was also reported that when working in snow depths up to 10 inches, the folding wing plow can achieve speeds up to 13 MPH while clearing a path 17 feet wide with plow angled.

The only unfavourable comment about the performance of the folding wing plow reported, was that the plow harness and push frame required reinforcing to be able to withstand heavy duty work. Other than this problem, all users reported that the unit is well suited to airfield snow removal.

7.6 Rotary Snowblowers.

For airport use three types of rotary snowblowers are currently in general use. These are:

7.6.1 The High Speed Rotary Snowblower - Cost \$77,000.00

This dual-purpose machine is primarily used for removing newly fallen snow from priority airfield surfaces at relatively high operating speeds. Normally the unit when used in combination with high speed snowplows, progressively picks up and casts the snow accumulations entirely off the airfield surface. This feature eliminates unnecessary snow rehandling and ensures maximum equipment operating speeds. This machine is also used for removing deep or heavy windrowed snow when required.

High speed all-purpose rotary snowblowers are used at three of the airports visited. The users reported that the machine worked well under all snowfall conditions, but with some qualifications. There were some reports about minor mechanical faults, but nevertheless these machines were reported to be a decided improvement over the older, slower, heavy-duty snowblowers. Because the newest rotaries can achieve far faster operating speeds, runway clearing using high-speed plows and these new rotaries in combination, has made it possible to reduce snow handling and eliminate the use of the slower machines from runway surfaces.

7.6.2 High Capacity (Low-Speed) Rotary Snowblowers - Cost \$35,000.00

This type of general purpose machine is designed primarily for removing heavy accumulations of deep or windrowed snow.

Each airport visited had two or more of these snowblowers, which are being used for a multitude of tasks, from removing windrowed snow from runways, taxiways and ramps to clearing intersections and loading snow hauling vehicles.

At airports where the high-speed rotaries are also available, however, the slower machines are used mainly for clearing secondary airfield areas. Their low operating speed when used on runways retards considerably the clearance operation.

7.6.3 Attachment type Rotary Snowblower -
Cost \$8,000.00 - Medium Size.

Self-contained rotary snowblowers are available for use on front end loaders, fork lifts, road graders and other general purpose equipment. Attachment type snowblowers are particularly suited for use in medium to light snowfall areas as back-up machines for use in emergency conditions. Only two of the airports visited have rotary attachments. At one location two of the three rotaries used are of the attachment type and are said to be capable of performing a multitude of snow removal tasks. At this airport, the two rotaries are installed on road graders for winter use and are removed when no longer required.

At one other airport one medium size rotary attachment is being held in "immediate readiness" condition. If required the rotary attachment can be quickly mounted on the front of a road grader.

7.7 Rotary (Runway) Sweepers: Cost of towed type \$18,000.
Self propelled \$67,000.

Rotary sweepers were designed for all-season airfield maintenance and as such are capable of thoroughly removing dirt, debris, surplus water, snow and slush from the paved surfaces used by aircraft.

When used for dry sweeping, they can maintain speeds of 20 to 25 MPH. When used for snow or slush removal, where only the plow residue is to be removed, sweepers are capable of thoroughly cleaning a path of 12 foot width at an average speed of 12 MPH. When deep snow or slush is to be removed it is necessary to plow aside the surplus snow before the sweeper is used. This performance is achieved by the use of a plow equipped tow vehicle at two of the airports visited, with reportedly excellent results. At one airport this system is employed continuously, and they report that as a result

faster overall snow removal is achieved and it is possible to maintain the runway in blacktop (Summer) condition throughout the winter. In this regard it is found that on many airports, sweepers are not being used for other than dry sweeping or loose sand removal. In most instances it was reported that the sweepers are not used because they are too slow, and generally retard the entire snow removal effort, especially on the high priority areas. There is considerable evidence however that had sweepers been employed correctly, as mentioned above, the use of sand and other methods needed to recover traction, could have been largely eliminated.

7.7.1 The Use of Rotary Sweepers.

During the visits to the airports it was found that different opinions existed regarding the utilization of rotary sweepers. Some airports considered the sweeper to be the most important item of snow removal equipment, and included sweepers in all snow removal and ice control operations. Other airports seldom if ever included sweepers because of their low operating speed. All agreed, however, that for other than winter use, the sweepers were very useful for removing dirt, debris and surplus water from airfield surfaces.

At the airports visited, only towed rotary sweepers are being used, although it is known that self-propelled rotary sweeper units are being used on other airports. Irrespective of type, rotary sweepers were designed primarily for clearing light accumulations of snow, slush, water and debris at a fairly fast operating speed. If attempts are made to remove deep snow or slush accumulations, the broom assemblies become overloaded and the sweeper can no longer maintain speed.

In talking with the various operating personnel, it was apparent that there has been some misunderstanding concerning the use of rotary sweepers and their operating limitations. Apparently, sweepers have been operated at some airports in heavy snow and slush accumulations (over 1 inch) and have thus been reduced to a crawl. In this regard it was found that updated sweeper operating procedures were lacking and this had

led to many of the problems and misunderstandings.

In reviewing operating limitations with key personnel, they stated that the sweepers could be put to more use in the snow removal, if their speed could be increased. One airport reported that although they were quite aware of the sweeper capabilities, their presence on the runway could not be tolerated due to the fact that during adverse weather conditions only the main instrument runway was in use, and the sweeper units could not maintain a faster speed than 15 MPH when sweeping snow or slush, however, another airport reported that by using medium duty plow-equipped vehicles to tow the rotary sweepers it was possible to maintain an average speed of 20 MPH when removing newly fallen light snow residue.

7.7.2 Rotary Sweepers - Modifications.

One or more towed type rotary sweepers were available at all but one of the nine airports visited. Most of the sweepers were five or six years old and except for one or two airports it was noted that none of the essential modifications developed since manufacture had been incorporated. For example, engine block heaters had been installed on sweepers at only one airport, even though block heaters are essential for sweepers that are stored outdoors. In this regard one of the main complaints regarding sweepers concerned "hard starting" of the engine throughout the winter even in moderate temperature conditions.

Another serious deficiency, which has influence on sweeper operations, is the design of the original remote control box. Because of recurring problems, a modified remote control box of quick-connect design employing toggle switches (as replacement for the original "dimmer-switches") and the addition of an engine tachometer was developed by the manufacturers. The tachometer replaces the original one mounted on the engine control panel which had proved useless because of its location. Moving the tachometer to the remote control box, which is placed in the cab of the towing vehicle, provides the driver with an accurate means of gauging his best operating speed under every condition. At some airports, however, there was no knowledge of these modifications.

7.8 Snow Melters.

Permanently installed snow melting pits were observed at only one of the airports visited. Very little information about the performance of these units was available other than that they were located in the aircraft loading area and were of very limited capacity (50 - 75 tons per hour). They cost approximately \$15,000.00 per unit. Despite this low capacity, it was reported that under heavy snowfall conditions the melting pits were useful even though the consumption of the huge snowpiles required a considerable time.

Two portable snow-melter machines were also used at the same airport but again very little information as to their capabilities or performance was available. It was reported that the value of these machines lay in the fact that they could be transported to any problem area on the airport.

Portable melters are usually loaded by front-end loaders. It was said that the most serious drawbacks of these machines are their low capacity, and the problem of getting rid of the resultant water.

At one other airport, interest was expressed in portable snow melter machines. They felt that such a machine could be required to get rid of snow from certain confined and congested ramp areas.

Considering the general interest in snow melting systems for airports it is suggested that this may be another area where research to determine the feasibility and overall benefits of such systems would be of value to all concerned. Their use is of course determined by the marginal value of airport land compared to the costs of this technique, which exists essentially to save on land consumed for snow storage and on men and machines used for snow hauling.

7.9 Adaptiveness of Snow Removal Equipment.

There is an obvious cost advantage for the buyer of equipment capable of being used for different tasks. Where

snow removal equipment is concerned, this feature can directly affect the buying decision. For example, a machine which costs \$80,000. and has a ten-year life will cost approximately \$10,000. per annum to own, if interest charges are included. If this machine can be used over a full year rather than the winter months only, then the charge to snow removal will be halved. It is important to keep in mind, however, that two conditions must exist before a machine be considered adaptive:

- a) That it be capable of doing other work.
- b) That other work exists for it to do.

It must also be remembered that single-purpose equipment is generally more effective than one which has been devised for a multiple role.

In regard to off-season use of major items of snow removal and ice control equipment, it was noted that some airports had obtained equipment types that could be readily converted to off-season use. For example, at one airport only one of the three rotary snowblowers was of the single-purpose integral design with the result that after the winter season only this machine has to be placed in storage. The other two machines, using the "attachment type" snowblowers, could be returned to their normal all-season airfield maintenance tasks. Similarly, most of the snowplows could be removed from the dump body carrier vehicles enabling these trucks to be used as normal haulage vehicles.

All-season utilization of snow removal equipment seemed to be the policy of most of the airports located in the light to medium snowfall areas. On the other hand two airports located in the heavy snowbelt area explained that their policy was not to use the major snow removal machines such as plow carriers, for any purpose other than snow removal. Summer use was thus deliberately avoided, to enable preventative maintenance to be carried out, and to reduce cumulative wear.

It was also noted that in the heavier snowbelt areas, the trend in rotary snowblowers was to the heavy duty,

integral type, rather than the "attachment type" rotaries, which having no function other than snow removal, can be serviced and stored in the off-season.

Rotary sweeper units are designed for all-season maintenance of airfield surfaces. When more than one sweeper is available however, only one machine is used for other than winter maintenance. The other machines are normally serviced and placed in storage until needed again.

To summarize the question of adaptiveness of snow removal equipment, it appears that the policies followed by the airports visited seemed to be realistic. In general, it is suggested that at small and medium hub airports located in areas of low annual snowfall, the policy of dual purpose snow removal equipment, with emphasis on attachment rotary snowblowers and the use of light, fast "off-the-shelf" snowplow carrier vehicles, would seem to be a practical approach to consider.

On larger airports in high snowfall areas, an adaptive equipment policy is not to be discounted, however, traffic needs demand that reliability of equipment be high and thus a policy of operating non-adaptive equipment becomes admissible, to obtain maximum effectiveness and reduce the possibility of delays due to breakdown.

7.10 Life of Equipment.

In general, equipment used in snow removal and ice control is long-lived, due mainly to the following factors:

a) Total working hours may be less than would be expected for a given age, since their working year is only about five months long, and usage is only intermittent during those months.

b) Over a twenty-year period almost every detachable part will be replaced. In fact, after this time the original machine will have been gradually rejuvenated.

c) Technological change in snow removal equipment and methods has been slow. Thus complete obsolescence is not likely, and a twenty-year old machine is remarkably similar in specification to this year's model.

During the visits to the airports it was evident that although there was every evidence that the older types of snow removal and ice control equipment were being gradually replaced, there was a reluctance on the part of certain airports to part with some vintage equipment (see Table 7). This is understood in part when one considers the mechanical condition of these machines. As a rule they are well maintained, and in many cases, such as where more powerful replacement engines have been installed, these machines have a greater snow removal capability than they originally had. Many of the machines and plow types are considered by many to be quite equal to the task for which they are used, so it is understandable why there is a reluctance to retire the older types in favour of machines of relatively unknown capabilities and high cost.

In regard to rotary snowblowers, especially to those machines produced over 10 years, it should be realized that under the existing requirement for more efficient snow removal in support of ever-increasing jet aircraft activity, much more efficient equipment is required, with the emphasis on high-speed, rather than heavy duty high-capacity capability, which was once the main requirement. No longer can machines that remove windrows of snow at speeds of 2 - 3 MPH be tolerated on busy runways, where traffic delays are costly. Since equipment that is specifically designed for high speed airfield snow removal is now available, it can be predicted that transition to new equipment will be more rapid in the future, if only because increasingly high labour costs of maintaining obsolete equipment will justify replacement.

7.11 Maintenance and Storage Policy for Machines.

A good maintenance and storage policy implies the existence of the following conditions:

TABLE 7

TABLE SHOWING THE AVERAGE AGE AND OTHER CHARACTERISTICS
OF SNOW REMOVAL AND ICE CONTROL MACHINERY AT VISITED AIRPORTS

	Total No of Snow and Ice Removal Equipment	Number of Machines over 10 years old	Age of Oldest Machine (Years)	Average Age of equipment in use (Years)
Boston	16	3	19	7
Pittsburgh	14	-	5	3
Minneapolis	14	-	9	4
Buffalo	15	7	34	11
Columbus	13	4	28	8
Salt Lake City	18	8	30	13
Anchorage	13	1	12	5
Billings	10	-	10	5
South Bend	7	2	21	7

a) A heated garage facility located reasonably close to the area of operations.

b) Skilled well-equipped manpower.

c) An information system to monitor the usage of each machine together with its maintenance history, such as maintenance costs and times to failure of key parts.

d) A policy for preventive maintenance based on information provided by c).

Heated, indoor storage for all major snow removal and ice control equipment was available at two of the nine airports visited. Of the remainder, two have indoor storage facilities for all snow removal equipment except the rotary sweeper units, and five airports have limited storage for equipment other than the bulky machines such as sweepers, snowblowers and heavy duty snowplows, which have to be stored outdoors. Only one airport however, has installed engine block heaters in those equipment normally stored outdoors.

At six airports, the maintenance facility is located relatively close to the terminal area, whereas the other three have maintenance facilities on the other side of the airfield. In one airport for example the maintenance facility is estimated to be over one mile from the ramp area.

At one airport, all but two major items of snow removal equipment are on loan from the military, who share the airfield. All equipment on loan from the U.S.A.F. is repaired and maintained by the military. Of the other eight airports, four service the equipment after winter use and perform routine servicing and maintenance when required throughout off-season operations. The other four airports completely service the machines after winter use and store them for the summer.

Sophisticated maintenance information systems were not encountered at the airports visited. This was due mainly to the fact that the airports felt that the total value of the operations was not capable of justifying such systems.

However, their growth rates are such that eventually computer-based systems will become mandatory if an efficient maintenance policy is to be followed.

7.12 Safety and General Technical Characteristics of Vehicles.

During our visits numerous operational features and trends were noted. Once again some of these were particular to a certain situation, and are thus not of general interest. Only these, therefore, which we feel justify general discussion are outlined here.

It is also worth pointing out at this stage the general lack of a structure for diffusion of information about snow removal and ice control. The need for a formal structure for dissemination of technical information is apparent, since an individual airport does not have such access to objective technical information about modern practice.

7.12.1 Gasoline Versus Diesel Power.

For high speed airfield snow removal it would appear that the use of plow carrier vehicles of 35,000 - 50,000 GVW rating, 4x4 drive and of dump body design is preferred to the lighter units. It was noted that most of the snowplow units are gasoline powered whereas the trend is toward diesel power for rotary snowblowers. One airport reported that they would be replacing all gasoline engines with diesel engines in future.

7.12.2 Automatic Transmissions.

It was noted that automatic transmissions are used in many of the latest snowplow carrier vehicles, and where used, the operators are highly in favour of them. It was also reported that the maintenance on vehicles with automatic transmissions was comparatively low, and it was the general consensus that all snowplow equipment should be so equipped in future.

7.12.3 Constraints on Use of Rollover Plows.

This plow unit was praised by all users for its performance in high-speed runway snow removal. It was said to have excellent snow casting characteristics and no undesirable snow overspray or "water-falling" problems.

This plow does have one drawback however; its design does not include a safety device to absorb plow and harness (or chassis) impact damage, or operator injury.

It is necessary therefore that it be operated on a relatively smooth surface, such as the landing area, especially when operating at high speed. This is not a serious drawback, since airport surfaces normally are maintained in good condition. However, the inferior condition of the ramp area at some airports, leaves much to be desired, and would make it necessary for the rollover plow, if used in such an area, to operate slowly and carefully.

7.12.4 Plow Cutting Edges.

a) Tungsten Carbide Tipped Cutting Edges.

The rollover plow has two cutting edges which normally wear out in a short period, especially if used on concrete surfaces. This is true for all plows fitted with mild steel cutting edges, where replacement normally causes delay and inconvenience throughout the winter.

At one major airport, carbide-tipped cutting edges are installed on all four rollover plows. On inspection, it was noted that very little wear had occurred even though these cutting edges had been used for two seasons. According to the supervisor, the long wearing characteristics of the carbide-tipped cutting edges well justified the additional cost involved. (It has been reported that these edges will out wear normal edges by as much as 30:1).

b) Rubber Cutting Edges.

At several of the airports visited one or more snowplows equipped with rubber cutting edges are being used. At one airport these edges are installed on all three sections of the large folding wing plow, primarily for the purpose of clearing runway lights. It was reported that this plow does a thorough job of clearing the centre-line lights without causing damage. At another airport, because of the problems encountered in clearing centreline lights, rubber cutting edges will be fitted to a rollover plow next season in an attempt to solve this difficult clearing problem. At two other airports rubber cutting edges are fitted on one-way snowplows and are said to be effective for removing wet snow and slush. Paradoxically, one airport reported that they had tried rubber cutting edges but had found them entirely unsatisfactory and had since abandoned the concept. This difference of opinion concerning the value of rubber cutting edges cannot readily be understood. It is thought however, that perhaps the difference in the actual material used and method of mounting may provide a clue. Research in this area would be of interest to all those involved in snow removal and ice control operations.

c) Polyurethane Cutting Edges.

A reversible plow fitted with a polyurethane cutting edge is currently being used exclusively at one airport visited for removing snow from the centre-line lighting system. Because of the resilience of the polyurethane cutting edge, it is said to be an excellent means of plowing over the lights without damaging them.

d) Curved Cutting Edges.

Curved plow cutting edges are installed on all three sections of the 24 foot folding wing plow as original equipment. These cutting edges of reverse curve design, unlike a conventional plow cutting edge, permit a plow unit to travel safely over a low obstruction without

digging in and causing shock and impact damage to the plow or injury to the operator. Curved cutting edges were reported to be a boon, particularly when the plow unit is operated in ramp areas where the paved surface is uneven and sometimes badly in need of repair or has obstructions such as gratings and manholes.

For example, at two of the airports visited, front end loaders fitted with extra wide plows equipped with curved cutting edges, were reported to be extremely efficient for clearing the ramp area. It was also reported that the curved edges had proved superior to the conventional straight cutting edges because of their better wearing qualities and added safety features.

7.12.5 Safety Trip Feature - Snowplows.

With the exception of the rollover and one-way plows, all of the snowplows used at the nine airports visited, are equipped with some form of safety trip feature. This device, as the name implies, is designed to permit the plow to absorb shock without damage. Many forms of trip devices are used but the design generally used is one which permits the plow moldboard to hinge over upon meeting an obstruction. This is usually achieved by spring loading the entire moldboard or hinging the lower section. Reversible snowplows of various types with similar safety devices are in general use at all of the airports visited and are reported to be very effective.

One-way snowplows without a safety device are being used at two of the airports visited but no adverse comments concerning this were reported. As on rollover plows which are also used on airfield areas where the surfaces are generally well maintained, the lack of a safety device was not said to be a problem.

7.12.6 One-Man or Two-Man Snowplow Operation.

At most airports it is the practice to use only one man to operate a snowplow or a rotary snowblower. At two of the airports visited, however, two men are used to operate certain snow removal machines. Where two men are used, one

man drives the vehicle and the other operates the plow controls and the two-way radio. This leaves the driver free to concentrate on operating the vehicle while the second man acts as an assistant and safety lookout. At one airport, the single-man cab of a folding wing plow unit has been modified to accommodate a driver's helper. On this machine the cab was extended so that the helper could sit behind the driver. In the event of an emergency, where the driver may become incapacitated, the helper can cut the ignition by means of an emergency shut-off switch located in the rear cab section. At most airports where the two man system is used, this is the manner in which novice operators are trained to operate the plow unit. At one airport however, a labourer is used as a helper and it was reported that the helper could not become a plow operator because of union regulations.

On heavy duty snowplow carriers where one or two side wings are used and side visibility is restricted, the practice of providing a driver and an assistant is generally considered to be a necessary safety precaution, especially if the unit is to be operated in congested or confined areas. When working on runways and taxiways, such a practice reduces driver fatigue by relieving the driver of some of his tasks such as operating plow controls, monitoring the two-way radio and acting as a side and rear lookout. Where sufficient manpower is available the practice of using operator assistance on the larger snow removal machines is considered justifiable, but not entirely necessary.

8. SNOW REMOVAL AND ICE CONTROL SYSTEMS.

8.1 Relevance to Model Design.

The design of snow removal and ice control systems is a key requirement of our study, whose importance is reflected by its definition as a sub-model.

8.1.1 System design will consist essentially of a specification of the following aspects:

- a) an equipment mix
- b) a labour force
- c) a communications structure
- d) a strategy for deploying resources

8.1.2 System evaluation is carried out by:

- a) testing whether the effectiveness of the proposed system will meet specified criteria for service level and safety.
- b) measurement of the total system cost (costs of removal plus costs of delay) and choice of that system/service level combination for which it is least.

It is apparent that a multitude of descriptors for snow removal and ice control exist. For analysis such as we are engaged in, however, not all are relevant. One of the purposes of our visits was to enable us to perform that sifting which will enable us to concentrate on the essentials. Therefore, our choice of headings within which the many systems observed on our visits are discussed in the next section reflect their relevance to our model analysis.

8.2 System Effectiveness.

The effectiveness of a snow removal operation may be defined by the time period during which traffic is interfered with when a clearance operation takes place. The more effective the system, the less aircraft arrivals and departures will be delayed.

In our present account of practices at the airports visited another factor which also indicates system effectiveness will not be evaluated in detail, but will nevertheless be taken into account in future work, that is, the effect of increasing snow depth on runway capacity. It was observed that separation between aircraft lengthened during the time period from the beginning of the storm to the time of closure. Thus the choice of a criterion depth for clearance can affect effectiveness as well as the safety level. The effect is illustrated on Figure 2, which shows in general terms the changing profile of airport capacity during a storm for a single runway situation. Succeeding sections will only discuss removal system effectiveness from the point of view of the "Minimum Clearance Interval". T.

Ice control methods may be treated in the same manner, even though the aim is generally prevention of ice formation rather than removal. However, even the prevention operation interferes with traffic in that currently, the compound is laid down by an on-runway vehicle, while the resultant surface water is usually swept off after the compound has done its job.

8.3 Estimate of Snow Removal System Effectiveness at Airports Visited.

The following section illustrates our estimate of the effectiveness of the various methods of snow removal in use at the airports visited. Equipment speeds are based on using a start-up criterion of about $1\frac{1}{2}$ " of newly fallen snow, taking into account the fact that as snow is moved across the runway, it becomes both deeper and more dense. The methods outlined are based primarily on information obtained from supervisory personnel directly involved with snow removal and ice control operations at each airport visited. Each of the methods is numbered for report reference purposes.

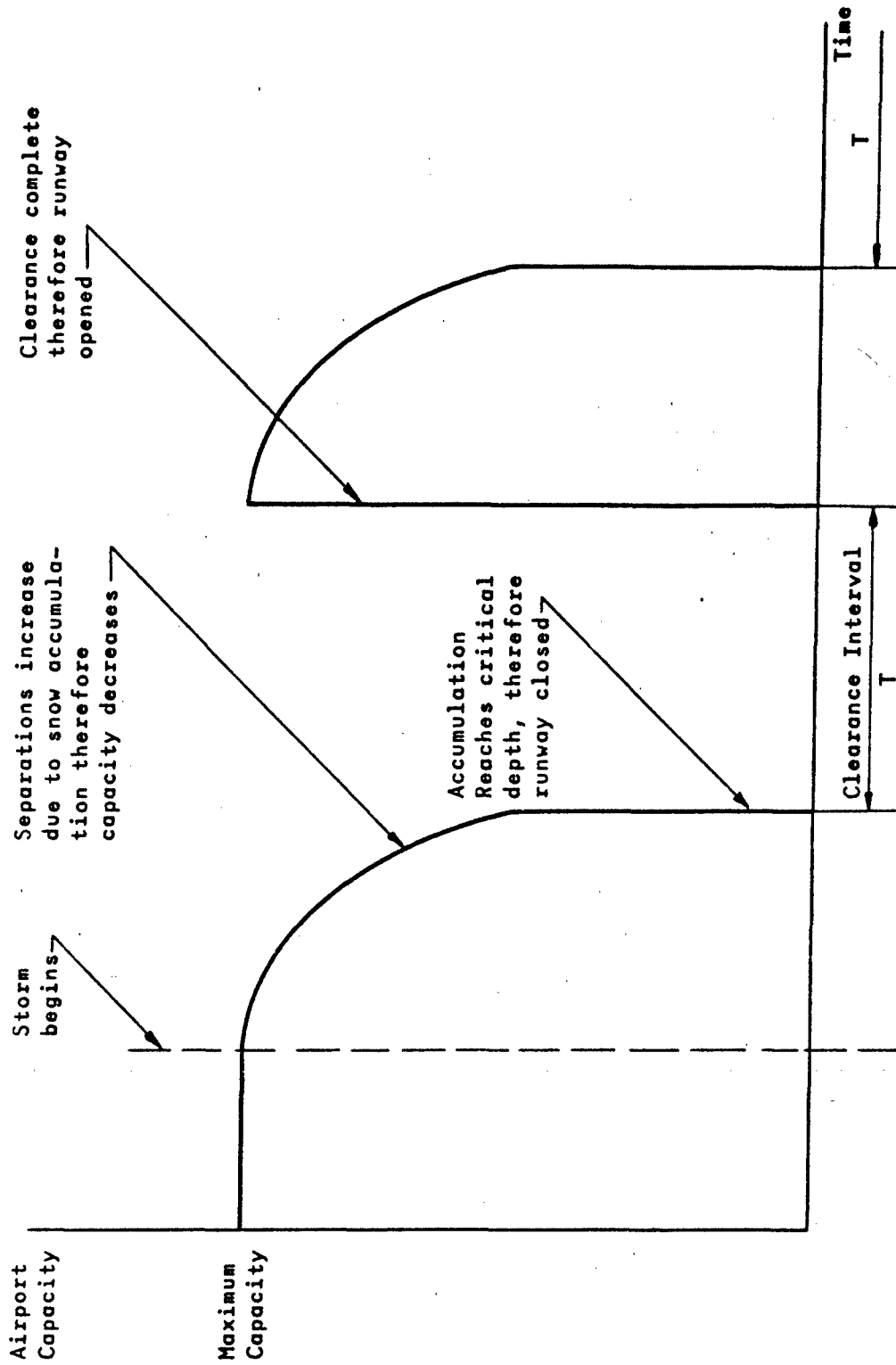


Figure 2

The impact of clearance interval and start-up criteria on airport capacity over the duration of a storm

It should be noticed that the estimates of system effectiveness, summarized in Table 8, are maxima. In other words, turnaround time is minimal (one minute per pass) and it has been assumed that turnoff and taxiway clearance has been simultaneously performed, possibly by the removal equipment while taking up position for runway clearance. In practice, as will be seen in a future section, runway clearance is generally for longer periods, due mainly to additional cleanup tasks to be performed during off peak hours. It should be kept in mind also that such estimates are approximate, and are intended merely to illustrate the principle of varying clearing interval (effectiveness) due to many different equipment types and ways of using them.

8.3.1 Method 1

a) Main Runway Area - 10,100 ft x 150 ft

b) Equipment Used -

Sweepers - none

Plows - Three 10 ft wide rollovers on
50,000 GVW 4x4 dump body trucks

Blowers - none

c) Snow Removal Procedure -

Assuming no severe cross wind conditions exist, the three plows start removing snow from the runway centreline and in an ever-increasing circle, the plows, arranged in echelon, move the snow over to both edges of the runway. On the last pass the accumulated snow is cast entirely off the runway surface and over the runway lights.

It is calculated that travelling at 30 MPH (as reported) the plows will clear a path 25 feet wide (total) for the full length of the runway in 5 minutes approximately. Allowing for additional plow overlapping, it is estimated that the three plows will have to complete six more passes to clear the entire runway width. Allowing for an unavoidable decrease in vehicle speed because of increasing snow weight, it is estimated that the plows maintain an average speed of 25 MPH for the remaining six passes. At approx-

TABLE 8

A summary of the nature and effectiveness of runway clearance systems for each method observed during the airport visits.

Method No	Length of Runway	Minimum Clearance Interval Required (minutes)	Number of High-speed Plows used	Number of Sweepers used	Number of High-Speed Blowers used	Number of Low-speed Blowers used
1	10,100	38	3	0	0	0
2	10,500	27	5	0	2	0
3	10,000	35	5	0	1	2
4	8,100	31	5	0	1	0
5	700	36	9	0	0	2
6	10,000	18	2	2	0	0
7	10,600	30	2	2	2	0
8	8,600	52	4	1	0	2
9	6,000	48	3	0	0	2

imately 5½ min per pass, including the additional time for turnarounds, the three plows could complete clearing of the entire runway in 33 minutes. Adding the time for the first pass, then the total time to clear the runway would be approximately 38 minutes.

8.3.2 Method 2

a) Main Runway Area - 10,500 ft x 150 ft
- equipped with centreline lighting.

b) Equipment Used -

Sweepers - none

Plows - One 10 ft wide rollover on
44,000 GVW with two 10 ft wings
- Two 24 ft folding wing plows on
50,000 GVW carriers

Blowers - Two high speed blowers

c) Snow Removal Procedure -

Assuming no severe cross-winds prevail, the first operation consists of removing snow from the runway centreline lights. This is accomplished by the 44,000 GVW truck and rollover plow with both wings extended. This first step is reported to be performed at 15 MPH. Immediately following, the two 24 foot wide folding wing plow units move the snow further over toward the runway edges, with one plow working on either side of the centreline. After the first pass, a path 60 feet wide will have been cleared (approximately one-third of the runway width).

Following immediately behind the folding wing plows, one on each side of the centreline, the two rotary blowers then pick up the total snow accumulation and cast it entirely off the runway surface. It was reported that the speed of the snowblowers averaged 15 MPH in this operation.

On the second, or return pass, the rollover plow, with only one wing extended, plus the two wide plow units, clear another 54 feet followed by the two rotaries that again throw the snow accumulation off the runway. After this second pass only approximately 36 feet of runway remains to be cleared (or roughly 18 feet on either extreme edge of the runway). One wide plow unit followed by one rotary working on each side finish the entire operation by throwing the last accumulation off the runway and over the edge lights.

Since the rotary snowblowers are used on each pass, all passes are limited at 15 MPH and take approximately 8 minutes.

Allowing for turnaround time therefore, the total time to clean the runway would be approximately 27 minutes.

8.3.3 Method 3

a) Main Runway Area - 10,000 ft x 200 ft
- equipped with centreline lights.

b) Equipment Used -

Sweepers - none

Plows - Five 12 ft wide large molb-board reversibles on 36,000 GVW carriers

- One 12 ft wide reversible with polyurethane blade on 36,000 GVW carrier

Blowers - Two attachment type blowers on road graders.

- One integral high capacity low/medium speed blower

c) Snow Removal Procedure -

The one plow with polyurethane blade is used to make two passes down the centreline to clear the lights at 30 MPH. This clears a 20 ft width. At the same time, the other 5 plows make two 45 ft wide passes also at 30 MPH. Thus a 110 ft width is cleared in approximately 10 minutes, allowing for turnarounds. Two more passes of the 5 plows completes the plowing in 20 minutes (note that on the last pass, two of the plows make backcuts in from the edges to form windrows).

Now the two attachment rotaries at 2 MPH, and the one integral rotary at 10 MPH clear the resultant windrows in approximately 15 minutes.

Therefore the total time to clear the runway would be approximately 35 minutes.

8.3.4 Method 4

a) Main Runway Area - 8,100 ft x 150 ft
- equipped with centreline lighting.

b) Equipment Used -

Sweepers - none

Plows - One 24 ft folding wing plow
equipped with rubber cutting edge
on 50,000 GVW carrier
- Four 10 ft wide rollovers on
42,000 GVW 4x4 dump body trucks

Blowers - One high speed blower

c) Snow Removal Procedure -

Except under severe cross wind conditions, snow removal operations commence at the runway centreline where on the opening pass, the 24 foot wide plow unit with rubber cutting edges (to prevent damage to lights) will clear a path approximately 20 ft wide at an average speed of 15 MPH. The four rollover plow units, two on either side of the runway centreline, then proceed to push the snow towards the runway edges, at an additional 30 ft width per pass. The rotary snowblower follows the plows and picks up and casts the snow accumulation entirely off the runway surface at 15 MPH. With only one available rotary snowblower, the one unit must operate in a path around the centreline in order to remove the snow accumulations from the plow units working on either side of the runway centre. This procedure is followed until the plows and rotary reach the extreme runway edges. At a total of 50 ft per pass, this requires 3 passes.

Therefore the total time required to clear the runway is approximately 31 minutes, allowing for turn-arounds.

8.3.5 Method 5

a) Main Runway Area - 10,700 ft x 150 ft

b) Equipment Used -

Sweepers - none

Plows - Nine 10 ft wide reversibles
on 22,000 GVW carriers

Blowers - Two slow speed blowers

c) Snow Removal Procedure -

To remove snow from the main runway, nine snowplows with a combined effective clearing width of about 80 feet, make two full length (runway) return passes each, commencing at the runway centreline and moving the snow

towards the runway extreme edges at speeds reported to be about 25 MPH with the plows in echelon. In this manner the bulk of the snow is cleared over to the runway edges in approximately 11 minutes (including turnaround time). This snow accumulation now formed into one long windrow along each side of the runway; is then removed by the two rotary snowblowers at an estimated speed of 5 MPH (in light snowfall conditions). Each blower removes the windrow from each side of the runway in approximately 25 minutes.

Therefore the total time to clear the runway is approximately 36 minutes.

8.3.6. Method 6

a) Main Runway Area - 10,000 ft x 150 ft

b) Equipment Used -

Sweepers - Two towed type, pulled by 20,000 GVW dump trucks with 9 ft manually reversible plows.

Plows - Three 12 ft one-way plows on 36,000 GVW 4 x 4 carriers with auxiliary engine and 12 ft "roto-wings". These side wings have a snow casting impeller at their outside edge.

c) Snow Removal Procedure -

During light snowfall conditions, the two rotary sweepers are operated continuously along the runway centreline, in order to keep the painted centreline clearly visible at all times for the pilots of aircraft during landing and take-off operations. Normal sweeping operations are performed in between aircraft operations as often as necessary to ensure the visible centreline condition.

Being plow equipped these machine combinations are able to simultaneously plow and sweep the centre section of the runway without any appreciable decrease in operating speed due to snow accumulation. By using the plow whenever the snow depth reaches one inch, for example, it was reported that the plow/sweeper units are able to maintain a constant 20 MPH speed.

As often as necessary, when the snow accumulation from the sweeper units becomes too heavy, the three roto-wing plows move the snow build-up over to the runway edges where, by the action of the roto-wing, the snow is cast entirely off the runway surface.

Assuming the sweepers clear a total of 20 feet wide along the centreline, during a typical light snow removal operation, the three high-speed plows will be required to clear the remaining runway width of 130 feet. Since the 3 plows can clear a total of 50 feet per pass, allowing for a slight overlapping of the plows, they would be required to make two passes of the full length of the runway. At this point approximately 30 feet of uncleared runway width would remain. This is cleared by two high-speed plows; one along either edge of the runway on the last pass.

The speed of the first pass is limited to 20 MPH by the sweepers, and thus takes 6 minutes. The second and third passes are at 25 MPH and thus take 4½ minutes each. Allowing time for turnarounds, the total time required to clear the runway would thus be 18 minutes.

8.3.7 Method 7

a) Main Runway Area - 10,600 ft x 150 ft

b) Equipment Used -

Sweepers - Three towed-type pulled by road graders.

Plows - none

Blowers - Two high speed blowers.

c) Snow Removal Procedure -

Runway sweeping operations commence as soon as snow starts to fall and continue between landing and take-off operations until the snowfall ends. As often as air traffic permits, the three plow/sweeper units are concentrated on the centre portion of the runway in order to prevent the painted white centreline from becoming snow covered. These three sweeper units with a combined clearance width of 30 ft keep approximately 80 feet of the centre section of the runway entirely free of snow.

It was reported that, under light snowfall conditions, the three road graders, when operated in sixth gear are capable of towing the sweepers at an average speed of 20 MPH.

The total snow accumulation from the sweeper units is continually picked up and cast entirely off the runway surface by the two rotary snowblowers which also operate at an average speed of 20 MPH in this operation. By this means snow handling is minimized and potentially hazardous snow ridges are eliminated.

When snowfall conditions are severe and too heavy to cope with as mentioned above, it was reported that the runway would be closed down so that it could be cleared rapidly without aircraft interruptions. It was stated, however, that runway closure was seldom necessary because of the progressive removal procedures used.

Each pass of the three sweepers and two blowers would clear a 30 foot width in six minutes. The total time to completely clear the runway is therefore thirty minutes.

8.3.8 Method 8

a) Main Runway Area - 8,600 ft x 150 ft

b) Equipment Used -

Sweepers - One towed-type pulled by any available truck.

Plows - One 12 ft wide large moldboard reversible on 42,000 GVW 4x4 drive carrier.

- One 11 ft wide reversible on 54,000 GVW carrier.

- Two 11 ft wide reversible on 36,000 GVW carrier.

Blowers - Two slow speed blowers.

c) Snow Removal Procedure -

Except under severe cross wind conditions, snow removal operations are started at the runway centreline. The four plows split the runway centreline and move the snow outwards toward the runway edges, forming the snow into two long windrows along the full length of the runway. These snow piles are then cast off the runway by the two snowblowers, one on either side of the runway. Once the snowplows have cleared the centre area, the rotary sweeper is used to clear the snow residue towards the runway edges.

If at any time during this operation the snow accumulation from the sweeper builds up to any appreciable depth, the snowplows double back and move the snow over to the windrows. When the sweeper reaches the windrow, the operation is considered complete, at which time the runway is reported to be in "blacktop" condition.

The four plows clear a total width of approximately 35 ft at 25 MPH in 4 minutes. To clear 150 ft, four passes would be required, taking 20 minutes, including turnarounds.

The two blowers, moving at 3 MPH, would then require 32 minutes to remove the windrows.

The total time required to clear the runway is therefore 52 minutes.

8.3.9 Method 9

a) Main Runway Area - 6,000 ft x 150 ft

b) Equipment Used -

Sweepers - none

Plows - One 11 ft wide reversible on
54,000 GVW 4x4 drive carrier.

- Two 10 ft wide one ways on
27,000 GVW 4x2 drive carriers.

Blowers - One slow-speed blower.

c) Snow Removal Procedure -

While the two high-speed plows start to remove snow from the runway centreline outwards, the heavy duty plow makes one 8 ft wide cut along at both sides of the runway, at the extreme edges, in order to form the backcut windrow. The speed of the heavy-duty plow during the backcut operation was reported to be 20 MPH. The two high-speed plows were reported to be capable of clearing an 8 ft wide path at an average speed of 40 MPH on their opening pass. As the snow is progressively moved toward the outer runway edges, it becomes deeper and heavier. As a result the vehicles' speed will be reduced to an estimated average of 20 MPH for the remaining four passes required to complete the runway clearing operation.

The first pass of 20 ft width at 40 MPH, takes 2 minutes. From then on, three plows clear 30 ft per pass, therefore requiring 4 passes at 20 MPH or 18 minutes including turnaround.

The blower, moving at 5 MPH, takes 28 minutes to remove the windrows. The total time to clear the runway is therefore 48 minutes.

8.3.10 Snow Removal under Cross Wind or Shifting Wind Conditions.

Most airports are designed so that the active runway is in the direction of the prevailing winds, therefore on most occasions, snow is removed from the runway centreline outwards to both edges. This method is desirable since the centre section of the runway can be cleared first, permitting aircraft take-offs or landings if necessary. On the other hand, when severe cross winds exist (say over 15 knots), it is necessary to start removing snow from one edge of the runway, and, taking advantage of the wind, to push the snow over to the far side of the runway. The main disadvantage to this method is that as the snow is pushed across the runway, the centre portion will be covered with snow, thus precluding even emergency air operations. In addition, snow must be rehandled more often than in the normal methods. This method however is frequently used at airports where the traffic is very light and speed of snow removal is not essential. The advantage here is that only one windrow of snow need be formed along one edge of the runway for final removal by rotary blowers. (In the parallel or no-wind operation, two windrows are formed, one along each side). At airports where high speed rotary blowers with excellent snow casting capabilities are available, snow removal under cross-wind conditions is not so acute as the snow accumulation is progressively thrown off the surface.

8.4 Clearing of Runway Centreline Lights.

At most airports where runway in-pavement lighting was installed, it was reported that the clearing of the lights had proved to be a difficult problem. Each airport reported that after considerable experimentation with various equipment types, they had adopted what they considered to be the best method. At one airport for example, a plow with a hinged lower section moldboard had been unsuccessfully used and as a result a plow with a rubber cutting edge was to be tested next winter. At another airport it was reported that a wide folding-wing plow fitted with rubber cutting edges, had proved suitable for clearing the centreline lights without damage.

On another airport one special snowplow with a polyurethane cutting edge was used exclusively for clearing the centreline lighting system with reportedly good results. Another airport, however, uses a conventional rollover plow with metal cutting edges for clearing the centreline lights and reported that they had never damaged any of the lights even when plowing over them at 30 MPH. In view of the general comments concerned with clearing snow from runway centreline lights, it is difficult to understand how the latter method has proved satisfactory at this airport but when attempted at other airports, the metal plows had caused severe damage to the lights. It is felt that perhaps the lighting installation of this airport differs somewhat from the other airport lighting systems. At any rate it is the most logical explanation for this paradoxical situation.

One other problem with centreline lights is the prevention of "igloos" of ice from forming around each light. This problem was considered serious at two of the four airports with centreline lighting systems. To date, it was reported that these "igloos" had resisted all removal or prevention methods attempted, though the use of Urea and sweepers had achieved partial success. Since "igloos" also create a hazard to aircraft operations, it is felt that the clearing of runway centreline lighting systems is an area where the results of research would prove helpful to airport operations.

8.5 Estimate of Ice Control System Effectiveness at Airports Visited.

Airfield icing and the various means of combatting this problem was discussed with all those concerned with snow removal and ice control operations at each of the airports visited.

It was reported that although each airport had developed a reasonably effective means of controlling the icing condition, most were considered to be only emergency measures to be discontinued when a better system of ice control was found. The general consensus among airport administrators, was that there is an urgent need for a more effective,

simple and inexpensive means of combatting the airfield icing problem, and that research for a solution to this problem should be undertaken, especially in view of the ever-increasing air traffic conditions and the necessity for maintaining airfields at the highest standard of safety. Many managers felt that the best solution lay in the development of heated runways, either buried cables, pipes, or radiant surface heat, while others felt that a less revolutionary solution was required such as the use of a liquid chemical that would effectively remove ice even below zero fahrenheit temperatures. Such a chemical would need to be completely safe for handling, causing no damage to paved surfaces, vegetation or other environmental factors.

Of the nine airports visited it was noted that no two airports had adopted identical means of ice control. The methods employed ranged from using sand only, as a means of recovering airfield traction, to the use of "hot sand" and sand/chemical mixes, to a mixture of these various ice control methods (see Table 9).

Road graders are generally used on every airport to remove compacted snow and/or ice, especially from the heavily used ramp areas. The road graders are reported to be reasonably good for removing snow compaction but not effective in removing hard bonded ice.

On one airport, it was reported that they were successful in combatting airfield ice by the use of "weed burner" machines. In operation the weed burners melt the top surface of the ice, into which sand is dropped and becomes imbedded. This provides a sand-paper-like surface on which, according to reports, the aircraft may safely land, take-off or taxi.

For reference purpose, details of the above mentioned ice control methods as used by the various airports, are recorded below.

TABLE 9

TABLE SHOWING METHODS IN USE FOR ICE CONTROL AT EACH AIRPORT VISITED

AIRPORT LOCATION	Sand Only	Sand and Urea	Sand and Urea Mixed	Urea Only	Glycol Only	Glycol and Sand	Thermal Sand Bond	Is Sweeper Used for Ice Prevention YES/NO
Boston	x		x					No
Pittsburgh	x			x				No
Minneapolis	x						x	No
Buffalo	x			x				No
Columbus	x	x			x			No
Salt Lake City	x							Yes
Anchorage				x		x		Yes
Billings	x				x			Yes
South Bend	x			x				No

8.5.1 Method No 1

Traffic : large hub
Structure : multi-runway complex
Weather : moderate winter season

Until recently only finely graded sand was spread on the icy surfaces as often as required. Recently Urea and sand mixed in proportion of 25 lbs sand to 1 lb Urea is spread on ice runways. Straight Urea is also used with reported good success but such use is limited at this time. Runway sweepers were not used in the past but will be in future in conjunction with Urea.

8.5.2 Method No 2

Traffic : large hub
Structure : parallel runways
Weather : very moderate snow and temperature condition

In the past, sand was spread on the airfield as often as required when traction was poor. This season Urea has been used with reportedly good results. It is intended that it will be used more frequently in future. Rotary sweepers are normally used for sweeping slush, water and loose sand, but rarely for removing snow residue.

8.5.3 Method No 3

Traffic : large hub
Structure : intersecting runways
Weather : medium snowbelt area

Sand and Glycol have been used as has Urea on a few occasions but results were inconclusive. Further experimental use with the Urea concept is intended. This airport employs two weed burners to melt the ice so that sand, when dropped into the temporarily melted ice, will imbed itself. These burners treat a path 5 feet wide at from 2 - 6 MPH, operating on fuel oil.

8.5.4 Method No 4

Traffic : medium hub
Structure : one main instrument runway
Weather : airport located in heavy snowbelt area

This airport uses the "hot" sand concept of ice control in which heated sand is spread on the icy surface, imbeds itself into the ice and thus is not blown away by the wind or jet blast. Unheated sand is also used at this airport, in that after each snow removal operation, unheated sand is spread on the runway centre section to ensure traction. Runway sweepers are not normally used because they are considered too slow in removing snow residue left by plows, on the only available instrument runway. Urea had been used in the past but with disappointing results.

8.5.5 Method No 5

Traffic : medium hub
Structure : one main runway
Weather : airport located in medium snowbelt

This airport uses a mixture of sand and Urea in equal proportions to combat runway ice. In operation the Urea/sand mixture is spread on the ice surface. This provides immediate traction for the aircraft. When the temperature reaches the effective working range of Urea, it melts the ice, at which time the water and loose sand can be swept off the pavement.

When first applied, the Urea has a tendency to moisten the sand so that the sand will adhere to the ice. Experiments are currently being performed using "hot Glycol" to remove thick hard ice, of the type that is usually found on ramps and taxiways. The Glycol is poured into a modified tanker which has several heating elements installed, to enable the Glycol to reach an operating temperature of 180°. The results of this experiment are not yet known.

8.5.6 Method No 6

Traffic : medium hub
Structure : one main runway
Weather : airport located in medium snowbelt

Runway icing is not a serious problem at this airport but quite frequently glaze ice conditions occur in the early morning during the winter. Normally loose sand is used to provide traction on the slippery surface. This sanding is performed by a local contractor on an as-required basis. It is intended that Urea will be tested next season in an attempt to find a more effective solution for eliminating the glaze ice condition. Under normal snow removal conditions, two rotary sweepers are used to prevent snow residue (after plowing) from being compacted into a slippery condition. By this means many icing problems have been eliminated and only icing through natural weather phenomena has to be dealt with.

8.5.7 Method No 7

Traffic : small hub
Structure : one main instrument runway at present but second parallel is soon to be activated.
Weather : this airport is in the far northern snowbelt area with moderate snowfall but intense, prolonged cold periods

Rotary sweepers are used continuously to prevent snow compaction on the runway surfaces, by removing all traces of snow left by the plows. By this means only natural icing conditions need be dealt with. At this airport Urea has been used so effectively that it has been possible to maintain the main active runway in "blacktop" condition through the entire winter season. On the other hand in secondary areas where Urea (and sweepers) had not been used, the pavement was completely covered with hard firmly bonded and severely rutted thick ice which defied removal. This was the condition of the main taxiway and the ramp area. It was reported that next season Urea would also be used on

the taxiways and other vital areas. Glycol was to be used this season in an attempt to dissolve the ice on the taxiway but the results of this experiment are not yet known to the study group.

8.5.8 Method No 8

Traffic : small hub
Structure : one main runway
Weather : airport located in heavy snowbelt

This airport uses a rotary sweeper continuously to remove all snow, slush and surplus water. Thus only natural icing conditions need be dealt with. Looss sand is used to recover traction rapidly but for ice removal "Glycol" is sprayed on the centre section of the runway. When the ice melts the water is swept off the runway. A rubber cutting edge plow unit is used for removing slush when required and is reported to work very well. This airport intends to use Urea experimentally next season as a possible replacement for Glycol.

8.5.9 Method No 9

Traffic : small hub
Structure : one main runway
Weather : airport in medium snowbelt

This airport does not have a rotary sweeper, and therefore cannot maintain a blacktop runway at all times. After each plowing operation, if the runway condition is doubtful, sand is spread on the runway surface. It is intended that Urea will be experimentally used as a means of ice control next season.

8.6 The Use of Chemicals

The use of chemicals for airfield ice control proved to be a highly controversial subject, but in the main it was apparent that much of the controversy stemmed from a lack of reliable information on the subject. Most airports have used Urea at various times over the past three years.

One or two airports have achieved a measure of success with this chemical, others only a fair success, and yet others had no success at all. One airport had never used Urea but stated that because of excellent reports received, they would be experimenting with it next season. For the most part all agreed that Urea held more promise than any ice control method used to date and that they would continue to experiment with it next season. The most remarkable results were achieved by the most northern airport visited. In this area where the winter is severe, Urea had been used as an anti-icer agent on the main runway at the start of the winter season, and having been applied at the proper time, prevented ice from forming, with the result that when the severe cold weather arrived, the runways were bare. Other chemicals, most notably Glycol, are used but in very limited quantity, and mostly experimentally.

8.7 Use of Sweepers and Chemicals for Ice Control

It was observed that less need for sanding and de-icing operations existed at airports where a policy of frequent sweeping was adopted, especially in those areas where for most of the winter season the ambient temperature normally remains just around the freezing mark. Also, by using a chemical such as Urea as an anti-icer, rather than as a de-icer after the ice has formed, it is suggested that most icing conditions could be prevented with considerable savings and at the same time safer aircraft operating surfaces could be achieved. The good results obtained by using the sweepers in conjunction with Urea were clearly apparent at one airport located in an area that is normally subject to severe weather extremes throughout the winter.

8.8 Chemicals - Storage, Handling and Mixing

It was noted that Urea was being stored in bulk in either heated or unheated buildings at three of the airports visited. Except for a slight crusting of the top layer, which could be readily reduced, it was reported that bulk Urea presented no storage problems, provided that the material was protected against excess moisture.

On one airport, Urea and sand mixed in a proportion of one pound of Urea to twenty-five pounds of sand is being used for ice control. The pre-mixed material is stored on the floor of the vehicle garage where it is protected and can be readily loaded into spreading vehicles by means of a front end loader.

At another airport, Urea is stored in a covered, unheated building, in bulk form. When required the Urea is spread on the runway and then covered with a layer of sand. Urea in bulk form is stored in a heated building in a bin with a heated floor at one airport and according to reports, no caking of the materials had been experienced in this first year of using Urea for ice control, and none was anticipated.

A brief summary of the various methods employed to combat the icing problem at the airports visited is shown in Table 9. Considering that of the nine airports visited, each one had a different method of ice control, one can reasonably assume that for all other airports, there must be numerous variations of ice control methods employed. This clearly points up the fact that research into a solution that could be universally adopted would be an immediately worthwhile undertaking.

It is felt that the use of Glycol as a method of ice control, now being used or considered for use at some airports, should be well researched. Recent published reports indicating that Glycol is not compatible with certain types of pavement, and that when used with sand can create a potential jet engine ingestion hazard, are reason enough for suggesting caution.

8.9 Snow Removal Priorities.

Since it would not seem to be economical for an airport to have a family of snow removal equipment large enough to work at clearing all airport surfaces at once, it becomes necessary for the airports to set up a system of priorities for snow clearing. Thus the attention of the snow removal crews will be directed to selected areas at the beginning of a storm and will move to succeeding areas as clearing progresses.

TABLE 10

Table showing clearance priority for main airport surface areas

	BOS	PITTS	MINN	BUFF	COL	S L C	ANCH	BIL	S BEND
Instrument runway into wind *	2	2	2	1	1	1	-	1	1***
Other instrument runways *	1	1**	1	-	-	-	1	-	-
Other runways *	3	4	4	2	2	3	3	3	1
Basic ramp area	1	3	3	3	2	2	2	2	2
Remainder of ramps	3	4	4	4	3	4	4	3	4

* Implies also taxiway and turnoff

** Parallel to other instrument runway

*** Not I L S

As shown in Table 10 there are two main airport types as far as snow removal priorities are concerned, those with two instrument runways and those with only one main runway, whether instrument equipped or not.

On the first type, with two instrument runways, the procedure seems generally to be that the main one of the two is left operational as long as possible, while clearing takes place on the other. Then, if the first deteriorates to where it requires removal, the runway operations switch. This results in the secondary ILS runway having number one priority as far as snow removal is concerned. Note that at Pittsburgh both ILS runways are parallel. However, they are in opposite directions and thus still follow the pattern.

On those airports having only one main runway, whether ILS equipped or not, this becomes number one priority for snow removal. Note that at Anchorage, the one main ILS runway is not into the wind.

On both types of airports, taxiways accompanying runways assume the same priority as the runway they serve.

Second priority on all but two of the airports visited was the basic ramp area, enough to allow aircraft access to and from the landing area. On one airport, a separate crew carried out removal on this area at the same time as the number one priority runway was being cleared.

Third priority generally consisted of other runways, and finally all remaining ramp areas are cleared.

8.10 Criteria for Snow Removal and Ice Control Start-ups.

It can be seen from the summary on Table 11 that a wide variation exists in published quantitative criteria, but that all are within the limits suggested by the Air Transport Association of America.

A large number of airports had no published quantitative criteria, start-up decisions being based on the judgement of local snow removal personnel.

TABLE 11
 CRITERIA USED FOR RUNWAY CLEARANCE
 AT VISITED AIRPORTS

Organization/Airport	Start-up Criterion
Air Transport Assoc. *	An accumulation of 2" of dry snow, or 1/2" of wet snow.
Airport 1	Any accumulation of slush, wet snow or dry snow.
2	Accumulation of 3/8" slush or snow.
3	Accumulation of 1" to 2" of snow.
4	Intermittant clearing if light cover of slush or snow. Complete closure for clearing of accumulated 1 1/2" of snow.
5	At accumulation of 1/2" of snow, snow controller notified. He then uses personal judgement as to start-up.
6, 7, 8 and 9	No published quantitative criteria.

* From Air Transport Association Snow Removal Handbook 1968

In practice, it would seem that personal judgement plays a major role at all airports whether or not they have definite quantitative criteria, since no one was witnessed actually measuring snow or slush depth, and also since snow is not distributed evenly over the runway surface. Often, the centre of the runway may be bare and dry due to aircraft movements, while at the same time the outside edges are covered by two inches of snow. It then becomes a matter of personal judgement whether or not to suspend flying operations to remove that snow. In other words, the published criteria are not explicit enough to cover real life situations and are therefore, in practice, of doubtful value as they presently exist.

In general, ice control took the form of sanding. The criteria for starting sanding operations was runway surface condition as reported either by ground maintenance crews, or by pilots who had just landed.

8.11 Interference of Removal with Air Traffic.

Two basic systems of removal were observed. The first is an intermittent system which is intended to fit in between flights as much as possible and thus eliminate aircraft delay. The second type, essentially a one-time system, waits either until traffic decreases and/or stops, or until runway surface condition forces some action. Sometimes the latter system is modified by the fact that there are two main runways. In this case, clearance can take place on one while all traffic uses the other. Thus, when runway conditions force traffic to abandon the use of the one runway, the second is ready for use, with the exception of any intersection between the two. Traffic is therefore only interrupted enough to allow clearance of the intersection.

The intermittent interruption system usually results in a more uniformly good runway surface. Conditions are not allowed to deteriorate completely before removal action is taken, thus the surface conditions remain close to "black-top" condition. On the other hand, the "one time" system often results in a runway surface deteriorating to an

unusable level before removal is commenced. This, in turn, often results in a much more difficult removal task due to the compacting of snow by aircraft, sometimes even eliminating the possibility of recovering a "blacktop" condition.

8.11.1 Interference Pattern at Airports with Two ILS Runways.

a) Method 1. It is considered that one ILS runway is usually the active runway during a storm. Plowing therefore commences on the other ILS runway. This runway is plowed full length and width, but no attempt is made to clear behind edge lights until cleanup. All intersections are plowed back 100 ft and the taxiway to and from the second ILS runway is done in the same initial priority.

Eventually, the first ILS runway is no longer used as the active runway. This could occur in the early morning when traffic naturally stops. It could occur due to a wind change or runway surface conditions could also force closure. At this time, clearing commences on the first ILS runway. It is plowed to the full length and width, followed by clearance of the connecting taxiways.

During clearance therefore, airport capacity is reduced to one instrument runway most of the time, but complete interruption of traffic should not occur if the intersection of the two runways can be cleared between aircraft operations.

b) Method 2. Traffic is allowed to operate on both parallel ILS runways as long as possible. Eventually, one of the two is closed for clearing, and all traffic is diverted to the other. The runway is cleared to the full length and width including clearance around the edge lights, and banks tapered to no more than 18" at 15 feet from the edge. All associated taxiways and turn-offs are also completely cleared. This runway may remain closed for up to two hours for clearance.

The process is then switched, with the other ILS parallel being closed, and all traffic diverting to the recently cleared one.

During clearance, therefore, airport capacity is reduced to one instrument runway most of the time, but complete interruption of traffic should not occur since the two ILS runways do not intersect.

c) Method 3. Clearance begins on the ILS runway not in use, i.e. that one not into the wind. When clearance becomes necessary on the main runway it is carried out as much as possible between flights so that the main runway will remain operational. Some operations can be diverted to the second ILS runway, but in general it seems that the preference is to operate on a partially cleared main runway instead. This affects both traffic and removal since neither can proceed uninterrupted.

8.11.2 Interference Pattern at Airports with One ILS Runway.

a) Method 4. Where possible, intermittent clearing of the centre section of the ILS runway is accomplished without interfering with traffic. When runway condition forces complete closure, the runway is cleared full length and width. This complete clearance usually takes about 45 minutes.

Often this is pre-planned to interfere as little as possible with air carrier movements, but occasionally this is not possible. A complete interruption would therefore occur for 45 minutes.

b) Method 5. As there is only one runway with ILS and of suitable length for all air carrier traffic, removal operations are phased in between aircraft operations as much as possible, with major cleanup postponed until the off-peak night hours. This often results in traffic interruption, however, as the snow removal can fall far behind accumulation during peak traffic hours.

8.12 Information Flow.

A system cannot function without communication between its components. To describe information flow it is useful to discuss it under the following headings:

- a) Who uses or transmits information
- b) What decisions are taken
- c) What is the nature of the information
- d) How good is the information
- e) How is it transmitted

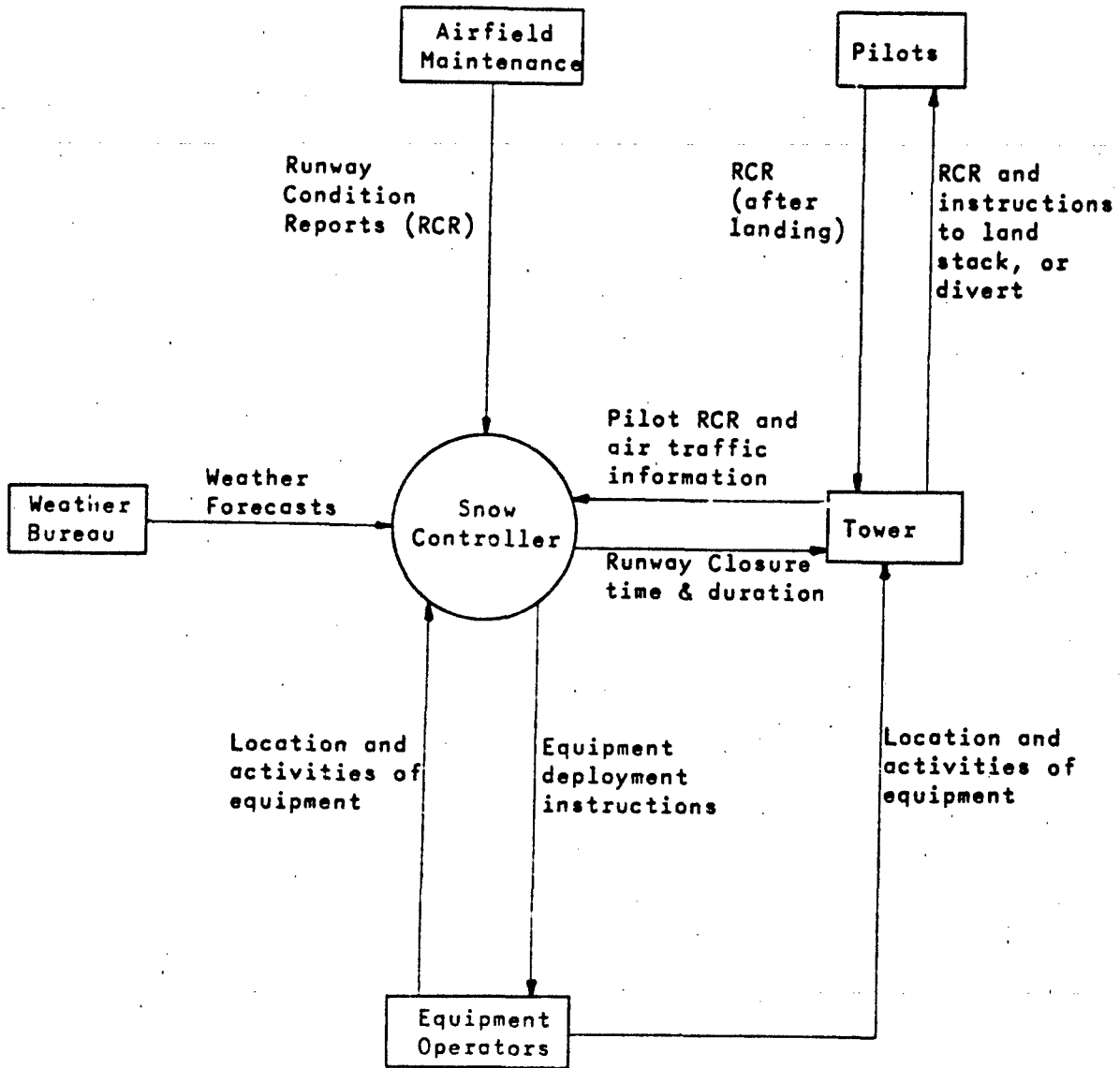
At all airports visited the procedure was remarkably similar (see Figure 3). More or less continuous contact is maintained with the weather bureau, to obtain a maximum advance warning of an incident. On learning that a storm is imminent, the snow controller will decide whether or not to hold men over, or whether to call the operators in from their homes (usually within a half-hour drive). Once the storm has begun, continuous monitoring of runway conditions is maintained.

On all airports visited, there were two main methods of determining the runway conditions; maintenance personnel reports, and pilot reports. Of the two, the reports submitted previously by pilots, rather than maintenance crew reports, controlled their successors' landing/take-off decisions when discrepancies occurred. Also, pilot reports tended to show the runway condition poorer than maintenance crew reports.

There were various methods used by the ground personnel to arrive at a measure of the runway condition. Some used measuring devices such as the Tapley and the James Brake Decelerometers, and relayed the readings of the meters to the towers. Others used only personal judgement after making a visual inspection, often involving a vehicle braking procedure, but with no meter.

Figure 3

Patterns of Information Flow within the
Snow Removal & Ice Control System



The results of both these methods ended up as runway condition reports giving descriptions of the surface, such as "snow covered with icy patches", and a categorization such as "braking action fair to poor". There were minor variations from airport to airport, but the basic categories for braking action, the most heavily relied on factor, were as follows:

- good to excellent
- fair to good
- fair to poor
- poor to nil

Pilot reports are generally relayed to the tower immediately after completing their landing and turn-off. There were, however, gross variations between pilot reports for any given runway even within very small time ranges. These were the result mainly of different characteristics of various aircraft, and were therefore always related to a specific aircraft type when being repeated. For example, "braking action is reported fair to good by DC9". Further discrepancies arose however, even within aircraft type, depending on such things as pilot experience.

Incoming aircraft were informed by the tower of the runway condition as reported both by the maintenance crew and by pilots of previous aircraft, and allowed to choose which one to believe, if any discrepancy existed. As previously stated, the pilot reports were invariably accepted as being the more realistic.

Runway condition having deteriorated to the extent that a clearance operation is necessary, close contact must exist between the following:

- a) snow controller

- b) tower controller
- c) snow removal equipment operators
- d) pilots

Essentially, an interference pattern with airline traffic must be decided upon and communicated via the tower to incoming and outgoing traffic. While equipment is on the field, its location must be known to the tower, to avoid the possibility of accidents, and to the snow controller, to enable him to deploy them to best advantage. Thus it appears universal to install and operate two-way radios in each machine concerned with removal. However, some airports had two radios, one on FAA Ground Control frequency, the other frequency for snow removal only. This existed to eliminate interference with air/ground communications.

8.13 Runway Condition Measuring Devices.

It was observed that a remarkable lack of standardization exists in the method of measuring and reporting runway condition information. Pilot reports are subject to bias, according to the type of aircraft, and the experience of the pilot in low braking conditions. Semi-scientific methods, such as the decelerometers mentioned previously, are distrusted since they only measure a small sector of the total runway. In addition, even the scale by which condition is measured can vary. (An analagous situation would exist if an inch varied according to location). Pragmatic methods, such as braking hard in an inspection car from a high speed, or testing the surface condition by walking on the runway, were quite popular, possibly with good reason, since it seems subject to less total bias and errors of interpretation than the other methods. It is our opinion that a reliable estimator of runway condition should be developed to meet the following criteria:

- a) Subject to minimal bias
- b) Possessing a measurement scale which is consistent
- c) Provide a measurement of the entire used length and not a small sample of it
- d) Quick to operate and reasonably inexpensive

8.14 Manpower.

Snow removal vehicle operators and mechanics at all of the airports visited are permanent employees whose duties also include the all-season maintenance of the airfield. In addition to the operation of snow removal and ice control machines these personnel are responsible for cutting grass, repairing lighting system, repairing paved surfaces and a multitude of similar tasks that must be taken care of at any airport.

Training for snow removal and ice control operations is mainly achieved by the "on-the-job" training method whereby new employees are employed as assistant to experienced vehicle operators for as long a period as necessary. Training also includes a series of pre-season "dry runs" in which all snow removal crews are required to familiarize themselves with the entire airfield and perform simulated snow removal operations for the benefit of all concerned. This training also serves to familiarize all with the airport layout and any changes that may have been made since the previous winter. Most of the airports visited reported that in addition to pre-season dry runs, some classroom lectures on snow removal and ice control were usually held prior to the winter season. One airport advised that snow removal and ice control lectures were also conducted at frequent intervals during the off-season.

Unlike the training program, each and every airport has a different work schedule, and vastly different pay rates and overtime policies. Considerable variation existed

TABLE 12

TABLE SHOWING STRUCTURE OF LABOR FORCE FOR SNOW REMOVAL AND ICE CONTROL

Location of Airport	Total No employed in operations	Method of Deployment			Average hourly rate	Overtime at hourly rate	Overtime hourly rate x 1.5	No over Time paid
		Single Shift 8 hrs	Two Shift 12 hrs	Three Shift 8 hrs				
Boston	32		x		4.20	x		
Pittsburgh	28	x			4.50	x**		
Minneapolis	40	x			3.55	x		
Buffalo	26		x		4.35	x		
Columbus	12	x			3.60	x		
Salt Lake City	15	x			3.00	x		
Anchorage	16	x		x	5.40		x	
Billings	6				3.15	x		
South Bend	7	x*			2.75		x	

* 48 hour week

** Operators paid at 2 x hourly rate

between airports with respect to numbers employed, even between airports of the same size. Furthermore, management assessment of the ideal number varied. At a number of airports, the scarcity of skilled labor was emphasized, while at other airports, two operators per machine was customary. Six of the nine airports operated on a one eight hour shift schedule, which means that when required to move snow after hours, all personnel are required to work overtime until the airport is completely operational. Under light snowfall conditions where the personnel are only required to work for three or four hours overtime and not too frequently, this system is said to present no real problems. On the other hand, under severe snowfall conditions, where men and machines were required to work for prolonged periods of time, with only short rest periods, the system has not worked too well in the past. Most personnel agreed that the one-shift snow removal crew system was not entirely satisfactory, especially for the medium to heavy snowbelt areas. It was for this reason that two of the six airports, now using the one-shift system, indicated that they would likely be changing to a two shift system next season.

8.15 General Aspects of the System.

8.15.1 Organization.

In a snow removal operation there are a large number of decision-makers. Thus, potential conflicts arise. For example, runway closure even for a clearance operation, will not be popular with air traffic controllers, airlines, pilots, passengers and airport managers. Controllers, because the pressure brought to bear on them by waiting aircraft, and the presence of machines on the runway increase the already considerable stresses which the nature of their work imposes. Airlines, because delays cost money and thus erode their profits. Pilots, because they feel responsible to their passengers for the discomfort and inconvenience of circling around for a half-hour. Passengers, because such waiting is unpleasant and delays could cause serious diff-

iculties. Finally, airport managers see loss of concession revenues and possible loss of future business. Notwithstanding their emotional reactions, however, closure will be accepted as an alternative logically superior to operating on a poor surface, with the implied high risk of a catastrophe.

The decision, therefore, to close a runway is not an easy one. Neither is it one which, having been decided upon, should be debated. Thus it appears logical that the decision-makers in full possession of relevant facts should make this key decision. Normally this would be the snow removal co-ordinator.

8.15.2 Task Division Between Airport Interests

It was observed that the limits on the task-domain of the airport system varied among airports. At some locations, the airport accepted responsibility for all clearance of runways, ramps, gates, car parks and access roads. At others, car parks were considered to be the responsibility of the concessionaire. In one airport visited, the ramp area close to the gates was considered to be the job for the airlines, while in another, ramp clearance (usually after midnight) was only carried out if the airline moved parked aircraft elsewhere.

This division is not of major significance, therefore, in our study it will probably be assumed that the entire area is the airport's responsibility.

8.15.3 Airport Purchasing Policies

It was noticed that the Municipal/Regional or State environment frequently imposed certain pressures on purchasing decisions. In at least one airport, for example, all requirements were put out to tender, the lowest bidder being accepted. This apparently resulted, in some cases, with the purchase of a make of machine different to that requested by the airport.

In another airport, all airport equipment was purchased by the State, and then leased back on an hourly basis to the airport. This was seen as a disadvantage by the airport. However, since the leasing fee did not appear to include capital and depreciation charges, it may have been a more generous policy than was realized.

In most cases airport labor was subject to the labor agreement of the Municipality or State. This often resulted in various overtime anomalies. At one location no overtime premium was allowed. In another, no overtime at all was permitted. In general, airport management felt that such constraints were not conducive to an efficient operation.

In our study, a more or less traditional structure will be assumed, such as normally encountered in profit-oriented organizations, i.e. interest or depreciation cost will be included and charged to the airport, while labor will be assumed to work either a standard eight hour day with time-and-a-half on the excess, or a two or three shift system.

9. PRINCIPAL CONCLUSIONS ABOUT CURRENT AIRPORT PRACTICE.

9.1 Measurement of runway surface condition is subjective and non-standardized between airports. This appears a potentially unsafe situation.

9.2 Criteria for both "start-up" and ultimate cleanliness of operating surfaces were not standardized throughout the airports visited. From a safety standpoint, standardization would appear to be desirable.

9.3 At the airports visited information about cost of snow removal and ice control was not readily accessible, due to the fact that the use of such a cost-centre is not normal accounting practice. Thus information for equipment cost/effectiveness evaluation is not available to management.

9.4 Airport management lacked objective technical information about the range of equipment and techniques available to them.

9.5 Airport design does not appear to take the special needs of snow removal and ice control into account. For example:

- a) The shapes of terminals interfere with efficient plowing.
- b) Ramp areas provide no locations for snow dumping.
- c) The lack of a paved surface outside the runway edge lights inhibits clearing around them.

9.6 A lack of knowledge existed at many airports regarding the use of rotary sweepers. For example:

- a) Sweepers should only be used for clearing plow residue or snow or slush accumulations of up to approximately one inch.
- b) The use of sweepers in conjunction with an ice control chemical will prevent a build-up of ice or compacted snow.

9.7 Management lacked information about the effectiveness, limitations, and consequences to aircraft of ice control methods, for example, the application of Urea, sand, or Glycol singly or in combination. In effect, each airport was conducting its own research program in isolation.

9.8 The use of low speed (3 MPH) rotary blowers on busy airports is questionable, except in trough periods for general clean-up, since their low speed negates any advantage gained from the use of high speed plows.

9.9 The use of sand for ice control is widespread. In addition, Glycol and sand is used, but to a lesser extent. There is evidence that the use of such methods leads to aircraft jet-engine wear. Whether the cost consequences of this wear are outweighed by the benefits has not yet been evaluated. A study along these lines would seem to be required.

9.10 As a corollary to 9.9, the use of Urea as an ice control compound is at an early experimental stage at most airports. Access to recent work in this area would reduce their time spent on individual research efforts.

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