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Ergonomic Time and Motion Studies of Aircraft De-icing Work

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Abstract

This paper reports results of time and motion studies and ergonomic consequences of aircraft de-icing work. De-icing of aircraft on the ground is extremely important for maximizing technical safety, but also a major challenge for persons performing it. Between December 2016 and March 2017 we carried out video-supported time and motion studies on 11 personnel performing de-icing work in open baskets at a Canadian airport. Total time analyzed was 788 min, during which 1192 individual observations were made. Our observation sessions varied in length from 59 to 96 min, partly for weather reasons. After ascertaining the work systems used by the de-icers and determining the principal factors influencing them, we used REFA methods to perform a hierarchical analysis of work activities. Energy turnovers generated by these activities were calculated. These lie between 4 and 13 kJ/min, depending on weather conditions, air traffic density and individual work patterns of the de-icing personnel. Contributions of the individual activities to total value added were classified. Roughly one third of the de-icing activities made a direct contribution. The remaining two thirds made only indirect contributions or none at all. Stresses arising from the work were compared with the few findings reported in the literature. Further investigations are needed to understand thoroughly centralized de-icing activities.

Keywords: De-icing; Aviation safety; Motion study; Ergonomics; Value added

Scope of Study

The ground staff at large airports provide a wide range of services ranging from baggage handling to aircraft maintenance and provisioning. The literature contains a large number of reports on ergonomic aspects of baggage and freight handling, but ergonomic analyses and evaluations are lacking for many other ground staff jobs. Aircraft de-icing is one such case. This work has numerous environmental and ergonomic impacts. De-icing of aircraft on the ground is extremely important for maximizing technical safety, but is also a major challenge for the persons performing it. Organization and performance of de-icing work differs widely at the world's major airports.

De-icing can be carried out by either the airline itself or delegated to a contractor, at the gate or in centralized facilities. The techniques used can be either chemical or thermal. This paper does not address thermal (infra-red) radiation techniques, and we refer instead to other reports [1,2]. Environmental issues like de-icing fluids and water consumption have been examined, for example, by Corsi [3], Beisswenger et al. [4] and Gibson [5].

This report addresses organizational aspects of de-icing work as performed at numerous airports in North America and Northern Europe-by ground staff working, in centralized facilities, from either open or closed baskets (Figure 1).

De-icing work is done in accordance with the air operator's approved ground icing program subject to national and international norms applying in the country where the airport is situated. This paper does not address this aspect and refers instead to American Norm [6] and European Norms [7,8].

Ground staffs performing de-icing work are usually seasonal workers with temporary employment contracts. They perform static holding work, sometimes in extreme postures, heavy dynamic work, one-sided dynamic work, plus a small amount of informative-mental work, mainly involving onward transmission of information. They are exposed to several physical and chemical environmental influences, including noise, vibrations and dazzling, and, above all, to, at times harsh, climatic conditions like cold, rain, snow and wind. The risk from exposure to ethylene glycol should not be underestimated. The most recent Canadian study [9] needs to be updated as it was done for gate de-icing situations and the airport traffic has, since then, increased considerably. In addition, there are various work safety issues like risk of falls, contact with propellers or aircraft surfaces and accidents while driving on the apron or when leaving the basket or walking on the apron.

Current Research Status

There are several descriptions of de-icing activities, mainly in synopsis form [10-13]. Work safeties directives have been formulated [14-17] have published reports on the technical safety aspects of de-icing work while aircraft are on the ground. Breton et al. [18] have examined the question of ice detection on outer surfaces of aircraft. Bilodeau et al. [19] have published their findings on quality assurance of de-icing work. The question of how to gauge distance between de-icing basket and aircraft surfaces has been addressed by Leurs [20].

Studies of stresses and fatigue arising from de-icing work have been published by Torres Medina et al. [21-24]. A study by Torres et al. [23] demonstrates that ground staff perceives work in open baskets as significantly more stressful and tiring than in closed baskets. Günebak et al. have examined questions of traffic management coordinator (de-icing facility personnel controlling all movements on the de-icing apron from the control tower) communications [25,26].

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Figure 1: De-icer working in an open basket.

Apart from the few cited above, no other systematic studies on work stresses arising in de-icing work have been found. The authors of this paper decided to perform a project analyzing stresses and strains arising in de-icing work in open baskets at a Canadian airport. We formulated the following working hypotheses:

- The methods of analysis and evaluation to be used should comply with the expanded stress/strain concept [26].
- The results from the procedures used should enable identification of requirements and current deficits in job design.
- The methods used in the project should enable drafting of a register listing the physical requirements for ground staff employed for de-icing work.

Description of Work System

Figure 2 gives an overview of the work system of a de-icer working in an open basket in a Canadian airport. The de-icer performs his/her tasks standing in the basket in various postures. His/her tools are two spray guns connected to hoses, one of which delivers type 1 de-icing fluid (for removal of existing ice on the aircraft's outer surfaces), the other type 4 anti-icing fluids (to prevent formation of new ice after takeoff). He/she is equipped with a watertight flat screen and a walkie-talkie for communication with team foreman and colleagues. The positions of the basket (in three axes) and its truck standing on the apron are regulated by a control panel located in the basket. It should be noted that the personnel actually performing the de-icing work also controls the movements of the truck from the work station in the basket. No member of the ground staff is stationed in the cab of the truck.

As already explained above, the micro work system de-icer/basket is exposed to a number of physical and chemical environmental risk factors. The macro work system includes the aircraft undergoing de-icing, other aircraft and vehicles present on the apron, other members of the ground staff in other vehicles or the control tower. Anything between two and five de-icing vehicles will be in operation simultaneously, depending on the size of the aircraft. Four de-icing vehicles will normally be in use for a medium-sized aircraft, e.g. an Airbus A 320. Two of these equipped with open baskets will treat the wings, while two equipped with closed baskets treat the stern section of the aircraft.

Table 1 lists definitions of terms used during the observation periods and factors capable of influencing time requirements in de-icing work. De-icing activities are listed in Table 2.

Methods

Our investigations are structured in accordance with the highly reliable stress/strain concept [27-34]. All influences arising from the work task and the work environment were examined for strains affecting the worker. Due modulations were made for the effects of stresses resulting from physical differences and skills of individual workers. Variations in conditions cause variations in stress effects. Whereas the strains arising in individual workers are subjective, the stresses resulting from work task and environment are entirely objective.

In the discussion of work-related energy turnover in this paper we only address the question of (calculated) stress level. However, the evaluation of the time studies and the observations of body postures also cover certain aspects of both stresses and strains. The total stresses arising from the individual work tasks are definitely the key priority. But the individual operative's way of working has its effects on the work processes and postures. Our studies of strains alone, for example heart rate or respiratory frequency, are published separately in Le Floch et al. [29].

In this paper we are only analyzing time studies. The methods used for analysis of body posture and strains are explained in Landau et al. [28] and Le Floch et al. [29]. Airport safety regulations and the risk of seriously inclement environmental conditions made it impossible to perform time studies on the apron itself. Instead, we were forced to use video recordings for this purpose. DMC-Ortim software was used to make the video recordings of the time studies. The well-known REFA (Verband für Arbeitsgestaltung, Betriebsorganisation und

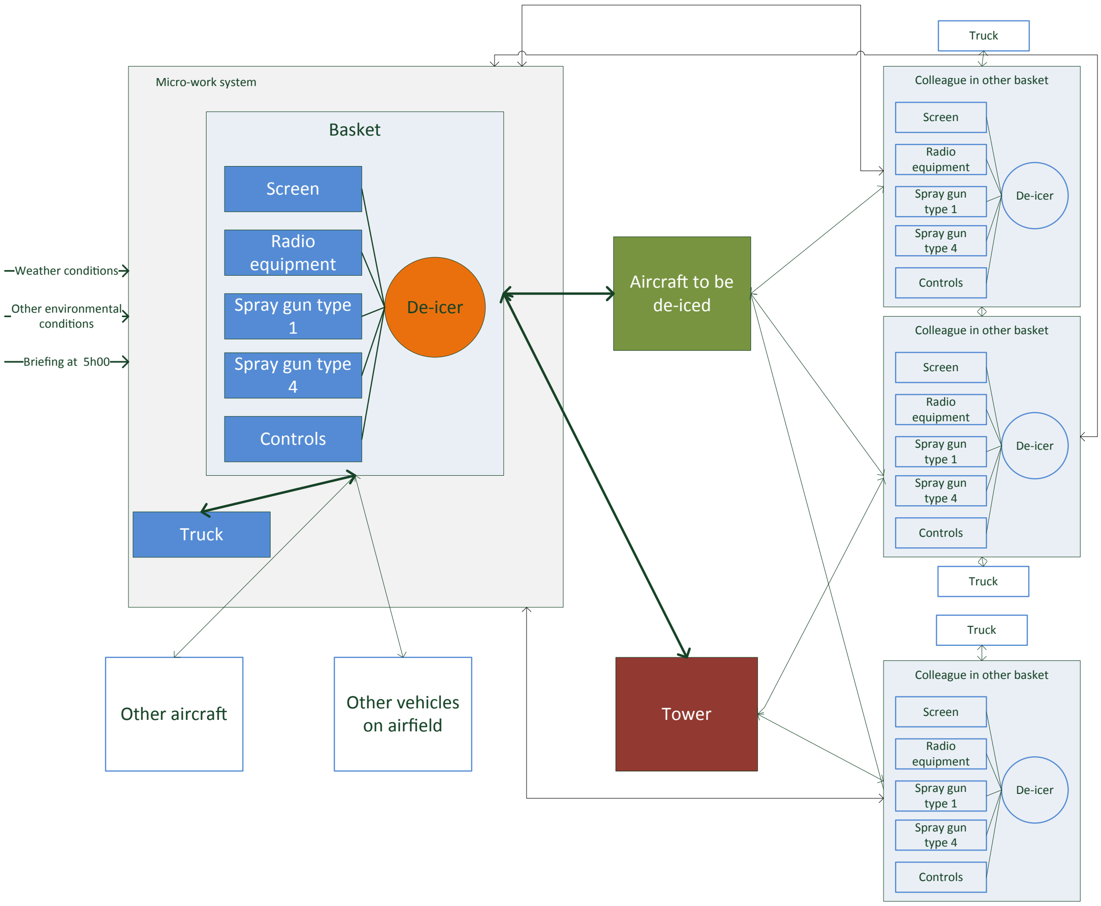

Figure 2: De-icing work systems.

Determining factors	Definition
Weekdays	Monday to Saturday
Time of analysis	Typical hour is stated; thus, if the analysis covered the period from 06:45 to 07:38, a 7 was entered
Aircraft type	1. Propeller-driven 2. Small to medium-sized jet 3. Jumbo aircraft
No. of de-icers working on aircraft	Mean number during observation break
Physical environmental conditions	1. Dry temperature (mean level during observation break) 2. Relative atmospheric humidity (mean level during observation break) 3. Wind speed (mean level during observation break) 4. Snowfall or ice rain (classification by Canadian airport) 0. Incorrect or not applicable 1. Negligible 2. Low 3. Close to mean level 4. High 5. Very high
Details of test persons	14 subjects: 12 men, 2 women (3 subjects left the company during our investigations and could not be included in the test group) Age: • 1 subject over 65 years old • 4 subjects over 40 years old • 10 subjects between 21 and 28 years old Mean height: 179,8 cm (min: 157 cm, max: 195 cm), mean weight: 79,5 kg (min: 52 kg, max: 109 kg) Shifts: • 5 subjects were working on the evening shift • 8 subjects were working on the morning shift • 1 subject was working on both shifts.
Work form of test person	Dealt with in Landau et al. [28].

Table 1: Factors capable of influencing time requirements and stresses and strains arising in de-icing work.

Time type	Activity
Effective times	De-icing type 1
	De-icing type 4
	Tactile checks
	Special checks
Auxiliary times	Entering basket
	Truck driving
	Moving up basket
	Moving down basket
	Radio contact
	Exiting basket
	Lateral movements+visual checks
Supplementary times	Not foreseeable
Idle times	Staying in truck
	Staying in basket
Unidentified	

Table 2: De-icing activities.

Unternehmensentwicklung) methodology [30] was used in the time studies.

We used the results of the time study to calculate energy turnover in accordance with the evaluation table of Spitzer et al. [31]. Although we also recorded pulse rate and respiratory rate, these will be analyzed and discussed elsewhere [29]. The risks of musculoskeletal disease to which de-icers are exposed are dealt with in Nadeau et al. [32].

The table system devised by Spitzer et al. [31] was used to calculate energy turnovers generated by de-icing work. The typical body posture and typical work pattern were determined for each task and the resulting energy turnovers (ET) for those tasks ($ET_{Posture}+ET_{work\ pattern}$) were calculated and then multiplied by the relevant work time:

Energy turnover of individual task (ETA_i)=($ET_{Posture}+ET_{work\ pattern}$) × t_i (kJ)

Division by the observation time ($\Sigma\, t_i$) yields the equation:

$$\overline{ET} = \frac{\sum ETA_i}{\sum t_i}\left(\frac{kJ}{\min}\right)$$

We have compared the energy turnovers calculated by the abovementioned methods with the generally recognized upper limits [33]:

- 16.5-17.5 kJ/min for men; 12-13 kJ/min for women.

Attention needs to be drawn at this point to the limitations of this method of calculation:

- Only physical tasks are measured;
- No allowance is made for climatic working conditions;
- The precision of the calculated values is ± 20%;
- The personal working pattern of an individual worker will not always correlate with the normal body posture and work pattern determined for a specific task.

Another weakness is the calculation of three summary indices for value added from the time study. It is emphasised that these calculations are based on economic and not ergonomic conditions (Table 3).

This is admittedly a very strict classification of value added, but it seemed important to us to make allowances for the interests of the airlines, which have to pay the entire bill for de-icing work and safety checks.

Direct contribution (De-icing spraying activities and aeronautic safety relevant activities)	Indirect contribution (necessary activities without direct contribution to De-icing)	No contribution
Type 1 De-icing Fluid	Entering basket	Sitting in truck
Type 4 Anti-icing Fluid	Truck driving	Standing in basket
Visual checks+lateral movements	Raising basket	Unidentified
Special checks	Lowering basket	
Tactile checks	Radio contact	
	Exiting basket	
	Other tasks generating energy turnover	

Table 3: Contribution of individual tasks to value added.

Table 1 lists the relevant data for the test persons. The study was conducted in compliance with the requirements demanded by the ÉTS ethics committee.

Investigations Performed

A total of 11 video recordings of complete de-icing shifts were obtained. Each video file contains recordings made with three cameras, two of which were anchored on the basket at right angles to each other, the third located in the control tower and filming the overall scene.

The video-supported time study reported in this paper is based on an excerpt of between 1 and 1.5 h duration from the recording of the full shift. We made every endeavor to select only representative excerpts from the recording (intensive de-icing activity), but were unable to do this in some cases because of extreme weather conditions that made video recording impossible, especially during heavy nocturnal snowfall.

A total of 11 time studies were performed in 11 (volunteer) test persons during the period from 01 December 2016 and 31 March 2017. The test persons, accompanied by representatives of the workers and the de-icing management facility, were present at an introductory meeting held in November 2016, where the ergonomic objectives of our study (analysis and evaluation of stresses and strains arising in de-icing work and formulation of job design recommendations) were explained to them.

Ground staffs working in open baskets are employed for the winter period only and attend a 2-week training course to familiarize themselves with their duties. Although ground staffs drive trucks within the airfield perimeter, they are not required to hold a valid HGV license.

Opportunities for the team foreman to influence work were not investigated. The aim of the time and motion study was not to fix standard times. It was to:

- Determine average times and standard deviations for the individual tasks;
- Enable ergonomic interpretation of the time requirements for the individual tasks;
- Calculate the work-related energy turnovers;
- Determine degree of dependence of results on person-related variables;
- Compare the results of the multi-moment study of body postures with the results of the time and motion study.

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The recording time for the 11 studies totaled 13.12 h. A total of 1192 observations were made, i.e., approx. 110 observations per study. No assessments of performance levels were attempted, because these would have been meaningless in view of the high proportion of static holding work involved in holding the spray guns and hoses.

Results

Figure 3 gives an overview of the results obtained in the 11 observation sessions. The time classification devised by REFA [30] was used. This subdivides human work activities into Effective time (MH), Auxiliary time (MN) and Supplementary time (MZ). For each individual activity (shaded blue) the number of observations (orange), the overall mean time in hundredths of a minute for all sessions (green) and the percentage of total session time taken up by that activity (brown) were recorded.

Overall analysis time totaled 788 min. Our observation sessions varied in length-partly because of weather conditions-between 59 and 96 min. For this reason, it is difficult to make meaningful comparisons of the total times per session listed in the green boxes. It is also for this reason that we have calculated the percentage figures for each session (Figure 4).

The de-icing team spends one quarter of the time sitting in the truck cab waiting for their next deployment. This cannot be classified as genuine relaxation time, as the team has to remain in radio contact and comply with instructions received from either the tower or their team foreman. This has therefore been classified as idle time. The opportunity to shelter from the cold, snow and wind in the truck cab is obviously a relief. The next timed item is de-icing with type 1 de-icing fluid, which accounts for 15.1% of total working time. This is followed by driving the truck around the de-icing apron, which accounts for 14.3%. Lateral movements of the basket above the wings account for 9.5%; this is an important task, because the de-icer not only has to seek the best position for spraying the wing surface, but must also make visual checks for ice deposits and also for the efficacy of his de-icing efforts. Tactile testing of the wing surface is equally essential, because the de-icer has to report the wing's ice-free status before receiving permission to start spraying the type 4 anti-icing fluid. The tactile test must be performed with the bare hand, i.e., without gloves. To enable manual contact with the wing surface, the basket has first to be lowered into position and then raised again. Time requirements for basket movements account for over 10% of working time. The item Special checks require the de-icer to exit the basket and make a hands-on tour of inspection of the aircraft for ice deposits. This is only required for small propeller-driven aircraft. The remaining times are self-explanatory.

Figure 5 lists the results of our calculations of work-related energy turnovers. The figures show extremely high variances of between 4 and 13 kJ/min. The waiting periods in the truck cab (sitting without performing any manual activity) does not exert any strong influence.

Figure 6 demonstrates how widely the individual contributions to total value added vary in the individual test persons. This is attributable to a number of causes: firstly and most important, the climatic conditions applying and-directly linked to this-the traffic density. In second place comes the shift being worked at the time. In cases where a shift was not fully manned, the de-icers reporting for duty had to work under increased pressure. Finally, the work patterns of the individual de-icers and the experience and skill of the team foreman also had their effects. Figure 7 shows the mean figures for all test persons.

Discussion

The small number of test persons precludes discussion of the influences of shifts worked and of age and weight of test persons. It is

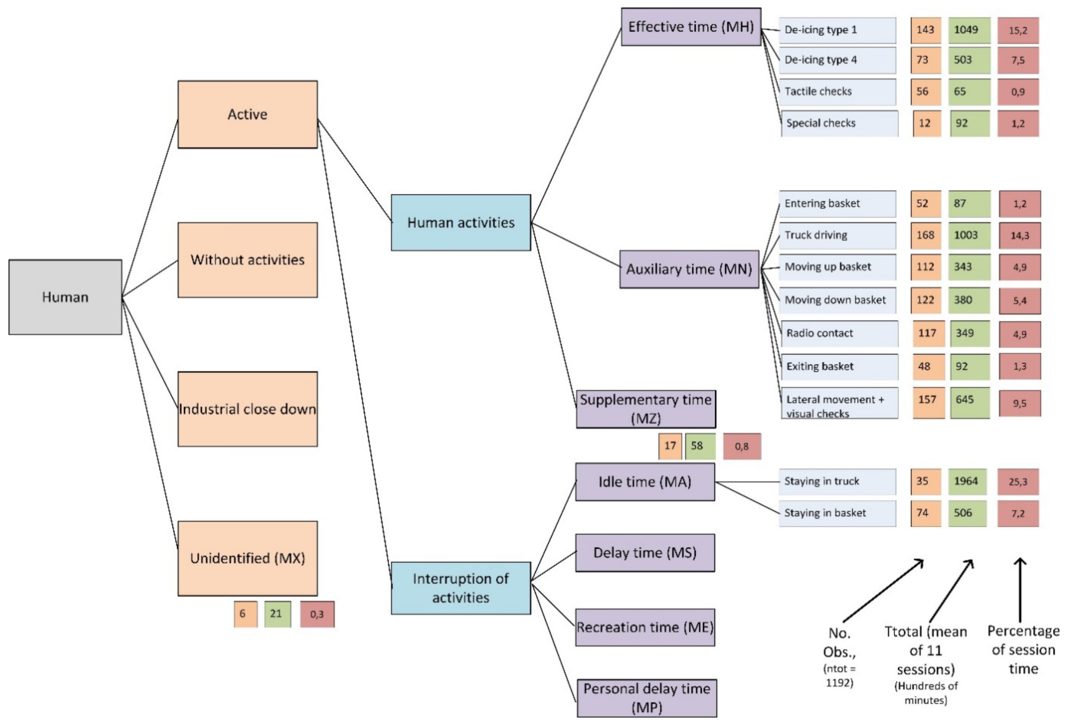
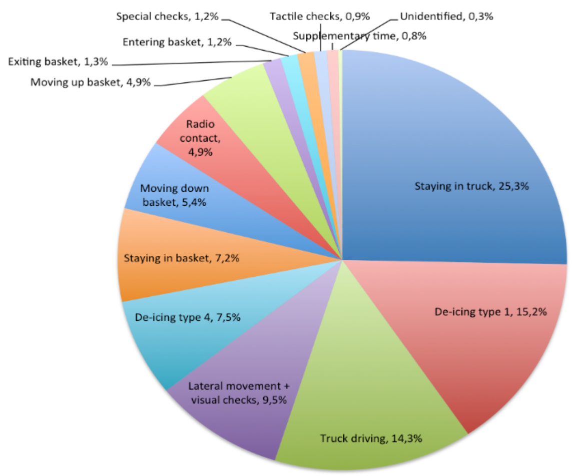


Figure 3: Time classification of observations, mean values for the sessions and percentage of session time devoted.



Activity	Min	Mean	Max	Stand. Dev.
Sitting in truck	3,4%	25,3%	75,4%	2014,5
De-icing type 1	2,7%	15,2%	26,2%	505,5
Truck driving	5,4%	14,3%	20,6%	248,5
Lateral movement + visual checks	2,1%	9,5%	21,9%	312,2
Anti-icing type 4	0,0%	7,5%	20,2%	404,6
Standing in basket	2,3%	7,2%	16,4%	302,1
Lowering basket	2,4%	5,4%	9,3%	106,8
Radio contact	1,7%	4,9%	9,7%	180,8
Raising basket	2,8%	4,9%	9,6%	118,3
Exiting basket	0,2%	1,3%	3,5%	62,4
Entering basket	0,5%	1,2%	1,9%	37,2
Special checks	0,0%	1,2%	4,2%	114,8
Tactile checks	0,1%	0,9%	3,2%	55,7
Supplementary time	0,0%	0,8%	2,3%	60,9
Unidentified	0,0%	0,3%	1,1%	31,7

Figure 4: Percentage of time required for various de-icing and anti-icing tasks (n=1192 observations, 13.1 h observation time between December 2016 and March 2017).

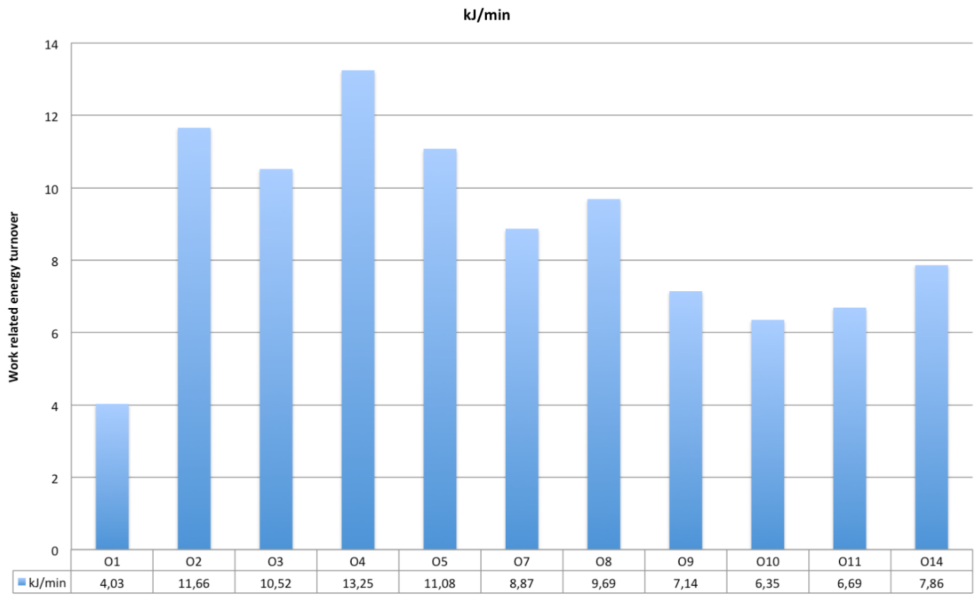
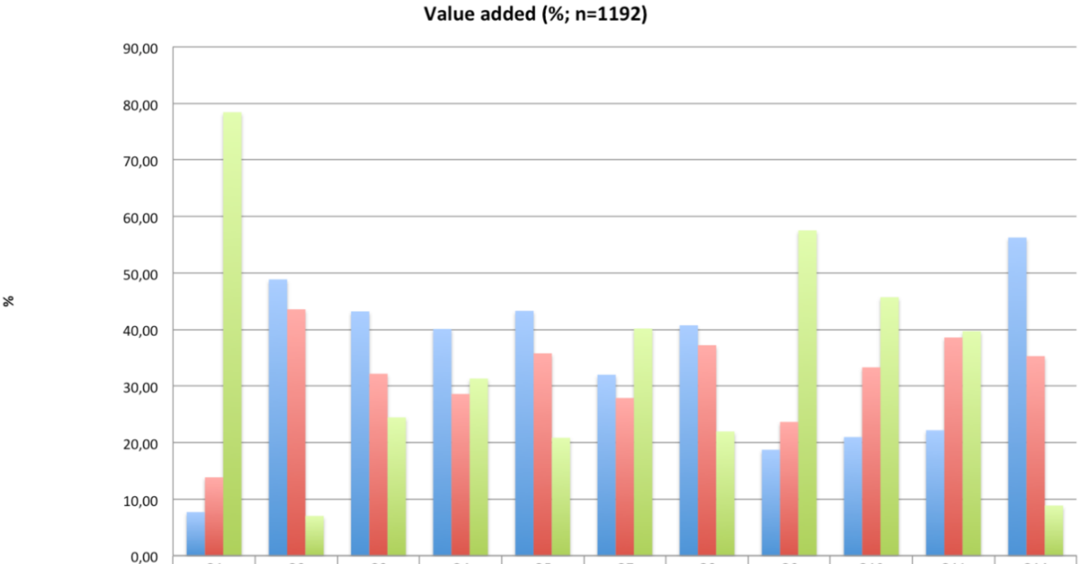


Figure 5: Work-related energy turnover calculated for 11 test persons (O1…O14 are participant numbers, subjects O6, O12 and O13 were not examined because of irregular weather and operation conditions).

also inadvisable to make any statements relating to gender of the test persons beyond the fact that the results for the only female test person in our group indicate an energy turnover of 13.25 kJ/min bordering on the recognized upper limit. The upper limit of energy turnover for continuous working by women lies between 12 and 13 kJ/min [31]. This means that job redesign is necessary in this case. Alternatively, additional rest breaks could be granted.

Our calculations show work-related energy turnovers ranging from 4 to 13 kJ/min. For male workers this represents low to moderate work intensity. The work calls for a wide range of body postures, including some classifiable as bent or extremely bent, trunk rotation or laterally inclined. Spraying requires work with both arms, some of which is performed at close to the limit of reach. Viewed in isolation, these would lead to high work-related energy turnover levels, but they are compensated by low energy-turnover activities like waiting in the truck cab or the basket, driving the truck and manoeuvring the basket. The result is that the net arithmetic energy turnover levels for the group as a whole, as shown in Figure 4, lies in the middle range. The figure of 165 watt/m^2 cited by Torres et al. [23] for work in open baskets is comparable with our results.

Figure 8 shows the combined results for work-related energy turnover and time required. The x-coordinates make due allowance for the work-related energy turnovers generated by this work form and are shown in kJ/min, the ordinate for the energy turnover for the job-typical body postures. The posture definitions shown on the y-axis use the classifications of work-related energy turnover described in the so-called Group Evaluation Table of Spitzer et al. [31]. The references to possible work forms listed on the y-axis also come from Spitzer et al.



	O1	O2	O3	O4	O5	O7	O8	O9	O10	O11	O14
directly value adding	7,72	48,87	43,22	40,11	43,31	32,01	40,74	18,74	20,99	22,19	56,27
indirectly value adding	13,86	43,57	32,19	28,61	35,79	27,89	37,23	23,66	33,32	38,60	35,31
no adding value	78,44	7,04	24,47	31,33	20,86	40,18	21,97	57,54	45,72	39,71	8,88

Figure 6: Level of contributions to total value added in individual de-icing workers (O1…O14 are participant numbers, subjects O6, O12 and O13 were not examined because of irregular weather and operation conditions).

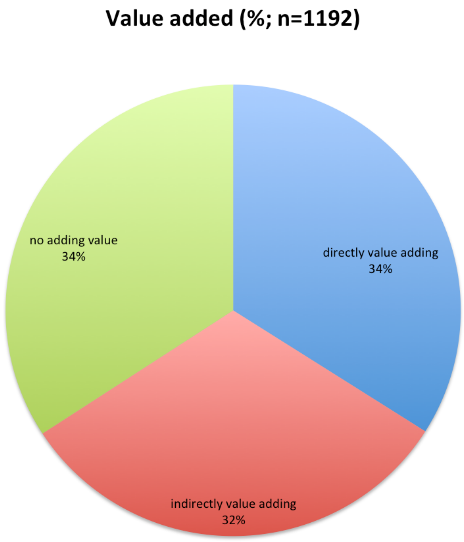


Figure 7: Overview of contributions to total value added for all test persons (Mean figures for group).

[31]. Total work-related turnover is calculated as the sum of the two components body posture and form of work.

The circles represent the individual activity; their diameter shows the mean time expenditure for the 11 studies. The greater the diameter of the circle, the longer is the time worked by these operatives in this combination of posture and work form.

This diagram highlights the main areas of activity of the de-icing personnel. Entering and exiting the basket and checking procedures on small aircraft necessitating exit from the basket involve low levels of time expenditure for walking and also light work with the hands. A whole series of activities call for standing upright combined with light hand work. The levels of time expenditure for these activities vary considerably. A large proportion of time is spent sitting in the truck. Tactile checks on the wings are performed in a standing position with one hand. The highest level of physical exertion is caused by the spraying of the type 1 and type 4 fluids.

Figure 8 demonstrates the differences in physical activities involving totally different energetic inputs demanded from individual operatives:

1. Sitting in the cab of the truck;
2. Standing in the basket performing light manual work;

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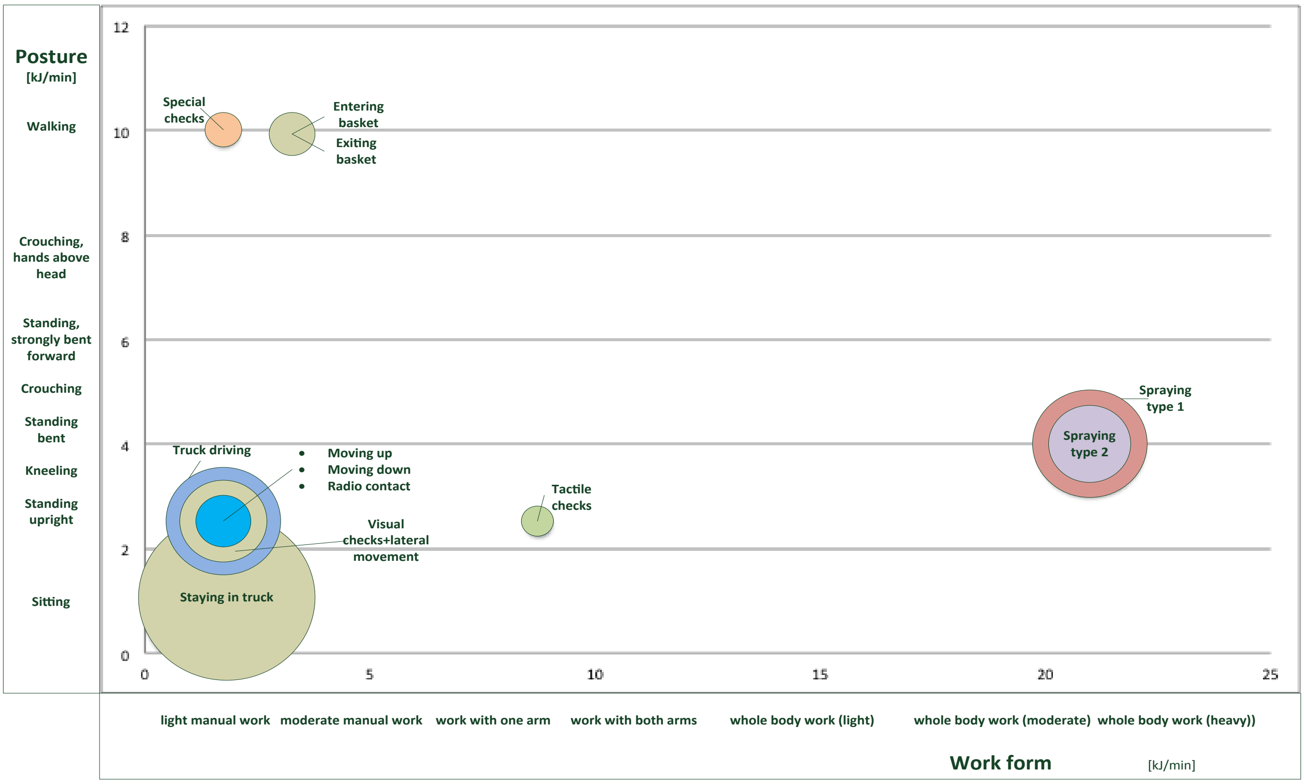

Figure 8: Posture, work form and mean process time for activities (n=1192 observations).

3. Moderately heavy dynamic work spraying the fluids;
4. Walking around the aircraft (special checks) and walking to and from between cab and basket.

Changes of stress result especially from switching from (1) to (3) and back, and also from (1) to (4) and back. And it would be incorrect to classify time spent sitting in the cab of the truck purely as rest periods, as this includes obligation to listen to verbal radio traffic and pay attention to aircraft movements. Time sitting in the cab obviously does yield physical rest effects that compensate earlier physical exertion. For example, rises in heart rate during spraying work subside to the former resting level after only a few minutes back in the truck. The switch from outside to inside climatic conditions on return to the truck is a mixed benefit; although an opportunity to warm up again after working in extreme cold, the frequent sudden switches between cold and warm bring their own risks, for example in the form of increased tendency to suffer from diseases of the respiratory system.

The authors of this paper know of no other discussions of value-added energy turnover in aircraft de-icing work in the relevant literature. It is therefore impossible to compare our results with existing reports.

In the majority of the test persons the direct contribution to value added generated by the spraying of the type 1 and type 4 fluids, plus the checking activities, exceeds the total indirect contribution from other activities. Direct value added ranges from 7.7 to 56.3% of observation time. There are two main reasons for the high direct value added levels:

1. The individual worker's work pattern [We differentiate between Work Method and Work Pattern: A Work Method is a series of procedures described and prescribed to the worker in the form of written instructions or training courses. A Work Pattern (or work form) describes the way in which an individual worker performs a work procedure]. Personnel lacking practical experience (e.g. O2 in Figure 5) tend to repeat spraying and checks on already treated surfaces, frequently several times-'just to be on the safe side'. This causes a sharp increase in direct contribution to value added.
2. Extreme weather conditions (O1, O9 and O14 in Figure 5). O14 were hampered by ice rain and high winds. A very high level of time expenditure on checks for ice deposits and their successful removal and intensive spraying was necessary in this case.

Time spent on activities making no contribution to value added varies very widely. O1 spent 78.4% of observed shift time waiting either in the truck or the basket, during which he/she made no contribution to value added. At the other extreme, O2 spent only 7% of observed time making no contribution. O14 shows a similarly low level of 8.9% spent waiting in the truck or the basket. The underlying causes of both these extreme cases have already been explained above (Figure 8).

As already explained above, we decided to opt for a rigid classification of value added. It therefore comes as no surprise that the Figure 6 shows activities making no contribution to value added or making only an indirect contribution each accounting for one third of total activities. It would however be advisable to review the adequacy and suitability of all work instructions and their relevance to current organizational activities and to update these, where necessary. In the final analysis, long waiting periods in the truck and long drives around the airport are unproductive for management and cannot be classified as genuine rest periods for the de-icing ground staff.

Conclusion

This time and motion study provides first impressions of time expenditure on various activities in connection with ground de-icing of aircraft. Even though the number of test persons was very limited, the observations, which cover an entire season, provide data on physical stress factors to which de-icing personnel are exposed and enable calculation of work-related energy turnovers and their value-added components. It is hoped that it will prompt further investigation of de-icing procedures at other large airports.

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