Design of an Expert System for Airport Rubber Removal

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Abstract. The most important parameter for airport operator is safety. Minimizing any possible risks for passengers, crew, and equipment is the main objective of applying safety management systems at airports. The rubber deposits that accumulate on the runway surface due to aircraft operations is one of the most critical factors that directly effects on the skid resistance value of the airport runway.

Four common techniques are applied throughout the world for mitigating this rubber strip water blasting, chemical, shot blasting, and mechanical. Every technique has its pros and cons in terms of cost, efficiency, environmental effect, and damage to pavement surface. The current design involves developing an expert system that takes into account the parameters that may support choosing the optimal method for rubber removal in certain situations. These parameters include airport classification, cost involvement, accessibility, pavement damage concerns, environment damage or side effects, and any additional factors such as noise.

The system is developed using webpage-based Expert System builder ES- Builder. Simple user interface, windows based, easy to build the decision tree are the major concerns for choosing this program to build the proposed expert system. The expert system follows a deduction process, until the expert system makes the final conclusion according to user selected answers. The proposed expert system works very well when selecting appropriate answers taking into consideration specific characteristics for each airport category. Faulty conclusions could be given if the user does not use the appropriate parameters related to the airport category. There is no optimum solution, every airport situation is different, and the solution or the recommended method varies from one airport to another.

1. Problem Statement and Background

Foreign Object Debris (FOD), which can be found anywhere within an airport’s air operation area (AOA), no matter what type it exists, can cause damages to aircraft tires, turbines, even to the engines. Besides, FOD can also cause injuries to employees of the airport during their daily work [1]. According to Advisory Circular (AC) 150/5210-24, Airport Foreign Object Debris (FOD) Management, “The presence of FOD in an airport’s air operations area (AOA) poses a significant threat to the safety of air travel. FOD has the potential to damage aircraft during critical phases of flight, which can lead to catastrophic loss of life and airframe, and at the very least increased maintenance and operating costs. FOD hazards can be reduced, however, through the implementation of a FOD management program and the effective use of FOD detection and removal equipment.” Clearly, it is an essential aspect to remove the FOD from AOA [1].
As rubber occupies the second largest portion of FOD, which causes damage on runways, runway rubber removal has become an important issue in order to guarantee safety of landing areas of the airports. This phenomenon will be seen clearly with large jet airplanes, the runways will gradually be deteriorated, and some skid resistance will occur. The majority of ground base accidents are as a result of lack of good friction between the airplane tires and the runways. The pavement surface is the critical part in that problem, and it has two main characteristics that will be explained in the following articles [1].

1.1 Macrotexture

Macrotexture alludes to noticeable roughness of the pavement surface. The essential purpose of this is to provide tracks for water to drain out of the pavement surface to prevent any possible hydroplaning because of the water. Pavement grooving in perpendicular direction to the runway centerline has proven its usefulness for better skid resistance characteristics and reduce the potential hydroplaning of airplanes [2].

1.2 Microtexture

Microtexture is the irregularity in surface of the pavement. These tiny articles may not be seen by bare eyes, but it could be felt by touch. The type of aggregate used could help prolong and hold the microtexture of pavement. By using some kind of brushes and brooms new fresh concrete pavement can be done to strengthen the concrete surface. Another method called wire tinning using steel wires to give texture for the concrete pavement. This process provides adequate frictional characteristics for airplanes during their landing / takeoff. This property is important for airports with large commercial airplanes or military aircrafts [2].

2. Literature review

Most airports nowadays are using some common techniques for rubber removal, using specific method depends on several reasons ranging from cost to availability of in-house staff. These various methods have various results when producing. The four main techniques are water blasting, chemical removal, shot blasting and mechanical methods. Water blasting is one of most common method among the four techniques, this technique is done by applying high pressure water to the contaminated surface to clean it from the rubber deposits. Chemical technique uses some kind of chemical that spread over the pavement surface for several hours in conjunction with brooms or scrubbers. Shot blasting uses machines that apply abrasive particle to the pavement surface and blast away the contaminants. Mechanical methods include techniques not included in the above methods such as milling and grinding [3].

2.1 How Rubber Deposits Accumulate

Most airports in the world handling hundreds of operations every day from large aircrafts, and those has to deal with this potential problem of rubber removal from the runways for safer operations. The aircraft tires are stationary just before touching or meeting the runway, for the first 1000 feet (300m), those tires will gain some type of rotation speed. The tires will be under thousands of pounds of stress between the tires and the surface, this will originate paramount friction and heat. As a result of this, the heat causes a polymerization of the rubber and transforms it into hard material that spreads over 300 meter as a thin layer. Seven hundred grams of rubber, or about 1.4 pounds, are accumulated per tire per landing of each large jet like Boing 747. At this frequency of landings and takeoffs, this rubber will fill the microtexture of the pavement and make it smooth as glass, and this will make the landing and stopping process very difficult. On the other hand, this rubber will also fill the microtexture of pavement surface, and hence, decrease the grooves ability to drain the rain water out, extending the possibility of airplane hydroplaning [2].
2.2 Water Blasting Rubber Removal Techniques

Water blasting involves the use of a high-pressure stream of water to blast rubber and sweep them away from the runway pavement. These types of equipment are usually operated by one person and are either classified as high pressure or ultrahigh pressure, with pressures from 13.8 MPa (2,000 per square inch) to 103 MPa (15,000 per square inch) using up to 114 L (30 US gallons) to 30 L (8 US gallons) of water per minute [2]. In both cases, the process speed is the same, approximately 743 m²/h (900 yd²/h) to 1641 m²/h (1950 yd²/h) [4]. In addition, water blasting equipment involve a vacuum, which cleans the water, rubber and other debris from the runway pavement, simultaneously. The vacuums reduce the risk of runoff from the rubber removal process [5].

Using water blasting to remove rubber has certain advantages as shown in figure 2.1. First and foremost, water blasting not only cleans the runway by removing all of the residues, but also restores the texture of the runway pavement. Through the restoring the texture of runway pavement, the skid resistance is maintained for aircraft landings and takeoffs [5]. Water blasting has a “low probability pavement damage” according to the rubber removal contractor survey from ACRP. And because of this, a number of airport operators select water blasting as their airports’ rubber removal methods.

![Figure 2.1. Reasons for choosing water blasting][3]

Another benefit of using water blasting method is time efficiency and ease of application. Almost 60% percent of the respondents chose water blasting because of the “speed of operation” [3]. Also, as the equipment is self-contained, it can be operated by one individual, thus, reducing operator costs. Because the vacuuming process is simultaneous with removing rubber, the water blasting equipment can be moved off the runway pavement instantaneously. Water blasting equipment may remove runway paint markings; however, in good weather conditions, the runway will be ready within half an hour of the rubber removal after paint application (‘Water blasting Technologies’) [6]. The next benefit is environment friendliness. Since water blasting involves little chemical-based components, the process is generally considered as an environmentally sustainable option. Due to the ACRP...
survey, eight out of the twenty-two responses from the ACRP survey said there is “no need for environmental permit” for rubber removal using the water blasting technique.

2.3 Chemical removal methods
The data suggested that the chemical rubber removal technique effectively removed sufficient bulk rubber from the landing area of runway to restore pavement skid resistance to uncontaminated traffic pavement skid resistance levels [8]. Until this time, the chemical removal of runway rubber deposits has not been introduced to airports operations and maintenances. In comparison with figure 2.1.1 that shows reasons for selecting water blasting in rubber removal, figure 2.2.1 illustrates those reasons for chemical method with new and different ranking [3]. According to [3] the most used chemicals for rubber removal observed from an airport survey was Avion 50, Hurrisafe, and AVI-88.

![Image](image_url)

**Figure 2.2.1.** Reasons for choosing chemical rubber removal [3].

The reasons that airports choose chemical rubber removal method are almost the same reasons as why they choose water blasting as their rubber removal method [3]. However, choosing certain method over another depends on the airport conditions and available equipment and manpower.

2.4 Shot Blasting Rubber Removal Technique
This technique is not widely used for rubber removal on runway surfaces. This method involves applying abrasive action to the pavement surface, loosening rubber or paint on the runway surface [3]. The resultant steel and debris need to be collected using a vacuum or magnetic process. this method is also used to remove any foreign object debris (FOD), which is a real concern for those who would like to adopt shot blasting for rubber removal [9]. This technique is primarily used for
retexturing runway pavement surfaces and incidentally removes any rubber debris or accumulations [2, 9]. Figure 2.3 illustrates the components of shot blasting technique [10].

![Figure 2.3.1. Shot blasting System][10].

### 2.5 Mechanical Rubber Removal Technique

This method is very popular and are applied from the time when airports recognize the potential needs to recover runway friction values. Sand blasting and mechanical grinding have proven success, but the only disadvantage is the longer periods of runway closure [7]. Additionally, this method is considered the least friendly one among the other methods to pavement grooves because of the thin layer of pavement and rubber removed by this technique is about (1/8 to 3/16 in), as a result the pavement grooves need to be re-done to their acceptable depth of ¼ inch to drain the water properly [2].

### 3. Design approach

This design project consists of an expert system for selecting the appropriate rubber removal technique at airports. This design takes into consideration all factors and parameters that play vital roles in this essential process of operational safety of airplanes. Many factors are considered in order to conclude with the most suitable method of rubber removal for specific airport characteristics. These factors include but are not limited to [5].

- The expected number of operations or number of arrivals for airport (for the present study three categories of airports are used and these are high, intermediate, and low volume airports),
- Relationship between cost of rubber removal operation and the hourly cost of runway closure (including initial cost, maintenance cost, and operation costs),
- Availability of in-house staff, skilled workers, and ease of learning the technique to be applied by airport staff in future,
- Pavement condition and damage due to rubber removal process,
- The possible environmental damage for both human and for other airport surrounding living activities (i.e. natural reserve sites),
- Sustainable materials, and noise on the neighborhood.

For the volume of operations, instead of using the number of operations, this design uses three categories, as large, medium, and small hub of airports.

### 3.1 Expert Systems for Airport Maintenance management

The expert systems are programs that incorporate knowledge from both books and experts and use reasoning to give a cheaper solution in specific problems that require expensive human expert [12].
These expert systems are also called knowledge-based systems; this system consists of five main components: knowledge base, inference engine, user interface, working memory and knowledge acquisition [13]. The knowledge base includes any facts, or rules that contain the experience from human experts. The main objective of Inference engine is to use reasoning from the stored data to provide solution for the addressed problem [14]. The working memory is similar to the database in conventional programs. Knowledge acquisition is working as an editor for the input rules and modify rules [15].

3.2 Expert System Builder Web
Expert System Builder McGoo Software (ES-Builders) is an expert system shell application. Compared to other expert system builders, ES-Builders is much more user friendly with no need to download and install any software. There are some built-in functions which dynamically create web pages to: search the expert system, display conclusions, display the knowledge base, display the decision tree, display the decision table, list the attributes and values and test expert systems to determine certainty factors. This system uses a decision tree process in order to build and develop the expert system. Detection reasoning is the process by which the expert system is developed. The web page expert system consists of a series of attributes through a process of detection, which enables the user to come out with a conclusion, which is based on a set of values selected for the specific case of the airport under design. The ES-Builders has simple interface where the user starts to build his expert system using a decision tree interface. This tree consists of attributes, values, and conclusions, as shown in figure 3.1, which are added as leaf nodes on the tree. The final expert system can be saved as a web page, and the user only needs to click on the options appearing on the screen, which is shown in Figure 3.2. ES-Builder is a dual process program. It has the ability to create the expert system and to search the expert system for solutions or results. Conclusions here are gained through a process of forward chaining.

![Decision Tree](image)

**Figure 3.1. Decision tree**

![ES-Builders Web](image)

(a)
At the end of the expert system search, a conclusion will be made. In addition, the ES-BUILDER system will also show how this process happens, like in figure 3.3.

**Figure 3.3.** Conclusion and decision rule

3.3 Application of ES-BUILDER to Airport

Because of the volume of airport, the factors above contribute differently. Each level has its procedure and recommendation. For large hub airports, the most contributive factors are lost revenue for runway closure and long-term damage to pavement; for medium hub airports, cost of operation and availability of skilled workers occupy more percentage; and for small hub airports, start-up cost, cost of operation, availability of skilled workers, equipment and materials rank the first four attributes [11]. Also, based on these, there are some recommendations for different volume airports. Under these conditions, the most suitable method for high volume is shot blasting, intermediate volume airports are recommended for chemical and water blasting, and mechanical method is assigned for low volume airport. Besides, if the airports have different phenomena, which is possible, the built expert system could also provide recommendations to their operators. Figure 3.4 depicts how the system works considering different conditions. Moreover, Table 3.1 demonstrates the part of knowledge base rules that applied to this specific expert system.
Figure 3.4. Decision making process

Table 3.1. Knowledge Base

| Rule | Knowledge Base | Explanation |
|------|----------------|-------------|
| 1    | IF airport classification is large hub, THEN the optimal method is Waterblast. |
| 2    | IF airport classification is medium hub, THEN the optimal method is Waterblast. |
| 3    | IF airport classification is small hub, THEN the optimal method is Waterblast. |

Figure 3.5 (a) to (g) show screen shots of one trial for selecting a proper rubber removal method. For current situation, the chosen options are low volume, start-up cost, availability of skilled workers, damage to pavement, environmental damage, and noise and impact on neighborhood. Given these conditions, the most suitable method for this airport would be the mechanical method according to the proposed expert system.
Which one is the priority of your consideration about cost?
- Cost of equipment maintenance
- Cost of operation
- Lost revenue for closure
- Start-up cost

When considering accessibility, which one is the most important?
- Availability of equipment and materials
- Availability of skilled workers
- Ease to learn cleaning technique

Which one will you consider more about the pavement?
- Texture of pavement after cleanup
- Damage to pavement
- Additional work required

What kind of environmental issues matters?
- Permits required
- Environmental damage

What is your additional consideration?
- Noise and impact on neighbourhood
- Ability to re-open runway in emergency
- Sustainability of process

Based on the responses you have made:
The optimal method is Mechanical

Conclusion Notes:

Expert System Rule:
IF airport classification small Hub
AND which one is the priority of your consideration about cost? start-up cost
AND when considering accessibility, which one is the most important? availability of skilled workers
AND which one will you consider more about the pavement? damage to pavement
AND what kind of environmental issues matters? environmental damage
AND what is your additional considerations? noise and impact on neighbourhood
THEN the optimal method is Mechanical.
4. Safety Risk Assessment
According to Federal Aviation Administration in Advisory Circular No: AC 150/5200-37, airport operators need to follow the basic steps outlined for Safety Management System (SMS) [16]. This system will enable airport operators to detect and predict the possible risks and hazards in a reasonable time so as to prevent any likelihood of aircraft incidents. Safety Risk Management (SRM) is the core process of SMS, which consists of five major phases: system description, hazard identification, potential risks, risk assessment and analysis, and finally appropriate risk mitigation procedures. The present design involves building an expert system to help airport operators to choose the best economical method for rubber removal from the airport runways. The system takes into consideration airport characteristics in terms of air traffic volume, and the different priorities for three categories of airports (i.e. high, intermediate, and low).

4.1 Hazards Identification
Factors which could contribute to hazards are based on the objectives of the mission and requirements of systems. The inherent hazards or adverse conditions generated by the expert system are as follows. An operator who lacks knowledge about airport conditions may lead to the selection of an improper method for a particular airport. The main hazards are related to resulting application of specific rubber removal techniques at an airport site. The ultimate hazards are related to the unremoved rubber deposits on the environment, on the surrounding area, and possible risks from using chemical processes on the operation staff and environment.

The proposed expert system could involve some risks due to faulty or not optimal method for rubber mitigation. For instance, expert system could suggest using chemicals for specific airport characteristics instead of using water blasting. The environmental effect will be high in comparison to water blasting method. Moreover, using mechanical technique could lead to loss of pavement paints and marking, the resultant will be runway with good friction characteristics and poor visibility.

4.2 Risk Determination
There are minor risks related to faulty recommendations by the expert system, such as possible health issues that might affect the chemical staff during rubber removal process. On the other hand, the poor visibility, resulting from losing pavement marking and painting could result in improper airplane landing operations.

4.3 Risk Assessment and Analysis
The level of risk is determined by using the predictive risk matrix (AC – 5200) as shown in figure 4.1. The two main inputs are likelihood and severity, for the possible risks discussed earlier, the likelihood value is remote, and the severity is minor. This estimation is not easy to determine and requires well-trained personnel and a lot of operational experience. According to this matrix, the risk level is low.
5. Expert System limitations

Every application has some limitations that could hinder its capabilities, and our case is no exception. However, main limitations of this system are the essential factors considered to have the major impact on airport operator’s selection of the most appropriate method of rubber removal. For current expert system these factors are obtained from actual surveys in previous studies, which include most critical parameters to consider before deciding the method to be used for removing the accumulated runway rubber, such as cost, experience, logistics, speed and efficiency and environmental impact and health concerns of the staff.

6. Conclusions

1. Airport rubber removal is a very exhaustive process and every airport has to deal with it at some point.
2. Selecting the most appropriate method of removing the rubber due to friction between aircraft tires and runway pavement.
3. Several factors play a significant role in airport decision for selecting the most economic, efficient and sustainable method.
4. Current developed expert system takes into account most factors that might concern airport operators and recommends the optimum method of rubber removal based on your answer for the specified questions in the system.
5. The current work was based on multiple resources like human experts, manuals, and other research articles related to this field.
6. The current work can be used as tool to help airport operators choosing rubber removal technique that is compatible and matches their objectives and available resources.

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