

# Optimization Operations of Winter Maintenance of Airport

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**Abstract** The direct ensuring process of air transport by airport operators means to provide all components for safety landings, movements and clearance of particular flights. The mentioned factors depend on the quality and quantity of airport personnel and technical resources. Financial turnover of the airport depends on the number of flights and passengers. The higher the frequency, the higher profit items, whether it is the airport taxes or business of the company. However, to ensure regular income, the airport company has to ensure safe and regular air travel, especially without long-term and frequent limitations. These tasks are of particular importance in the winter, when the weather - snow and ice limit the effects of airfield serviceability.

**Keywords** Winter Maintenance of Airport, the Optimal Deployment of Technical Means, Regression Analysis

## 1. Introduction

Winter maintenance of airport (WMA) must be organized and carried out in order to maintain the all weather operational capability of airport operating areas in a comprehensive, cost-effective and expedient use of people and equipment intended for winter maintenance.

Composition of the WMA group must ensure continuity of the winter maintenance of the airport. Group WMA consists of a shift and the master (head) and drivers – mechanists of a single technique.

## 2. Snow Properties

Formation of snow must be seen as a part of the hydrological cycle which happens in the atmosphere. Evaporation of water from the earth gets a large amount of water vapour into the atmosphere. If atmosphere is overloaded or water vapours decrease the temperature to so-called dew point, water vapours in the atmosphere condense and there is rain. If temperature is below 0 °C, the gaseous state of water change right in the solid, recrystallization occurs. This process is linked to so-called crystallisation centres, which are ice cores or dust. Because of valence forces huge number of water molecules creates the formations of a crystal system resulting to snow crystals.

The whole process can be represented as follows: saturation of water vapour + centres of crystallization + temperature < 0 °C

Snow is hygroscopic and quite quickly depending on the temperature rise and its density increases. Snow density can be determined by sampling a certain volume of snow and measuring a volume of water after it melted. [1][2]



Figure 1. Snow at the Apron

Snow density ranges from 80 kg.m<sup>-3</sup> of fresh dry snow up to 800 kg.m<sup>-3</sup> slush, i.e. mass, which consists of ice crystals and water. Both these components may be represented in varying proportions in slush, which affects the resulting density and thus the size of the resistance to acceleration of the aircraft. [3]

The amount of snow, the height of the water column on the Runway and snow on load-bearing surfaces and a fuselage of the aircraft may have the effect of extending the total length of take off about 70 %.

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The relationship of weight of snow and temperature is determined:

$$m = \varphi \cdot V \quad (1)$$

where **m** is weight of snow,  $\varphi$  - is the density of snow and **V** - volume of a snow layer

With dry snow the value of density is rapidly variable, because snow raises its density by its own weight. The weight of snow is an important variable that determines the quantity and type of equipment deployed. Deployment of working mechanisms and speed of work must be adapted to the total time devoted to the maintenance of a movement area.[4][5]

**Table 1.** Density of snow

	Snow	Density
1	dry	350 kg/m <sup>3</sup>
2	wet	500 kg/m <sup>3</sup>
3	slush.	800 kg/m <sup>3</sup>

A layer of snow on the surface gives:

- resistance exerted on the wheels of the landing gear for the acceleration, the size of the resistance depends on the specific weight and thickness of a snow layer, the characteristics of the landing gear, weight and speed of aircraft movement,
- deterioration of the aerodynamic characteristics of aircraft during acceleration as a result of pollution of bearing surfaces and a fuselage of aircraft by splattering snow from the front bogie wheel,
- reduce braking action of the runway surface (mainly due to the coverage of surface by ice) creates a risk of extension of run down for landing or interrupted take-off.[6]

### 3. The Analysis of Technological Practices of Winter Maintenance of Airports

Enforcement of activities associated with WMA depends on:

- a size of the airport - the maintenance area → runway, taxiway, apron and service communications,
- density of air traffic for the airport → number of movements of aviation technology for the assessment period,
- an average amount of snowfall and snow under a year.

Following two factors determine the staffing and technical support WMA:

- whereby more movements of aviation technology, thereby reducing the time devoted to the maintenance of airport,
- more snowfalls with the higher volume of snow and extensive areas of maintenance, the more frequent changes of WMA.

For purposes of calculating the optimal deployment of technology to the winter maintenance of airports and the subsequent determination of the dimensions of the model airport, the following size of the airfield is used:

- Runway (RWY) 3000 x 45 meters
  - Taxiways (TWY) - parallel taxiway with runway 3000 x 23 m + coupling paths 2 x 300 x 23 m,
  - Apron (APN) 200 x 100 m.
- Total area is **237,800 m<sup>2</sup>**



**Figure 2.** Airport sweepers

The size of the model airport movement areas is given by a variable that can be changed in the process of calculating for each of the results depending on the actual values of the airport.

To ensure WMA, considering the density of air traffic is important at the airport - especially the number of movements of air technique on movement areas. These values are important in determining the movement of aviation technology during the one hour on one RWY, TWY and APN - it means time which is available for the WMA shift to dispose snow and make rated airport movement areas operative. An important factor emphasizing the seriousness of time of the maintenance is decreasing the time for aircraft waiting to land - inability of a movement area to take the flight.[7]



**Figure 3.** Airport's area

#### 3.1. The Performance Characteristics of Technology

Despite the technological process of disposal of snow in the movement area of airport, the performance characteristics of snow surfaces are primary rated, as the performance of airport sweeper motor is necessary to count with respect to amount and weight of removed snow. This quantity is given by the ability of snow blades to draw aside snow to the weight limits of the snow, which is affected by the technical design of airport snow blades.

**Table 2.** The values of snow on the model airport due to its size and density

		Snow Depth in m						
		RWY	0,03	0,06	0,09	0,12	0,15	0,18
		obj. v m <sup>3</sup>	4 050	8 100	12 150	16 200	20 250	24 300
I. Dry	Weight	a) kg	1 417 500	2 835 000	4 252 500	5 670 000	7 087 500	8 505 000
		b) kg	2 025 000	4 050 000	6 075 000	8 100 000	10 125 000	12 150 000
		c) kg	3 240 000	6 480 000	9 720 000	12 960 000	16 200 000	19 440 000
		TWY	2 484	4 968	7 452	9 936	12 420	14 904
II. Wet	Weight	a) kg	869 400	1 738 800	2 608 200	3 477 600	4 347 000	5 216 400
		b) kg	1 242 000	2 484 000	3 726 000	4 968 000	6 210 000	7 452 000
		c) kg	1 987 200	3 974 400	5 961 600	7 948 800	9 936 000	11 923 200
		APN	600	1 200	1 800	2 400	3 000	3 600
III. Slush	Weight	a) kg	180 000	360 000	540 000	720 000	900 000	1 080 000
		b) kg	300 000	600 000	900 000	1 200 000	1 500 000	1 800 000
		c) kg	480 000	960 000	1 440 000	1 920 000	2 400 000	2 880 000
		∑ Area	7 134	14 268	21 402	28 536	35 670	42 804
	Weight	a) kg	2 496 900	4 993 800	7 490 700	9 987 600	12 484 500	14 981 400
		b) kg	3 567 000	7 134 000	10 701 000	14 268 000	17 835 000	21 402 000

With a width of snow ploughs of five and more meters, when the weight of snow is more than 350 kg to 1 meter width of the cleaned surface there is a real threat of damage to the plough mount or its parts.[8][9]

### 3.2. The Performance Characteristics of Equipment

Despite the technological procedure of liquidation of snow on the movement areas in order to evaluate first the performance characteristics of snow blowers, since the motor performance of airport sweepers should be counted with respect to sweep and number and weight of snow. This amount is the possibility of snow ploughs snow pushed back into the weight limits of snow, which is influenced by the technical design of airport snow ploughs. The width of snow plough of 5 or more meters in the weight of snow above 350 kg per 1 meter of purified surface width is a real threat of damage to the handle or blade or its parts.

To approximate the distribution of basic snow blowers it is necessary to take into consideration their performance characteristics and engine performance, operating speed and overall performance. The techniques are divided into three performance groups listed in the Table No. 3.

**Table 3.** The resulting three values

Performance group	1	2	3
Engine power	to 100 kW	to 600 kW	to 900 kW
Cutting Width	2000 mm	2500 mm	3000 mm
Put the snow away	30 m	40 ÷ 50 m	50 ÷ 60 m
Operating performance for throwing the dry snow	to 1 500 t.h <sup>-1</sup>	to 5 000 t.h <sup>-1</sup>	to 10 000 t.h <sup>-1</sup>

Similar to the distribution of snow blowers, the division of motor sweepers at the airport is as follows:.

**Table 4.** Performance characteristics of airport sweepers

Performance group	1	2	3
Engine power	260 kW	315 kW	315 kW
Cutting width Brushes	3400 mm	3500 – 4500 mm	3600 – 5500 mm
Working speed	25 – 45 km/h.	35 – 50 km/h	35 – 60 km/h
Sweeper's Performance	to 180 000 m <sup>2</sup> /h	to 220 000 m <sup>2</sup> /h	to 260 000 m <sup>2</sup> /h

We used the performance characteristics and engine performance, operating speed and overall performance of the airport surfaces and sweepers to converge their basic ranking. That technique is divided into three performance groups.

Based on auxiliary calculations of equipment performance there are processed the resulting values of time needed for the maintenance movement area of the model airport based on height and density of snow and performance of equipment.[10]

Currently, for the assessment of the effectiveness of deployment and variation of technical means an information technology can be widely use. The design of optimal set of means of WMA can be solved according to specified input and output for a specific period such as five years. Then we can compare the actual cost and the solution of proposal of techniques to WMA for the two largest Slovak airports with mathematical model outputs of the winter airport maintenance.[11][12]

**Table 5.** The resulting three values – length of maintenance of the entire airport area based on the performance of technique

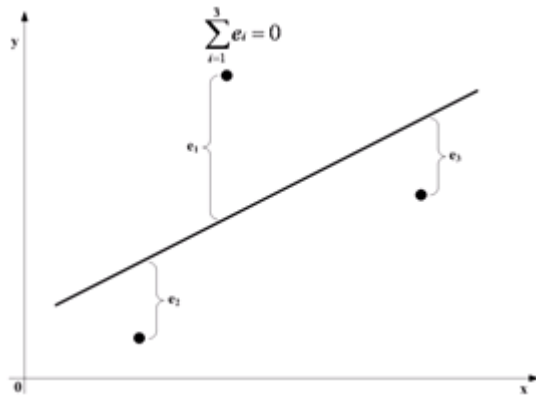
	Dry		Wet		Slush		type of snow, according to its density	
	0,03	0,06	0,03	0,06	0,03	0,06	Snow Depth in m	
1	1,095	1,245	1,245	1,245	1,245	1,395	RWY	lowest performance of technique
	0,747	0,747	0,747	0,927	0,927	0,927	TWY	
	0,178	0,189	0,178	0,200	0,200	0,222	APN	
	2,020	2,181	2,170	2,372	2,372	2,544	AIRPORT	
2	0,938	1,088	1,088	1,088	1,088	1,238	RWY	medium performance of technique
	0,747	0,747	0,747	0,927	0,927	0,927	TWY	
	0,144	0,155	0,144	0,166	0,166	0,188	APN	
	1,829	1,990	1,979	2,181	2,181	2,353	AIRPORT	
3	0,849	0,999	0,999	0,999	0,999	1,149	RWY	the highest performance of technique
	0,516	0,516	0,516	0,696	0,696	0,696	TWY	
	0,142	0,153	0,142	0,164	0,164	0,186	APN	
	1,507	1,668	1,657	1,859	1,859	2,031	AIRPORT	

#### 4. Optimization of Employment of Means WMA

As a means to solve the tasks of optimization of airport maintenance we can use fictional model of employment of proposed technique using the standard size of the international airport.

We assume that we are cleaning constant size of airfields:

Cleaning of the airport area can only be done by whole sets of airport technique, which is intended to winter maintenance of the airport (a kit consists of two airport motor snow blowers and one sweeper).[13]

**Figure 4.** Cache regression line and residues detected values

We expect that performance of technique can have three performance levels (1,2 and 3), these values may take the variables that we denote  $V$

The snow itself, we monitor the quality and quantity. The quality of the snow is marked  $K$  and it will be the type of snow.

The amount of snow we watch as its height and denote it by the letter  $S$ .

On the basis of technical parameters of technologies designed to maintenance of airport area, we calculated the base table that contains time information ( $T$ ).

These data correspond to the time needed to clear the airport if previously defined variables take values:

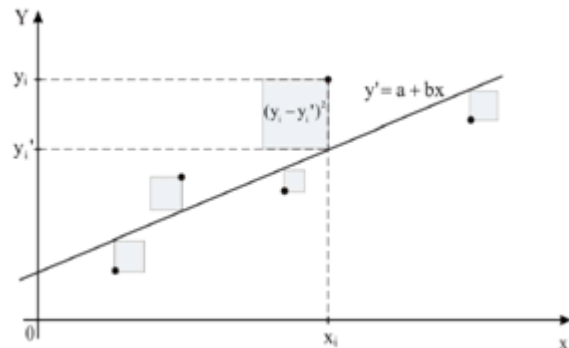
$V \in \{1;2;3\}$ ,

$K \in \{1;2;3\}$ , and

$S \in \{0,03;0,06\}$ .

We created a table, which corresponds to 18 theoretical measurements for the WMA at Kosice airport by given technique.

Under these assumptions and given numeric data, which are clearly shown in Table 2, we can establish a multiple linear model using the method of least squares.[14]

**Figure 5.** The graph of the least square method for linear dependence**Table 6.** Table of values of observations

NO	V	K	S	T	NO	V	K	S	T
1	1	1	0,03	2,020	10	2	2	0,06	2,181
2	1	1	0,06	2,181	11	2	3	0,03	2,181
3	1	2	0,03	2,170	12	2	3	0,06	2,353
4	1	2	0,06	2,372	13	3	1	0,03	1,507
5	1	3	0,03	2,372	14	3	1	0,06	1,668
6	1	3	0,06	2,544	15	3	2	0,03	1,657
7	2	1	0,03	1,829	16	3	2	0,06	1,859
8	2	1	0,06	1,990	17	3	3	0,03	1,859
9	2	2	0,03	1,979	18	3	3	0,06	2,031

This model has the form:

$$T = \alpha + \beta \cdot V + \gamma \cdot K + \delta \cdot S + \varepsilon \quad (2)$$

where  $\alpha, \beta, \gamma$  are unknown coefficients of the model ( $\alpha, \beta, \gamma \in \mathbb{R}$ )  $V, K, S$  are independent variables defined above and  $T$  is the dependent variable, which represents the time needed for WMA of the airport in determined parameters of the model.[15]

The method of least squares estimate the parameters  $\alpha, \beta, \gamma, \delta$  and denote them as the value of  $a, b, c$  and  $d$ .

Then the values of  $i$  (1, 2, ..., 18) we get the calculated model, which has the form:

$$t_i = a + b.v_i + c.k_i + d.s_i \quad (3)$$

Let us mark:  $\vec{h} = (a, b, c, d)^T$  a vector  $\rightarrow$

$$X = (\vec{1}, \vec{v}, \vec{k}, \vec{s}) \quad (4)$$

Where

$\vec{1}, \vec{v}, \vec{k}, \vec{s}$  are column vectors of the size of  $18 \times 1$ , the  $\vec{1}$  vector is a vector of the counted quantity, and  $\vec{v}, \vec{k}, \vec{s}$  vectors and  $\vec{t}$  the vectors are broken down above the table.

With this designation, we can then write the model described above in the form:

$$\vec{t} = X \vec{h} \quad (5)$$

Then, for the unknown vector  $\vec{h}$  is:

$$\vec{h} = (X^T X)^{-1} X^T \vec{t} \quad (6)$$

We calculate these values:

$$\vec{h} = (1,929833; -0,2569; 0,17875; 5,944444)^T$$

Specifically, we can write that

$$a = 1.929853$$

$$b = -0.2565$$

$$c = 0.17875$$

$$d = 5.944444$$

We get a model that has the form:

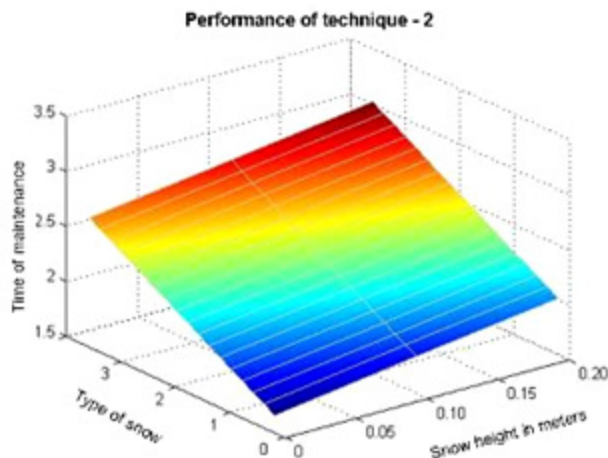
$$t_i = 1,929853 - 0,2565.v_i + 0,17875.k_i + 5,944444.s_i$$

At first glance it may seem that this model does not describe our situation properly, because the parameter value is not zero.

We could assume that if we have no snow, so WMA is the zero-time. This is not possible, because this would be contrary to the assumptions which we put to our model. In them it is stated that the variables  $v$  and  $k$  do not have zero values, i.e. if we have the snow height of 0, then maintenance takes place in non-zero time, because technique would be idle.[15]

**Table 7.** Time needed to maintenance of areas of a model airport by one set of techniques depending on the amount of snow

Performance of technique		1	1	1	2	2	2	3	3	3
Type of snow		1	2	3	1	2	3	1	2	3
		Maintenance time in hours								
Snow height in meters	0,01	1,9115	2,0903	2,2690	1,6550	1,8338	2,0125	1,3985	1,5773	1,7560
	0,02	1,9710	2,1497	2,3285	1,7145	1,8932	2,0720	1,4580	1,6367	1,8155
	0,03	2,0304	2,2092	2,3879	1,7739	1,9527	2,1314	1,5174	1,6962	1,8749
	0,04	2,0899	2,2686	2,4474	1,8334	2,0121	2,1909	1,5769	1,7556	1,9344
	0,05	2,1493	2,3281	2,5068	1,8928	2,0716	2,2503	1,6363	1,8151	1,9938
	0,06	2,2088	2,3875	2,5663	1,9523	2,1310	2,3098	1,6958	1,8745	2,0533
	0,07	2,2682	2,4469	2,6257	2,0117	2,1904	2,3692	1,7552	1,9339	2,1127
	0,08	2,3276	2,5064	2,6851	2,0711	2,2499	2,4286	1,8146	1,9934	2,1721
	0,09	2,3871	2,5658	2,7446	2,1306	2,3093	2,4881	1,8741	2,0528	2,2316
	0,1	2,4465	2,6253	2,8040	2,1900	2,3688	2,5475	1,9335	2,1123	2,2910
	0,11	2,5060	2,6847	2,8635	2,2495	2,4282	2,6070	1,9930	2,1717	2,3505
	0,12	2,5654	2,7442	2,9229	2,3089	2,4877	2,6664	2,0524	2,2312	2,4099
	0,13	2,6249	2,8036	2,9824	2,3684	2,5471	2,7259	2,1119	2,2906	2,4694
	0,14	2,6843	2,8631	3,0418	2,4278	2,6066	2,7853	2,1713	2,3501	2,5288
	0,15	2,7437	2,9225	3,1012	2,4872	2,6660	2,8447	2,2307	2,4095	2,5882
	0,16	2,8032	2,9819	3,1607	2,5467	2,7254	2,9042	2,2902	2,4689	2,6477
	0,17	2,8626	3,0414	3,2201	2,6061	2,7849	2,9636	2,3496	2,5284	2,7071
	0,18	2,9221	3,1008	3,2796	2,6656	2,8443	3,0231	2,4091	2,5878	2,7666



**Figure 6.** The graph of the dependence on performance techniques 2

So it is logical to assume that WMA is not made only at non-zero value of the parameter  $s$ , so the maintenance is not carried out, which means zero time, but not by the regression model, but upon the definition of the situation.

We have yet to determine credibility of the given calculated regression model.

The coefficient of multiple correlations

$$r_{T,VKS} = 0,992938835$$

shows strong relationship between the variable  $T$  and the independent variables  $V$ ,  $K$  and  $S$ . The strong relationship is between independent variables and the time  $T$ . [15]

## 5. Conclusions

Currently, for assessment of the effectiveness of deployment and variation of technical means, information technology can be widely used. The design of optimal set of means of WMA can be solved according to specified input and output for a specific period of such as five years. Then we can compare the actual cost and the solution of proposal of techniques to WMA for the two largest Slovak airports with outputs of a mathematical model of the winter maintenance of the airport.

The designed model to optimize the use of technical means of winter maintenance of the airport and to establish the optimal time depends on the capacity of airfields. For the established technique, also envisaged economic benefits, particularly in connection with the setting of input parameters of the airport in increasing density of air traffic, the management of airport can find an optimized set of techniques to airport maintenance and conversely of existing airport maintenance.

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