European Aviation Safety Agency

Research Project EASA.2008/4

RuFAB - Runway friction charateristics measurement and aircraft braking

Volume 1

Summary of Findings and Recommendations

6575C.FR

RUNWAY FRICTION CHARACTERISTICS MEASUREMENT AND AIRCRAFT BRAKING (RuFAB)

FINAL REPORT
VOLUME 1 – SUMMARY OF FINDINGS AND RECOMMENDATIONS

Submitted in response to
Contract: EASA.2008.C46

March 2010

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REPORT: Runway Friction Characteristics Measurement and Aircraft Braking (RuFAB): Volume 1 – Summary of Findings and Recommendations

DATE: March 2010

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ACRONYMS AND ABBREVIATIONS

ABS	Anti-lock Braking System
ADREP	Aviation Data Reporting Program
AFM	Aircraft Flight Manual
AIC	Aeronautical Information Circular
AIP	Aeronautical Information Publication
ASFT	Airport Surface Friction Tester
ASTM	American Society for Testing and Materials
CAA	Civil Aviation Authority
CEN	Comité Européen de Normalisation (France)
DGAC	Direction Générale de l'Aviation Civile (France)
EASA	European Aviation Safety Agency
ECCAIRS	European Coordination Centre for Accident Incident Reporting Systems
EFB	Electronic Flight Bag
EFI	European Friction Index
ERD	Electronic Recording Decelerometer
FAA	Federal Aviation Administration
FMD	Friction Measuring Device
FTF	Friction Task Force
GFMD	Ground Friction-Measuring Devices
ICA	Instructions for Continued Airworthiness
ICAO	International Civil Aviation Authority
IFI	International Friction Index
ISO	International Organization for Standardization
IRFI	International Runway Friction Index
ITTV	Instrumented Tire Test Vehicle
JWRFMP	Joint Winter Runway Friction Measurement Program
LLTT	Landing Loads Test Track
NASA	National Aeronautics and Space Administration
NOTAM	NOTice to AirMen
PIREP	PIlot REPort
RCR	Runway Condition Reporting
RFT	Runway Friction Testers
RI	Runway Inspector
ROAR	Road Analyzer and Recorder
RuFAB	Runway Friction Characteristics Measurement and Aircraft Braking
SCRIM	Sideway Force Coefficient Routine Investigation Machine
SFT	Saab Friction Tester
SNOWTAM	Snow Warning To Airmen
TALPA ARC	Takeoff And Landing Performance Assessment Aviation Rulemaking Committee
UK	United Kingdom
US(A)	United States (of America)

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

ACKNOWLEDGEMENTS

Werner Kleine-Beek of EASA was the Project Officer. He is thanked for his efforts throughout to administer and facilitate the work.

The contributions of the Project Steering Committee (listed below) are acknowledged as well. Their contributions included attending project meetings, providing guidance regarding the approach(es) for the project, providing information and references, reviewing the questionnaires that were sent out, and facilitating contacts.

Jean Baril, EASA;

Rachel Daeschler, EASA;

Xavier Vergez, EASA;

Chris Gash, CAA-UK;

John Matthews, EASA;

Herbert Meyer, EASA;

Ivan-David Nicolas, EASA;

Armann Norheim, Avinor (Norway);

Jerry Ostronic, FAA (USA);

Vincenzo Pennetta, EASA;

Francis Richards, Eurocontrol;

Maria Algar Ruiz, EASA;

Filippo Tomasello, EASA; and

François Watrin, DGAC-France.

Acknowledgements are made to various members of the Project Steering Committee for providing advance information regarding various ongoing initiatives as follows:

Jerry Ostronic, for information regarding the TALPA ARC recommendations;

François Watrin, for information regarding the French DGAC study; and

Armann Norheim, for information regarding the ICAO FTF.

Acknowledgements are also made to the various individuals and organizations who responded to the questionnaires which were sent out as part of the project. Although they cannot be named (to maintain their anonymity), their support is collectively acknowledged.

EXECUTIVE SUMMARY

This report constitutes the final submission under EASA Contract No. EASA.2008.C46 for the Runway Friction Characteristics Measurement and Aircraft Braking (RuFAB) study, which was sponsored by the European Aviation Safety Authority (EASA) to investigate and harmonize:

(a) Terminologies for runway surface conditions, related to functional and operational friction characteristics;

(b) Functional characteristics as they relate to friction measurement reporting; and

(c) Operational characteristics as they relate to runway surface condition assessment and reporting, friction measurement, and aircraft braking.

The overall objective of the work was to provide recommendations regarding the assessment of runway friction characteristics and Runway Condition Reporting (RCR). This is a broad subject, and thus, the project had several specific objectives, as generally summarized below:

(a) To conduct a broad information-gathering effort to determine the current state-of-practice.

(b) To compare the various approaches and definitions used for RCR and to suggest approaches for harmonizing them.

(c) To compare the various approaches used for assessing functional friction characteristics and to suggest approaches for harmonizing them. This included an evaluation of past approaches for harmonizing the readings from ground friction-measuring devices, and recommendations for an updated device equivalency table (to Table A-1 in ICAO Annex 14, Volume 1).

(d) To compare the various approaches used for assessing operational friction characteristics, and to suggest approaches for harmonizing them.

This is Volume 1 of a four-volume series of reports describing the project, as follows: (a) Volume 1 – Summary of Findings and Recommendations; (b) Volume 2 - Documentation and Taxonomy; (c) Volume 3 - Functional Friction; and (d) Volume 4 - Operational Friction.

It should be noted that for clarity, all recommendations are presented in this Volume, and they are not presented in any of the other Volumes.

1 INTRODUCTION, OBJECTIVES, AND OVERALL SCOPE

1.1 Background

Numerous studies have found that the runway surface condition has an important effect on the safety of aircraft operations on contaminated runways. In an effort to improve aviation safety, efforts are made regularly at aerodromes to document and report the runway surface condition. Runway Condition Reporting (RCR) is undertaken in various contexts and conditions as depicted in Table 1.1.

Table 1.1: General Contexts for Runway Surface Condition Reporting

Type of Contaminants	Functional Friction Assessment[3]	Operational Friction Assessment[4]
Summer[2] (e.g., wet)		not done in practice, except for evaluations of "slippery when wet"
Winter[1] (snow, slush, ice, etc)	not done in practice	

Notes:

1. "Winter" – this refers to conditions or contaminants for below-freezing situations. The types of contaminants to be encountered in "winter" conditions include ice, wet ice, all types of snow, slush, frost in all forms, and de-icing chemical residues.
2. "Summer" – this refers to conditions or contaminants for above-freezing situations, and is often termed "wet" in the literature. The types of "summer" contaminants or conditions include damp, wet, flooded, standing water, dirt, and rubber build-up.
3. Functional friction measurements are mainly intended for planning and undertaking runway pavement maintenance, and for setting criteria for the design of new pavements.
4. Operational friction measurements relate to operations on contaminated surfaces, such as aircraft operations or manoeuvres, including possible actions by the aerodrome such as the closure of a runway

The most appropriate RCR approach(es) depend on, among other factors:

(a) The end objective (i.e., functional vs. operational friction measurements); and

(b) The type of contaminant and conditions – in winter, the main contaminants of concern are snow, ice, and slush. In summer, the most significant contaminants include water, rubber build-up, and general debris.

The amount and type of RCR information varies between countries and even airports themselves, which is a safety issue. A major matter of concern is that lack of harmonization leads to surface condition information provided by airports to air carriers and aviators, especially for operational reporting, being generated using a variety of inspection methods and friction measurement procedures without uniform quality standards. Airplane manufactures and air carriers, therefore, have a limited ability to provide precise airplane landing and take-off performance instructions to pilots for contaminated runways. This in turn may lead to greater than necessary safety margins which financially penalize operators through operational limitations, or it may lead to misinterpretation of condition reports resulting in compromised safety.

Presently, harmonization does not exist with respect to reporting and friction measurement practices. The information provided can include or range from:

(a) Observations of just the runway surface condition, including the contaminants on it;

(b) Friction measurements made with a ground vehicle – some States and airports pass the measured friction values onto the pilots while others only the pilots with a general indication of the braking action (e.g., good, good-medium, medium, medium-poor, poor); and

(c) PIlot REPorts (PIREPs) from previous landings.

Among other variations, countries also use different: (a) RCR forms; and (b) friction-measuring devices. As a result, they report friction characteristics and runway surface conditions differently. This safety concern is exacerbated by the fact that different friction-measuring devices give different friction numbers when operated on the same surface at the same time.

It is generally recognized that the safety of aircraft operations on contaminated runways would be increased if runway condition reporting and friction measurement were internationally harmonized. The overall objective of this project was to promote common RCR procedures.

1.2 Project Scope and Objectives

The overall objective of the work was to provide recommendations regarding the assessment of runway friction characteristics and runway condition reporting. This is a very broad subject, and thus, the project had several specific objectives, which may be summarized as follows:

(a) To conduct a broad information-gathering effort to determine the current state of practice. This included conducting surveys using questionnaires, personal contacts, and an extensive literature review.

(b) To compare the various approaches and definitions used for RCR and to suggest approaches for harmonizing them.

(c) To compare the various approaches used for assessing functional friction characteristics and to suggest approaches for harmonizing them. This included an evaluation of past approaches for harmonizing the readings from ground friction-measuring devices and recommendations for an updated device equivalency table (to Table A-1 in ICAO Annex 14, Volume 1).

(d) To compare the various approaches used for assessing operational friction characteristics and to suggest approaches for harmonizing them.

The project was comprised of three parts as summarized in Table 1.2.

Table 1.2: General Task Breakdown for the Project's Work Packages

Project Part	General Task Breakdown
1- Documentation and Taxonomy – Discussed in Section 2 and Volume 2	Task 1.1: Establish List Task 1.2: Assess Feasibility of Methods for Harmonizing Different Taxonomies Task 1.3: Establish Inventory of Main Reference Documents Task 1.4: Reporting
2 – Functional Friction Characteristics– Discussed in Section 3 and Volume 3	Task 2.1: Scientific and Operational Consolidations of Harmonization Task 2.2: Investigations for Alternative Methods to Evaluate Surface Friction Characteristics Task 2.3: Define a Stepwise Procedure and Guidelines for Harmonization Task 2.4: Reporting
3 – Operational Friction Characteristics– Discussed in Section 4 and Volume 4	Task 3.1: Definition and Characterization of Wet and Contaminated Runways Task 3.2: Compatibility of Friction Characteristics Measurement Techniques Task 3.3: Runway Condition Information Task 3.4: Reporting

1.3 Organization of Report

1.3.1 Report Volumes

The reports for the work in this project have been organized in four volumes as follows:

(a) Volume 1 – Summary;

(b) Volume 2 - Documentation and Taxonomy;

(c) Volume 3 - Functional Friction; and

(d) Volume 4 - Operational Friction.

This report (i.e., Volume 1) provides a summary of the key findings and presents all recommendations from the work. For simplicity and clarity, recommendations are only presented in this volume.

1.3.2 Notice Regarding Definition of Depth

To avoid confusion, it should be noted that unless specifically stated in the text, all depths defined in this report series refer to the actual depth of material, and not the water-equivalent depth.

2 SUMMARY FOR PART 1 – DOCUMENTATION AND TAXONOMY

2.1 Scope

The work included the following general tasks:

(a) Extensive information-gathering was done to define the current state-of-practice;

(b) The relevant ICAO documents were reviewed and compared;

(c) Detailed lists were produced and comparisons were made regarding the definitions and taxonomies used at present;

(d) An inventory of the main reference documents was produced;

(e) Current trends within the aviation community were identified; and

(f) Assessments were made regarding the feasibility of potential methods for harmonizing the taxonomies used and recommendations were made.

2.2 Information-Gathering

Information-gathering was done by: (i) conducting surveys using questionnaires that were sent to many airports, airlines, aircraft manufacturers, and national civil aviation authorities (Table 2.1); (ii) personal contacts; and (iii) an extensive literature review.

Table 2.1: Questionnaire Distribution and Quantity of Responses Received

Questionnaire Type	Type of Organizations Contacted	Number of Organizations Contacted	Number of Responses Received
Functional Friction Characteristics	Civil Aviation Authorities	14	6[3]
	Airport Operating Authorities	45[1,2]	15[1,2]
Operational Friction Characteristics	Civil Aviation Authorities	13	6[3]
	Airport Operating Authorities	39[1,2]	16[1,2]
Operational Friction Characteristics	Air Carriers	23	12, and 5[5]
	Associations[4]	3	0
	Aircraft Manufacturers	6	3

Notes:

1. This includes a response that was prepared regarding functional and operational friction by Paul Fraser-Bennison of the UK CAA as a response on behalf of the UK CAA.
2. This includes a response that was prepared regarding functional and operational friction characteristics by the project team as a generic response on behalf of Canadian airports.
3. This includes informal responses from three CAAs that the responses from their airport authorities would reflect their policies, or which directed the project team to AIPs and other material.
4. This included associations of pilots and air traffic controllers.
5. Follow-up questions were sent by email to each of the air carriers that responded to the initial questionnaire. Five (5) responses were received in response to these follow-up emails.

2.3 Other Current Initiatives

A number of initiatives are currently ongoing that are relevant to this project, and initial information was received regarding them. Because reports or technical documentation are not available at present regarding them, the conclusions and recommendations made in this report regarding them should be considered to be preliminary.

2.3.1 The TALPA ARC (Takeoff and Landing Performance Assessment Aviation Rulemaking Committee) Process

This was led by the FAA with representation from aircraft manufacturers, airlines, airports, and regulatory authorities. The TALPA ARC has defined an overall system such that all the key components of information gathering and employment are linked, ranging from the runway reporting process to assessments of aircraft performance. This is a major step forward. If implemented, the proposed TALPA ARC system would bring about significant changes to the current state of practice in the US and other countries duplicating or emulating the process.

The TALPA ARC defined a Runway Assessment Matrix (Figure 2.1) which relates aircraft performance using a scale of seven codes to a combination of the contaminant type, the contaminant depth, and the contaminant temperature.

PAVED RUNWAY CONDITION ASSESSMENT TABLE

Airport Estimated Runway Condition Assessment				Pilot Reports (PIREPs) Provided To ATC And Flight Dispatch
Runway Condition Assessment – Reported		Downgrade Assessment Criteria		
Code	**Runway Description**	**Mu (μ)**	**Deceleration And Directional Control Observation**	**PIREP**
6	• Dry	-	-	Dry
5	• Wet (Smooth, Grooved or PFC) • Frost ***1/8" or less of:*** • Water • Slush • Dry Snow • Wet Snow	40μ or higher	Braking deceleration is normal for the wheel braking effort applied. Directional control is normal.	Good
4	***At or below -13°C:*** • Compacted Snow	39-36μ	Brake deceleration and controllability is between Good and Medium.	Good to Medium
3	• Wet (Slippery) ***At or below -3°C:*** • Dry or Wet Snow greater than 1/8" ***Above -13°C and at or below -3°C:*** • Compacted Snow	35-30μ	Braking deceleration is noticeably reduced for the wheel braking effort applied. Directional control may be slightly reduced.	Medium
2	***Greater than 1/8" of:*** • Water • Slush ***Above -3°C:*** • Dry or Wet Snow greater than 1/8" • Compacted Snow	29-26μ	Brake deceleration and controllability is between Medium and Poor. Potential for hydroplaning exists.	Medium to Poor
1	***At or below -3°C:*** • Ice	25-21μ	Braking deceleration is significantly reduced for the wheel braking effort applied. Directional control may be significantly reduced.	Poor
0	• Wet Ice • Water on top of Compacted Snow • Dry or Wet Snow over Ice ***Above -3°C:*** • Ice	20μ or lower	Braking deceleration is minimal to non-existent for the wheel braking effort applied. Directional control may be uncertain.	Nil

Notes:

- ***Contaminated runway.*** *A runway is contaminated when more than 25 percent of the runway surface area (whether in isolated areas or not) within the reported length and the width being used is covered by water, slush, frost or snow greater than 0.125 inches (3 mm), or any compacted snow or ice.*
- ***Dry runway.*** *A runway is dry when it is not contaminated and at least 75% is clear of visible moisture within the reported length and width being used.*
- ***Wet runway.*** *A runway is wet when it is neither dry nor contaminated.*
- *Temperatures referenced are average runway surface temperatures when available, OAT when not.*
- *While applying sand or liquid anti ice to a surface may improve its friction capability, no credit is taken until pilot braking action reports improve or the contaminant type changes (e.g., ice to water).*
- *Compacted Snow may include a mixture of snow and imbedded ice.*
- *Compacted Snow over Ice is reported as Compacted Snow.*
- *Taxi, takeoff, and landing operations in Nil conditions are prohibited.*

Figure 2.1: TALPA ARC Paved Runway Assessment Table (Ostronic, 2009)

Note to Figure 2.1 regarding the definition of "depth" (J. Ostronic, FAA, personal communication):

1. The depths specified in Figure 2.1 are actual depths, and not water-equivalents.

2. The runway condition codes are for each third of the runway. The depths are to be the highest measured depth within that third of the runway length within the cleared width of the runway if the runway is not cleared full width.

Friction measurements are downgraded in significance, as they are not the primary source of information, and they can only be used to downgrade the aircraft performance code. With this proposed system, the primary information source and emphasis for RCR is on descriptions of the surface conditions of the runway itself.

2.3.2 The ICAO Friction Task Force

The FTF has a broad mandate to recommend technical directions regarding many friction-related issues. There is consensus within the FTF that a global reporting format is required for runway condition reporting, but agreement was not reached regarding the most appropriate path for achieving this goal, including the role of ground friction measurements.

2.3.3 Information-Gathering Study by the French DGAC

A questionnaire study is in progress regarding: (i) the nature of the information to be transmitted; (ii) the assessment of operational friction characteristics; and (iii) the best approach for organizing and processing the data collected. The initial results from the French DGAC study generally support the results obtained in this project.

2.4 Summary Results from the Questionnaire Surveys

2.4.1 Information Priorities for Summer Conditions: Air Carriers

2.4.1.1 Friction-Related Information

PIREPS and ground friction readings were considered valuable by the largest number of respondents, in that order (Table 2.2). General indications of braking action were considered to be of lesser value.

Table 2.2: Friction or Braking Action Information for Summer Conditions

Parameter	Information Valuable?	Priority
Runway friction values, as measured and produced using a ground friction vehicle	Yes: 75 % of replies No: 25 % of replies	High: 60 % of replies Medium: 10 % of replies Low: 30 % of replies
Summary braking action reports (e.g. good, medium-good, medium, medium-poor, poor)	Yes: 58 % of replies No: 42 % of replies	High: 50 % of replies Medium: 25 % of replies Low: 25 % of replies
Runway braking action reports, as given by pilots of previous flights (PIREPs)	Yes: 92 % of replies No: 8 % of replies	High: 50 % of replies Medium: 37 % of replies Low: 13 % of replies

2.4.1.2 Runway Surface Condition Information

Information regarding the type and depth of contaminant was considered to be most valuable (Table 2.3).

Table 2.3: Runway Surface Condition Information for Summer Conditions

Parameter	Information Valuable?	Priority
Contaminant Type (e.g., damp, wet, flooded)	Yes: 100 % of replies No: 0 % of replies	High: 100 % of replies Medium: 0 % of replies Low: 0 % of replies
Location of contaminants on runway, sub-divided by type	Yes: 67 % of replies No: 33 % of replies	High: 56 % of replies Medium: 22 % of replies Low: 22 % of replies
Presence of rubber deposits (if this affects the braking performance), and their location on runway	Yes: 83 % of replies No: 12 % of replies	High: 56 % of replies Medium: 22 % of replies Low: 22 % of replies
Contaminant depth	Yes: 92 % of replies No: 8 % of replies	High: 89 % of replies Medium: 0 % of replies Low: 11 % of replies

2.4.2 Information Priorities for Winter Conditions: Air Carriers

2.4.2.1 Friction-Related Information

Friction measurements, braking action indications, and PIREPs were all considered to be valuable information with high priority. Generally, the respondents assigned higher value and priority to this type of information for “winter” conditions than for “summer” conditions. Compare Table 2.2 and Table 2.4.

Table 2.4: Friction or Braking Action Information for Winter Conditions

Parameter	Information Valuable?	Priority
Runway friction values, as measured and produced using a ground friction vehicle.	Yes: 91 % of replies No: 9 % of replies	High: 78 % of replies Medium: 11 % of replies Low: 11 % of replies
Summary braking action reports (e.g. good, medium-good, medium, medium-poor, poor).	Yes: 91 % of replies No: 9 % of replies	High: 78 % of replies Medium: 11 % of replies Low: 11 % of replies
Runway braking action reports, as given by pilots of previous flights (PIREPs).	Yes: 100 % of replies No: 0 % of replies	High:88 % of replies Medium: 12 % of replies Low: 0 % of replies

2.4.2.2 Runway Surface Condition Information

Information regarding the type and depth of contaminant was considered to be most valuable (Table 2.5).

Table 2.5: Runway Surface Condition Information for Winter Conditions

Parameter	Information Valuable?	Priority
Contaminant Type (e.g., snow, ice, slush)	Yes: 100 % of replies No: 0 % of replies	High: 100 % of replies Medium: 0 % of replies Low: 0 % of replies
Location of contaminants on runway, sub-divided by type	Yes: 80 % of replies No: 20 % of replies	High: 56 % of replies Medium: 33 % of replies Low: 11 % of replies
Contaminant depth	Yes: 100 % of replies No: 0 % of replies	High:100 % of replies Medium:0 % of replies Low:0 % of replies

2.4.2.3 Summer versus Winter Contaminants

In general, there were more similarities than differences from the survey results with respect to winter versus summer contaminants. Some comparisons are made below:

(a) Description of the Runway Surface Condition, in Particular the Type of Contaminant and its Depth – In both cases, most or all of the respondents indicated that these were valuable, and all respondents put a high priority on this information.

(b) Runway Braking Action Reports, as Given by Pilots of Previous Flights (PIREPs) – These scored high for both contaminant types as respondents considered these to be valuable and put a high priority on this information. PIREPs were considered to be of higher value and priority for winter-contaminated surfaces.

(c) Runway Friction Measurements – These were considered to be of high value and priority for both contaminant types.

(d) General Indications of Braking Action (e.g., the Categories in ICAO, Annex 14, Volume 1) – These were considered to be of medium-to-high value and priority for non-winter contaminants. This information was considered to be of somewhat higher value and priority for winter-contaminated surfaces.

2.4.3 Information Requested by Pilots

The responses regarding the information that was requested by pilots and the relative frequencies were used as an indicator of the relative priorities for the collected information.

2.4.3.1 Summer Conditions

The following general statements can be made:

(a) Most often, pilots request information regarding the runway surface condition, such as contaminant type and depth. Pilots ask for the measured friction values least often.

(b) Relatively few special requests are made by pilots for additional information.

2.4.3.2 Winter Conditions

The following general statements can be made:

(a) Almost all of the respondents indicated that pilots request information for: (i) the runway surface condition, such as contaminant type and depth; and (ii) the measured friction values. Pilots ask for general indications of braking action (i.e., good, medium-good, medium, poor-medium, poor) only about half of the time.

(b) Pilots make more special requests for information for winter conditions than for summer conditions.

2.4.4 Measurement Approaches and Reporting Formats

2.4.4.1 Summer Conditions

There is general similarity among airports, as summarized below:

(a) Friction measurements are not made for operational purposes in summer conditions.

(b) The contaminant type and depth, and the rubber build-up are usually observed, although there are some differences.

2.4.4.2 Winter Conditions

The following general observations can be made:

(a) Friction Measurements – All respondents stated that these are made for operational purposes. A variety of measuring devices are used. As well, the type of information reported to pilots varies as described in the next section.

(b) Runway Surface Condition Reporting – All respondents stated that the contaminant type and depth are observed. The ICAO SNOWTAM format is generally used as the basis for RCR, although several airports have customized it to suit their needs. The contaminant type is determined by visual assessments. The contaminant depth is assessed visually or using simple tools such as a ruler, for contaminant depth. Most, but not all, respondents stated that the cleared width is assessed. The cleared width is estimated visually in all cases.

The ICAO SNOWTAM format contains various contaminant types (e.g., frozen ruts or ridges, rime or frost-covered, etc.) for which definitions are unavailable.

2.4.5 The Friction-Related Information that is Provided to Pilots

Countries differ with respect to what information is provided (Table 2.6). Some countries provide the measured friction values to pilots while others only provide them with a general indication of braking action according to the ICAO scale given in Annex 14, Volume 1. Many of these countries include statements in their AIP regarding the limitations of this scale; and some include a code in the format to signify that the runway conditions are unsuitable for measurement with a friction device, thereby rendering the results from the ICAO scale inaccurate.

The ICAO scale is the one presently in active use. In the past, the FAA recommended providing friction values to pilots, but without any accompanying indication of the braking action. The FAA's position has recently changed such that it considers it "permissible" for airports to provide measured friction values, but it is not "recommended". See Table 2.6 for further information.

Table 2.6: Type of Friction Information or Braking Action Reported to Pilots

Country	Measured Friction Values	General Braking Action Index
United States	"Permissible" to be reported but not recommended[2]	Not recommended or reported[2]
Finland	Reported[3]	Only when friction data not available[3]
Norway	Not recommended to be reported & not reported[4]	Reported Using ICAO Scale[4]
United Kingdom	Not recommended to be reported & not reported	Reported Using ICAO Scale[1,5]
France	Varies among airports[6]	Varies - Reported Using ICAO Scale[1,6]
Germany	Reported[7]	Only when friction data not available[7]
Canada	Reported[8]	Not reported
Italy	Not recommended to be reported & not reported	Reported Using ICAO Scale[1]
Sweden	Not reported	Reported Using ICAO Scale[1]
Netherlands	Not reported	Reported Using ICAO Scale[1]

Notes:

1. See Figure 5.3 (in Volume 4) for the ICAO Scale.
2. The FAA has recently taken a strong position against friction measurements in its recently-updated Advisory Circular (FAA, 2008) which advises that:

   "Airport operators must not attempt to correlate friction readings (Mu numbers) to Good/Medium (Fair)/Poor or Nil runway surface conditions, as no consistent, usable correlation between Mu values and these terms has been shown to exist to the FAA's satisfaction. It is important to note that while manufacturers of the approved friction measuring equipment may provide a table that correlates braking action to Mu values, these correlations are not supported by the FAA".

   "Although the FAA no longer recommends providing friction measurements to pilots for the reasons stated in the paragraph above, some airport users still consider runway friction measurement values to be useful information for tracking the trend of changing runway conditions. Therefore continued transmittal of Mu values is permissible with the understanding that the particular numerical value has no particular significance other than to provide changing runway condition trend information when associated with previous or subsequent runway friction measurement values. Airport operators are cautioned against using Mu values as their sole indicator of winter runway slipperiness"
3. Finland's AIP states that the general braking action should only be reported when friction data are not available. In this case, the estimated braking action should be reported. It is noted that Finnair uses friction measurements made by a BV-11 as an input for operational assessments for its aircraft (Puronto, 2004).
4. In November, 2008, Norway amended its AIC to state that PIREPS are an acceptable means for establishing the braking action. The Norwegian AIP also notes that:

   "*In general there is great uncertainty related to measurement taken on a winter contaminated surface. A measured friction level is associated with the measuring device used and can not be used as an isolated numbe*r … *The table used in the SNOWTAM format item H, with* *associated descriptions, was developed in the early 1950's from friction data collected only on compact snow and ice. The friction levels should not be regarded as absolute values and they are generally not valid for other surfaces than compact snow or ice".*

5. The United Kingdom's AIP states that:

   "It is important to remember that the braking action assessment obtained from the Snow and Ice Table is only a rough indication of the relative slipperiness of a contaminated runway in conditions of compact snow and ice only. The description 'Good' is used in comparative sense – good for an icy surface – and is intended to indicate that aircraft generally, but not specifically, should not be subject to undue directional control or braking difficulties, but clearly a surface affected by ice and/or snow is not as good as a clean dry or even a wet runway. The description 'Good' should not be used for braking action on untreated ice but may be used, where appropriate, when ice has been gritted. 'Poor' will almost invariably mean that conditions are extremely slippery, and probably acceptable only, if at all, to aircraft needing little or no braking or steering. Where 'Poor' braking assessment exists, landings should only be attempted if the Landing Distance Available exceeds the Landing Distance Required on a 'very slippery' or icy runway as given in the aircraft Flight Manual. The intermediate values of 'Medium/Good', and 'Medium,/Poor' have been included only to amplify the description when conditions are found to be Medium. The procedure is insufficiently refined to be able to discriminate accurately in the narrow numerical bands as set out in the table."

6. France – a variety of responses were received from French airports. One stated that friction measurements are made where appropriate based on the limitations of the device, and information is reported to pilots according to ICAO. Another French airport stated that previously, they only provided general braking indications but now, in response to requests from pilots, they provide the measured friction values. Another French airport stated that they routinely report the actual friction readings to pilots and would only give a general indication of braking action if data were not available from a friction-measuring device.

7. Germany – the measured friction values are reported unless the conditions are outside the operational limits of the device. In that case, only general indications of the braking action are provided, based on a matrix that has been developed which provides guidance to the ground friction device operator.

8. Canada has a system based on the Canadian Runway Friction Index (CRFI), as described in its AIM. Also, as part of the regulatory regime in Canada, airports are required to report the CRFI. The CRFI is routinely reported to pilots. The Canadian system is described in detail in Volume 4.

For most of the countries reporting according to the ICAO scale, the braking action is determined based on friction measurements made with a ground vehicle. These countries generally use different friction-measuring devices which is a source of inconsistency, given that the various devices report different values when operated on the same surface. Warnings are present in the AIPs of many countries with respect to the range of applicability of the friction-measuring devices and, hence, the associated braking action index. Some countries include a specific code in their reporting format to signify that the runway surface conditions are unsuitable for measurement with a friction-measuring device.

Some countries use, or allow, other means to establish the braking action index. Examples follow:

(a) Recently, Norway amended its Aeronautical Information Circular to state that PIREPS are an acceptable means for establishing the braking action.

(b) Finland's AIP states that the general braking action should only be reported when friction data are not available. In this case, the estimated braking action should be reported. A similar approach is used by some French airports.

2.4.6 The Methods Used to Establish Operational Data Regarding Aircraft Performance

Five responses were received. This was supplemented with published information for a few airlines (i.e., Southwest Airlines, Finnair, Westjet).

This information-gathering showed that there is considerable variability among airlines with respect to the methods used for determining landing distance requirements. The methods used by the airlines generally ranged between those based on: (a) ground friction readings; (b) surface condition information, principally contaminant type and depth; or (c) a combination of the two information sources.

This information is presented and discussed subsequently in Section 4 and in Volume 4 (Operational Friction) of this report series.

2.5 Review of Relevant ICAO Documents

Relevant information is contained in the following ICAO documents: (a) Annex 6; (b) Annex 14, Volume 1; (c) Annex 15; (d) the Airport Services Manual; and (e) the ICAO ADREP 2000 Taxonomy document.

2.5.1 Taxonomies for Functional Friction or Operational Friction Applications

The first four ICAO documents listed above contain information for these applications. Annex 6 contains definitions for dry, wet, and contaminated runways. Annex 15 also has information regarding the definition of a wet runway, which differs from that in Annex 6. This discrepancy should be addressed by ICAO.

Annex 6 does not contain definitions for the contaminants themselves (snow, slush, ice, etc.) nor does it reference the definitions in the other ICAO Annexes (i.e., Annex 14 and 15). Also, Annexes 14 and 15 do not reference Annex 6 for a definition of a contaminated runway. These documents should be updated by ICAO to include cross-referencing.

2.5.2 Taxonomies for Aviation Accident and Incident Investigations

These are described in the ICAO ADREP 2000 Taxonomy document. They are intended for use as general classifications within the context of an overall database (ECCAIRS). The definitions used in this context are much more general than those used for RCR for operational applications.

2.6 Practices for Functional Friction Applications and Taxonomies

Different reporting requirements are imposed for function friction characteristics versus operational applications, and thus the need for taxonomies.

Functional friction characteristics are presently used by airports and regulators for maintenance purposes in the context that they provide criteria for action by airports as necessary. It is widely recognized that the functional friction maintenance criteria used by national civil aviation authorities are not related to aircraft performance.

The only operational application is that when a runway is approaching a level indicating that the minimum maintenance level is being approached or reached, a notice is sent out indicating that the runway may be "slippery when wet". The ICAO Friction Task Force (FTF) is studying this issue in detail. Because a report from the FTF is not yet available, detailed recommendations are premature. It is recommended that EASA maintain close contact with the ICAO FTF and develop policies accordingly.

With respect to functional friction characteristics, most countries use friction measurements as the basis for their runway maintenance criteria for maintenance planning and action. The Norwegian civil aviation authority (Avinor) appears to be the lone exception as it has implemented criteria based on the runway texture and pavement characteristics. This is considered to be the most significant deviation among those found from the surveys and investigations. This variation would impose the most significant difference in requirements for reporting and taxonomies.

Practices also vary among countries using friction measurements as the basis for their functional friction criteria. There are differences with respect to: (a) the device(s) accepted; (b) the tire types used; (c) the test speeds used; and (d) the water film depth used for measurement.

Functional friction characteristics are discussed in detail in Section 3 and in Volume 3 of this report series.

2.7 Runway Condition Reporting Practices for Operational Friction Applications

2.7.1 "Summer" Versus "Winter"

RCR varies between "summer" and "winter", which is roughly divided along the lines of liquid versus frozen contaminants. This distinction is an artificial one though as:

(a) Liquid precipitation and liquid surface contaminates also occur during winter when the surface temperature is approaching, is at, or is below 0°C; and

(b) Frozen precipitation often occurs during summer months in the form of hail or snow, and sometimes frost, particularly at sites in the northern hemisphere.

It is noted that various agencies and presently-ongoing initiatives (i.e., TALPA ARC, ICAO) do not explicitly distinguish between "summer" or "winter" contaminants. This is considered to be logical.

However, at the same time, runway condition reporting practices at airports generally vary between "summer" and "winter", in response to for example, the need to establish "snow plans" over certain parts of the year. As a result, often, there are variations in reporting procedures between "summer" and "winter", with respect to parameters such as the contaminant type and depth. This issue has been considered further in Section 4, which discusses operational friction characteristics and runway condition reporting.

2.7.2 "Summer"

Operational reporting for summer conditions can be briefly summarized as follows:

(a) Friction is not measured on an operational basis (e.g., during a rainstorm) although functional friction measurements are made at regular intervals.

(b) NOTAMs are issued when a runway may be "slippery when wet".

2.7.3 "Winter"

Operational reporting for winter conditions generally involves two main activities: (a) the collection of friction-related information; and (b) observations of the runway surface conditions.

With respect to friction-related information, the information that is transmitted to pilots varies among countries. It can include: (a) the measured friction values; (b) general indications of the braking action (based on the scale in ICAO Annex 14, Volume 1); and/or (c) PIREPs.

Different countries use different Ground Friction-Measuring Devices (GFMDs), which report different values when operated on the same surface. There is general consensus that GFMDs are most suitable for "solid" surfaces such as compacted snow and ice. Furthermore, they are all generally considered to be unreliable on fluid or fluid-like surfaces (slush, wet, de-icing chemicals, etc.). This is borne out by warnings in the AIPs of many countries regarding the limitations of GFMDs.

Observations of the runway surface conditions include defining parameters such as the contaminant type, the contaminant depth, the cleared width, and others. This information is typically estimated visually. In the case of the contaminant depth, it might be measured using crude instruments such as a ruler or estimated using a simple threshold exceedence gauge (i.e., to indicate whether or not the depth exceeds 3 mm for example).

Runway condition reporting for operational applications is discussed further in Section 4 and in Volume 4 of this report series.

2.8 General Nature of Present Definitions and Options for Harmonization

The definitions used at present are typically a mix between descriptive criteria that can be applied easily in the field and ones that are quantitative, which are intended to avoid subjectivity. For example, the ICAO definition for compacted snow contains practical/subjective descriptions such as "will hold together or break up into lumps if picked up" as well as the scientific/quantitative criterion that the specific gravity is to be greater than 0.5.

The harmonization process involves both technical and policy issues. Only technical ones have been investigated here. Various options for harmonization were considered:

(a) Maintaining the Status Quo – This is not considered to be acceptable, as it would not address the safety concerns being expressed.

(b) Making the Definitions More Scientific/Quantitative – This would have the advantage that they would be defined using measurable parameters. This would probably reduce the variability among observers; but in all probability, this approach would be impractical in an operational airport environment.

(c) Making the Definitions More Practical/Subjective – This would probably not meet the requirements of all user groups.

(d) Utilizing the Taxonomies in Place for Aviation Accident and Incident Investigation – These are considerably more general than those used, or considered to be needed, for operational RCR. Hence, this approach would not provide a feasible way forward for harmonizing the different taxonomies.

(e) Basing Harmonization Efforts on Relationships to Aircraft Performance – This is considered to be the most appropriate basis for harmonization, and it is the one that is most closely linked to the overall goal of maintaining a high level of safety. The TALPA ARC system is the only one that has been developed taking aircraft performance into account explicitly. This gives it a very strong advantage; and as a result, this has been used as the basis for many recommendations in this project. It is noted though that field trials related to the TALPA ARC reporting process will be taking place during the 2009-2010 winter at some American airports which may potentially lead to some changes. Consequently, the recommendations made here are preliminary. EASA is advised to monitor these field trials closely as well as any other developments related to the TALPA ARC's recommendations.

2.9 Definitions Related to Runway States and What Constitutes a Contaminant

These are the basic definitions, and it is fundamental that these be harmonized first.

It was found that the aviation community is trending towards a three-point scale for the runway state (i.e., dry, wet, and contaminated) and that the definitions for these three states are generally similar. This trend will help encourage harmonization.

For dry and wet runways, the various definitions are essentially equivalent.

For contaminated runways, the only difference of significance is considered to be which contaminants are specifically named or listed. None of the definitions specify whether the contaminant lists they contain are intended to be all inclusive or not, which leaves open the question of where materials not specifically named would fit. Some other contaminants of concern include:

(a) Sanded surfaces or sand itself;

(b) Ice control chemicals, whether they be in liquid form or in mixtures with materials such as slush or snow;

(c) Layered contaminants such as loose snow over compacted snow or ice; and

(d) Various other materials, such as dirt or debris, rubber build-up, and other infrequent frozen contaminants, such as frozen airborne residue from industrial processes.

2.10 Contaminant Definitions: Water on the Runway

There are three basic cases: (a) damp; (b) wet; and (c) flooded. The definitions for each case are essentially equivalent.

Because the aviation community is heading towards a three-point scale for runway state (i.e., dry, wet, or contaminated), the need for a definition of damp can be questioned, as a damp runway would be considered to be wet. However, there are a number of performance standards and advisory circulars presently in force that require a definition for damp. Consequently, a definition for damp is still believed to be required until consistency is achieved with respect to the associated performance standards.

2.11 Contaminant Definitions: Winter Contaminants

A very large number of surface conditions occur in winter. A precise classification system would involve a multitude of categories and parameters which would probably produce an unworkable system in an operational airport environment.

The TALPA ARC process has indicated that it is not necessary to define a large number of contaminant types as there is not a corresponding effect on aircraft performance. The TALPA ARC process has resulted in only seven aircraft performance codes being defined, in relation to various surface contaminants (Figure 2.1). This is considered to be a very important outcome, as it helps to identify the key surfaces while offering potential for simplifying the overall reporting process.

The contaminant types identified by the TALPA ARC can be broadly defined as follows:

(a) Loose contaminants such as dry snow or wet snow;

(b) Liquid contaminants such as water or slush;

(c) Solid contaminants such as frost, ice, or compacted snow; and

(d) Layered contaminants, such as wet ice, water on compacted snow, and dry or wet snow over ice.

Definitions are available from various sources for all of the above contaminants. The most serious gap in the present set of definitions is in relation to frost. Only Transport Canada has a definition for it at present. This is problematic because the TALPA ARC code varies greatly depending on whether the surface is frost (in which case the code is ‘5’) or ice (in which case the code is ‘1’ or ‘0’ for ice or wet ice, respectively).

2.12 Inferences from TALPA ARC Regarding Important Winter Contaminants

An examination of the TALPA ARC Runway Assessment Matrix shows that the same aircraft performance code is produced by various types of contaminants (e.g., dry vs. wet snow for all contaminant depths and temperatures), which suggests that it is not necessary to distinguish all of the surfaces listed by the TALPA ARC for RCR. See Table 2.7. Thus, some further simplification for RCR might be possible; but recommendations are reserved pending the results of the field trials that will be undertaken during the 2009-2010 winter.

The TALPA ARC’s recommendations have implications for RCR, as the significance of the parameters varies. In general, it can be seen that, for the purpose of RCR, one would have to define all of the ones below to determine whether or not they are significant:

(a) Contaminant type;

(b) Contaminant depth;

(c) Temperature; and

(d) Contaminant layering.

Table 2.7: Equivalent Runway Surface Conditions Based on TALPA ARC

Code	Contaminant	Temperature	Depth
6	Dry	Any	n/a
5	Wet Surface	Any	
	Frost	Any	
	Water	Any	<= 1/8”
	Slush	Any	<= 1/8”
	Dry Snow	Any	<= 1/8”
	Wet Snow	Any	<= 1/8”
4	Compacted Snow	<= -13 C	
3	Wet (Slippery When Wet)	Any	
	Dry Snow	<= -3 C	>1/8”
	Wet Snow	<= -3 C	>1/8”
	Compacted Snow	-3 to -13 C	
2	Water	Any	>1/8”
	Slush	Any	>1/8”
	Dry Snow	> -3 C	>1/8”
	Wet Snow	> -3 C	>1/8”
	Compacted Snow	> -3 C	
1	Ice	<= -3 C	
0	Wet Ice	Any	
	Water on Compacted Snow	Any	
	Dry or Wet Snow Over Ice	Any	
	Ice	>= - 3 C	

3 FUNCTIONAL FRICTION CHARACTERISTICS

Section 3 is divided with respect to the three main tasks in the scope of work for this part of the project:

(a) Scientific and Operational Consolidations of Harmonization;

(b) Investigations for Alternative Methods to Evaluate Surface Friction Characteristics; and

(c) Definition of a Stepwise Procedure and Guidelines for Harmonization.

The last sub-section of Section 3 presents recommendations regarding updates to the device equivalency table in ICAO Annex 14, Volume 1.

Detailed information regarding all tasks is presented in Volume 3 of this report series.

3.1 Scientific and Operational Consolidations of Harmonization

This part of the study investigated the scientific consolidation of harmonization of functional friction characteristic measurements.

As a start, present practices used for friction measurement devices were reviewed, including evaluations of the effect that different parameters can have on the friction readings. The presently-available friction-measuring devices can be grouped into four categories as shown in Tables 3.1 and 3.2.

Table 3.1: Methods of Measurement for Surface Friction Measurement

Device Type	Sampling Provided	Available Configurations
Locked-wheel testers	Spot Measurement Continuous record	Decelerometer mounted in a vehicle Trailer with locked wheel towed by vehicle
Side-force testers	Continuous record	Trailer towed by vehicle
Fixed-slip testers	Continuous record	Trailer towed by vehicle Fifth wheel in vehicle
Variable-slip testers	Continuous record	Trailer towed by vehicle Instrumented wheel under a truck body

The types of devices used commonly at airports are summarized below:

(a) Functional friction measurements: side force and fixed-slip testers.

(b) Operational friction measurements: locked wheel testers (decelerometers); side force testers; and fixed-slip testers.

Table 3.2: Overview of High-Speed Pavement Friction Test Methods

Test Method	Associated Standard	Description	Equipment	
Side-Force	ASTM E 670	Side-force friction measuring devices measure the pavement side friction or cornering force perpendicular to the direction of travel of one or two skewed tires. Water is placed on the pavement surface (4 gal/min [1.2 L/min]) and one or two skewed, free rotating wheels are pulled over the surface (typically at 40 mi/hr [64 km/hr]). Side force, tire load, distance, and vehicle speed are recorded. Data is typically collected every 1 to 5 inches (25 to 125 mm) and averaged over 3-ft (1-m) intervals.	The British Mu-Meter, shown at right, measures the side force developed by two yawed (7.5 degrees) wheels. Tires can be smooth or ribbed. The British Sideway Force Coefficient Routine Investigation Machine (SCRIM), shown at right, has a wheel yaw angle of 20 degrees.	 
Fixed-Slip	ASTM E 274	Fixed-slip devices measure the rotational resistance of smooth tires slipping at a constant slip speed (12 to 20 percent). Water (0.02 in [0.5 mm] thick) is applied in front of a retracting tire mounted on a trailer or vehicle typically traveling 40 mi/hr [64 km/hr]. Test tire rotation is inhibited to a percentage of the vehicle speed by a chain or belt mechanism or a hydraulic braking system. Wheel loads and frictional forces are measured by force transducers or tension and torque measuring devices. Data are typically collected every 1 to 5 in (25 to 125 mm) and averaged over 3-ft (1-m) intervals.	Roadway and runway friction testers (RFTs) shown at right. Airport Surface Friction Tester (ASFT), shown at right. Saab Friction Tester (SFT), shown at right. U.K. Griptester, shown at right. Finland BV-11. Road Analyzer and Recorder (ROAR).	   

Test Method	Associated Standard	Description	Equipment	
			ASTM E 1551 specifies the test tire suitable for use in fixed-slip devices.	
Variable-Slip	ASTM E 1859	Variable-slip devices measure friction as a function of slip (0 to 100 percent) between the wheel and the highway surface. Water (0.02 in [0.5 mm] thick) is applied to the pavement surface and the wheel is allowed to rotate freely. Gradually the test wheel speed is reduced and the vehicle speed, travel distance, tire rotational speed, wheel load, and frictional force are collected at 0.1-in (2.5-mm) intervals or less. Raw data are recorded for later filtering, smoothing, and reporting.	French IMAG. Norwegian Norsemeter RUNAR, shown at right. ROAR and SALTAR systems.	
Locked-Wheel for highways	ASTM E274	This device is installed on a trailer which is towed behind the measuring vehicle at a typical speed of 40 mph (64 km/h). Water (0.02 in [0.5 mm] thick) is applied in front of the test tire, the test tire is lowered as necessary, and a braking system is forced to lock the tire. Then the resistive drag force is measured and averaged for 1 to 3 seconds after the test wheel is fully locked. Measurements can be repeated after the wheel reaches a free rolling state again.	Testing requires a tow vehicle and locked-wheel skid trailer, equipped with either a ribbed tire (ASTM E501) or a smooth tire (ASTM E524). The smooth tire is more sensitive to pavement macro-texture, and the ribbed tire is more sensitive to micro-texture changes in the pavement.	
Locked-Wheel for airport runways	ASTM E2101	The device is a decelerometer that is installed in a host vehicle which is put into a locked-wheel skid. 	Testing requires a decelerometer and a host vehicle. The decelerometer types commonly used for runway friction measurements include: (i) the Electronic Recording Decelerometer (ERD); (ii) the Bowmonk;(iii) the Tapley; and (iv) the NAC device.	

It was concluded that, although the devices relevant for airports only employ a few different measurement principles, they all have a significant number of design and operational differences. In combination with major differences in measurement tires, this variation in measurement principles and design produces variations among the devices with respect to the measured friction values. These differences can be categorized as follows:

(a) Measurement principle, and design differences within the same principle, such as for example, slip ratio variations for fixed slip devices, and the side force angle for side force devices;

(b) Measuring tire parameters;

(c) Braking mechanism;

(d) Loading force; and

(e) Watering system.

Next, current and past harmonization trials were reviewed. This review included research projects aimed at harmonization, such as projects and trials aimed at: (a) investigating trends and effects; and (b) possible compensation methods for the differences employed by the different friction measurements devices in use.

It was found that the friction readings of the different devices are significantly affected by many factors including: (a) the braking slip; (b) the tire pressure; (c) the tire design; (d) the tire tread and materials; (e) the method used to derive the friction coefficient; and (f) the self-wetting systems used.

It was concluded that, of these parameters, the braking slip ratio is the only physical parameter that is sufficiently well understood, with a precise and empirically-tested model that is both of high enough quality and practical enough, to be used in harmonization models.

The relationship of the measured friction coefficient to differences in device braking mechanism and derivation of braking friction is relatively well explained from applied physical models, but the models are not sufficiently tested nor are they practical for use in a harmonization process in their present forms.

Variations in delivered water depth, water delivery and distribution profile and various tire parameters also affect the measured friction coefficient. However, although their significance is recognized, their effect cannot be reliably quantified and therefore accounted for using any of the presently available models.

One possible way to overcome these problems for scientific consolidation and harmonization would be to use a physically-based formula to compensate for the differences among the devices. This pre-supposes that a suitably well defined and precise formula is available. For parameters where a formula is not available, harmonization could proceed by standardizing these other parameters. This would eliminate the differences in the different friction measurement devices and consequently their effects on the friction measurement readings.

After examining the significance of the parameters affecting the friction readings and available or potential compensation models all of the recent and new harmonization models and trials (Table 3.3) were reviewed in an effort to determine the best candidate(s) for a harmonization model.

Table 3.3: Summary of Previous Harmonization Attempts and Models

	Scenario =>	#0	#1	#2	#3a	#3b	#4	#5	#6	#7	#8a	#8b	#9	#10	#11	#12	#13
F-model	$F = F_0 \cdot e^{-S/S_0}$	×	×	×	×	×	×	×	×	×	×	×				×	×
	$F = F_0 \cdot e^{-(S/S_0)^a}$												×	×	×		
S_0-model	$S_0 = 57 + 56 \cdot MPD$	×	×														
	$S_0 = a \cdot MPD^b$ (1)			×	×	×	×	×	×	×	×	×	×	×	×		×
	Actual S_0-value from *F(S)*															×	
EFI-model	$EFI = A + B \cdot F_{30}$	×	×	×	×	×	×										
	$EFI = B \cdot F_{30}$							×	×	×	×	×	×	×	×	×	×
Calibration method	$<< EFI >>= \alpha + \beta \cdot EFI$	×	×	×	×	×											
	$EFI = \alpha' + \beta' \cdot << EFI >>$						×										
	$<< EFI >>= \beta \cdot EFI$							×	×	×	×	×	×	×	×	×	
	$<< EFI >>= \beta \cdot < EFI >$																×
Statistical tests	$F > 0.01$	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×
	$S_0 > 0$	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×
	$\sigma_r(F) < 0.04$	×	×														
	$\sigma_{EFI} > 0.07$	×															
	$R_F^2 > 0.5$			×			×	×	×	×	×	×	×	×	×	×	×
	$R_{EFI}^2 > 0.5$			×	×	×	×										
	$CV_{EFI} >$				10%	5%	10%										
	"k-test" (0,5%)			×													
	"h-test" (0,5%)			×													
Discarded devices									F05	F05 F15	F05 F15 SFC	BFC (2)	F05	F05 F15	F05 F15	F05 F15	F05 F15

(1) With weighting . (2) F05 and F15 were also discarded here since they are of *BFC*-type

Note:

Table 3.3 is discussed in detail in Volume 3 of this report series.

This produced the following results and conclusions:

(a) All of the harmonization models had some success in reducing the differences in readings among the various friction measurement devices. Unfortunately though the reductions achieved were relatively minor and the harmonized results still had significant variations. Even though fourteen (14) different methods were investigated, including combinations of the alternative treatments, the resulting harmonization was better, but not ideal, and it was not believed to be acceptable for general use.

There are two main reasons for the relative lack of success in these harmonization efforts: (i) the friction readings contain uncertainty which can be attributed to issues related to the repeatability and reproducibility of the devices themselves; and (ii) the numerical models used as the basis for harmonization are imperfect, which reflects the fact that the current knowledge base is incapable of fully describing the interaction processes that occur in an accurate, reliable, quantitative manner.

(b) The devices are not time-stable as the device-dependent parameters of the physical and statistical representation of the investigated harmonization models changed significantly with time. This phenomenon had not been investigated to any significant extent by the prior work. However, for progress to be made, this must be addressed, and it has been considered in the recommendations made for harmonization in this study.

(c) The existing harmonization models do not guarantee that the friction estimate obtained can be correlated to actual aircraft braking performance within acceptable limits. It is widely recognized that the friction criteria used at present by airports for runway maintenance planning or action are not directly related to aircraft performance. This issue should be considered given that one of the most important purposes of harmonization trials is to produce results that are meaningful indicators of aircraft braking performance on wet runway surfaces.

It is understood that this issue is also being considered by the ICAO FTF in relation to the most appropriate interpretation of the term “slippery when wet”. Furthermore, the project team was advised that the ICAO FTF intends to develop detailed guidance with respect to how this issue should be addressed with future work. Because a report from the ICAO FTF is not yet available, detailed conclusions are premature.

Finally, assessments were made regarding the feasibility of harmonization. This included identifying issues and topics that need to be considered for the harmonization model.

It was concluded that none of the previous harmonization models produced satisfactory results in their present forms, with their presently established procedures. The reviews and the investigations, as well as the comparative research projects performed for evaluating the different harmonization models, showed that these unsatisfactory results can be traced to a number of sources including:

(a) Weaknesses in the models and procedures themselves;

(b) Changes in the reference sources used, whether they be reference surfaces, or reference devices; and

(c) Quality control issues related with harmonization trials.

A number of key elements were identified for the harmonization procedure and model development as follows:

(a) <u>Reference Surfaces</u>. It is necessary to develop special reference surfaces which deliver frictional characteristics that are time-stable, economical to produce, and for which manufacturing or construction is predictable and reproducible.

(b) Reference Device. It is necessary to develop or identify a reference device(s) that is: (i) stable in time in performance; (ii) economical to produce and use; and (iii) repeatable and reproducible with regard to measurement results.

(c) Quality Requirements. It is necessary to define a set of strict quality requirements for all the devices that can be included in a harmonization process. These quality requirements have to include repeatability, reproducibility, and time-stability requirements.

3.2 Investigations for Alternative Methods to Evaluate Surface Friction Characteristics

Alternative methods to evaluate surface friction characteristics were investigated as part of the work.

First, the technologies currently used for friction characteristics and texture measurements were surveyed as well as any other alternative methods. This review also included an extensive evaluation of friction characteristics and texture measurement technologies. It was based on the different categories of friction and texture measurement technologies including their method and basic make-up of equipment, measurement procedure, measurement indexes, and advantages and disadvantages.

It was concluded that the most suitable reference devices at present for possible harmonization are the DF Tester for friction measurements and the CT Meter for texture measurements. (These devices are described in Volume 3). This conclusion was based on the facts that both of these devices are very reliable, time stable and economical, and provide repeatable and reproducible results.

The last step in this investigation was to assess alternative methods for friction characteristics measurements other than the friction-measuring devices. Four different alternatives were considered, as follows:

(a) Theoretical Approach – This would be based on knowledge of the surface's macro- and micro-texture properties and the tire's visco-elastic properties.

(b) Calculating the aircraft braking action directly from data collected by the aircraft during landing.

(c) The use of pavement-only properties such as texture and geometry. It is noted that Norway has recently (July, 2009) implemented this approach.

(d) Visual Inspection – This approach involves: (i) using laser to detect surface irregularities and contaminants on the surface; and then (ii) using this information in a projection methodology to predict friction.

The first approach (i.e., a theoretical approach) has been available since Kummer developed his model in 1966 (Kummer, 1966). Unfortunately though, as of yet, there is no effective way of measuring pavement micro-texture. This made it impossible to effectively use this method in the past, and probably it will cause it to not be applicable in the near future as well. However, due to the rapid development of digital photography, this approach might be an option in the longer term future.

Approaches (b) and (c) are in their very early stages; and even though proof-of-concepts have been developed, there is still a need for a considerable amount of work to verify and evaluate their effectiveness, objectiveness, suitability, and comparability through the different climates, regions and countries.

As a result, for the very near future, this leaves no alternative method that can be used instead of friction-measuring devices. For longer time horizons, there are a number of promising technologies and EASA is advised to monitor them, and perhaps encourage them, depending on the initial results.

3.3 Definition of a Stepwise Procedure and Guidelines for Harmonization

The development of a stepwise procedure and guidelines for harmonization of friction measuring devices was the final result for the functional friction investigation. The full flow diagram of the recommended harmonization procedures and surrounding set of requirements is given in the flow chart shown in Figure 3.1. The recommendation includes the following steps:

(a) Quality testing requirements such us the repeatability, reproducibility, and time stability for each Friction-Measuring Device (FMD) - a detailed specification of the testing process is included (in Volume 3) in these requirements, as well as the calculation process for the repeatability, reproducibility, and time stability. Cut-off values are also recommended (in Volume 3) for repeatability, reproducibility, and time stability for a FMD that would be considered suitable to participate in a harmonization process.

(b) Technical specification requirements that define the necessary technical specification of the FMDs that is necessary for functional friction characteristic measurement on runways and fulfils our requirements for the harmonization process.

(c) Harmonization Process - the recommendations made include a detailed description of the harmonization testing setup and process and evaluation. The recommendation also includes information regarding the reference device and descriptions of the reference surfaces.

The recommended stepwise procedure and guidelines for harmonization for FMDs, was developed by first reviewing and evaluating the FMD quality testing requirements in ASTM, ISO, CEN, and ICAO standards. It was found that these standards and practices only include requirements for repeatability and sometimes accuracy, if they include any criteria. Furthermore, repeatability and accuracy are not defined consistently in some cases, which will lead to confusion. The only standard that refers to a specific methodology for calculating these values is the CEN/TS 13036-2:2009.

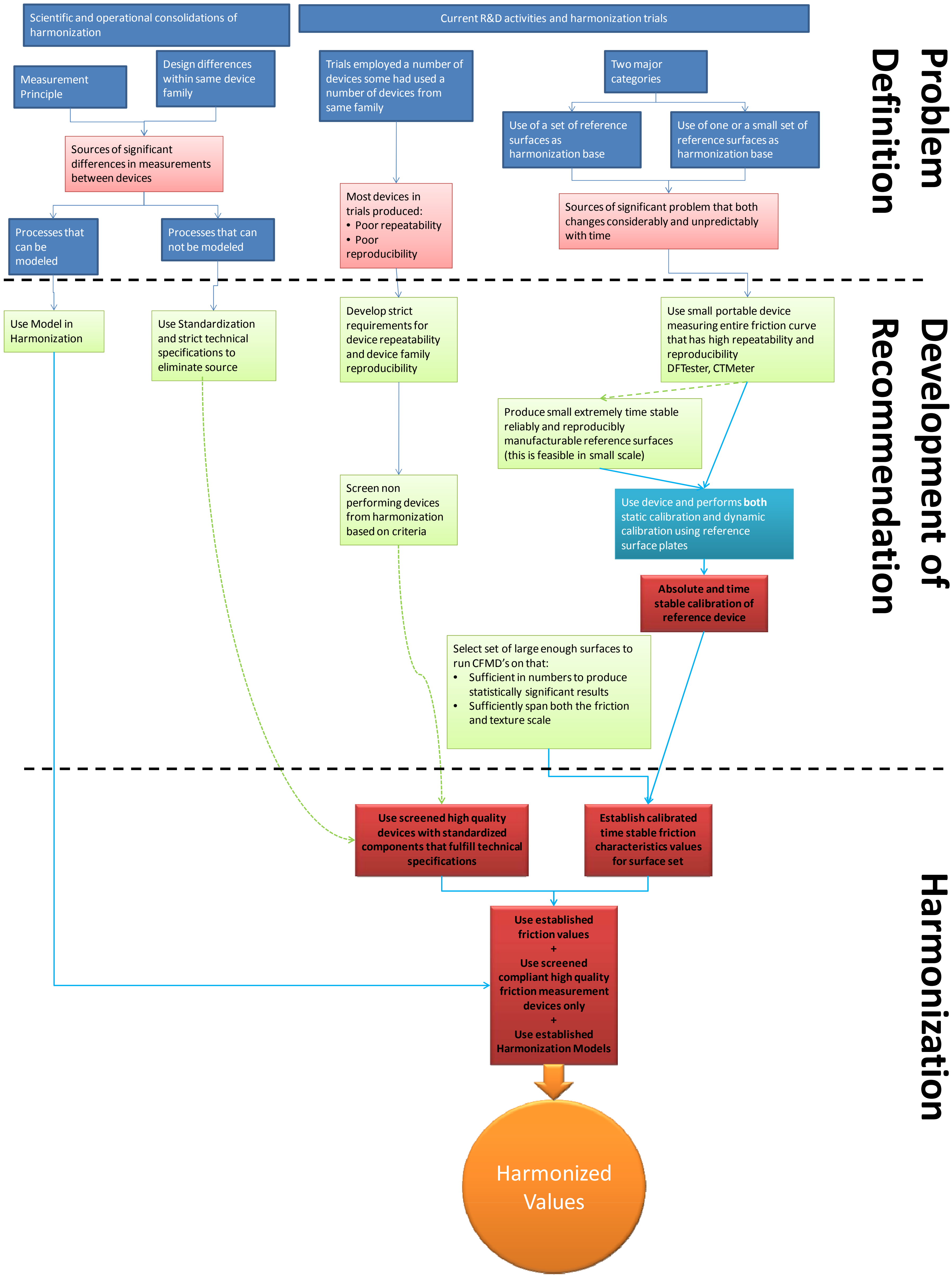

Figure 3.1: Full Flow Diagram of the Recommended Harmonization Procedures and Surrounding Set of Requirements

It is believed that these qualification testing requirements are not sufficient for consolidation of harmonization. Therefore, separate recommendations were developed in this project for complete qualification testing requirements.

The technical specification used for functional friction characteristic measurement with FMDs on runways was also reviewed to ensure they are sufficient for the harmonization purposes of this project. The proposed harmonization approach is based on the fact that some of the FMD parameters significantly affect the friction readings; and at this point, reliable methods are not available to compensate for these differences. As a result, the proposed technical specification is based on a recommendation to standardize all these parameters. Therefore, we developed our own technical specification where all the parameters significantly affecting the friction readings are standardized.

The recent and new harmonization processes were also investigated with respect to the quality requirements of these harmonization processes. It was concluded that these processes/models do not include sufficient quality requirements for accuracy, consistency, uncertainty and frequency. There are no cut off values defined that must be met by a FMD for it to be acceptable for functional friction measurements on runways. As a result, recommendations were developed in this project for the quality requirements, and they are included in this section of the report.

Recommendations for the harmonization process are based on all the results from the above investigations. Recommendation were developed taking all of the above into account for the harmonization process including the setup, testing process, and evaluation process.

(a) First of all, it is recommended that only those FMDs that fulfill the technical specification requirements be used in the harmonization testing. This will ensure that all parameters that are significantly affecting the friction readings have been eliminated by standardized components.

(b) It is also recommended that all FMD families be required to be tested for repeatability and reproducibility, and only those that fulfill the specified quality requirements be used in the harmonization testing.

(c) It is also recommended that the DF tester and the CT meter device family be used as the reference measuring device for frictional and texture measurements. (These devices are described in Volume 3). These devices are already proven reliable, with good repeatability, device reproducibility and time stability. Despite these good qualifications, dynamic calibration of these devices is still recommended before each harmonization testing. It is also recommended that at least three, and not just one single DF tester and CT meter, be used for reference device.

(d) As these devices are spot measuring devices, their dynamic calibration can be done on a small area, 2 feet by 2 feet in size. That would reduce the problem of producing a reference surface by only requiring the production of a 2-foot by 2-foot surface. After the dynamic calibration of the reference devices on these small reference surfaces, they can be used for harmonization process on any set of surfaces. The recommended process for the harmonization testing is included in the report in Volume 3.

(e) For the harmonization model itself, an EFI or IFI type of harmonization would be used, where it would only be necessary to compensate for differences in slip ratio because all the other parameters that could significantly affect the friction readings would have been standardized.

(f) It is recommended that quality requirements be set for the harmonization testing, and that only those devices that fulfill these requirements be allowed for use for functional friction characteristic measurements at airports.

(g) It is recommended that harmonization testing be conducted annually to ensure that the device has acceptable time stability. It is recommended that the annual device constants be compared. If the difference is more than a preset threshold value, the device should not be considered acceptable for use for functional friction characteristic measurements on airports.

3.4 Updating the Device Equivalency Table in ICAO Annex 14

The feasibility of amending the device equivalency table in ICAO Annex 14 Sup A was investigated using various harmonization approaches.

It was concluded that, at this point, only the established harmonization methods, such as the IFI with its already developed device constants, could be used to amend the ICAO Annex 14 Sup A table.

The results showed that this would result in substantial variations in the values depending on which year was used to establish the IFI device constants. Table 3.4 shows sample results for the Transport Canada SFT. This finding would be very similar for any other devices and any other harmonization models.

Table 3.4: Variations by Year Using the IFI Model for the TC SFT

	Minimum	Maintenance	Construction	New Grooved
SFT-TC79-E1551-100 (2000)	0.32	0.40	0.56	0.62
SFT-TC79-E1551-100 (2001)	0.46	0.54	0.72	0.79
SFT-TC79-E1551-100 (2003)	0.50	0.55	0.70	0.76

Therefore, at this point, it is recommended that the ICAO table not be amended. Instead, it is recommended that a harmonization test be designed based on the requirements and design parameters recommended in this part and that this be used with the new device parameters to amend the ICAO table.

4 PART 3 – OPERATIONAL FRICTION CHARACTERISTICS

For the sake of clarity, this summary is divided into four parts, together with the associated recommendations: (a) runway surface condition assessment; (b) condition reporting; (c) condition measurement technologies; and (d) friction-related information.

Detailed information regarding each topic is provided in Volume 4 of this report series.

4.1 Runway Surface Condition Assessment

4.1.1 Summary of Findings

The TALPA ARC concept for operational performance on winter contaminated runways is a major condition reporting and interpretation initiative which will result in significant changes to current airport operations if it is put into practice. If this were adopted by EASA, its member-states, air carriers, and airports would be directly affected and there would be a direct influence on the standards used.

There is a deficiency at airports regarding the information that aircraft operators require to effectively manage landing and take-off manoeuvres on contaminated runways. Airports try to err on the side of providing too much information rather than too little.

Current regulations lack sufficient detail for unambiguous interpretation. Enhancement of regulations addressing the following aspects of condition inspection would provide clearer direction to airports and improve the consistency and accuracy of operational condition reporting:

(a) Contaminant Definitions (addressed in detail in Volume 2 of this report series) – Clear direction to airport operating authorities and RIs is required on the source of contaminant definitions to be used in operational condition reports.

(b) Aircraft Movement Surface (AMS) Assessment Frequency – Clearer direction is needed regarding the permissible intervals between operational inspections, especially during rapidly changing conditions.

(c) RI Qualifications – Restricting AMS inspection and reporting duties to qualified staff would significantly increase confidence in reported information.

(d) Condition Estimating Techniques – Few if any references can be found regarding runway condition estimating techniques. Documented requirements would promote uniformity in reporting.

(e) Runway Inspector (RI) Training and Testing – Having RIs complete training that meets specific standards and providing direction on training content, retention of records, requirements for cyclical requalification, and other related issues would help to standardize inspection procedures and address some of the human factor issues discussed elsewhere in this report.

(f) Auditing of Airports' Internal Directions on Runway Inspection Procedures – Auditing by regulators of airport operating authorities' internal procedures, systems, and other related components of the inspection and reporting process would promote compliance with common standards.

Improved direction and advice is required to airport operating authorities regarding interpretation and accuracy of reporting terminology, contaminant measurement and location and the reporting of layered contaminants.

Human factors have a significant influence on the accuracy and timeliness of condition reports. Direction and advice to airports would assist them in recognizing and managing the related issues.

Clear direction to airports is required regarding the need to close contaminated runways for maintenance purposes and to act in consort with the air navigation service provider to ensure there is sufficient runway access and time to perform complete, uninterrupted runway inspections, especially during inclement weather.

4.2 Runway Condition Reporting

4.2.1 Summary of Findings

In the overwhelming majority of cases, formal operational condition reporting takes place only in winter. Airports structure their operations on the premise that this is when the requirement exists; however the requirement for reporting of contaminants, etc. exists year-round. Direction is required on year-round reporting of contaminated runways.

There is inconsistency in direction to airports and in airports' interpretation of the reportable condition parameters, the required degree of accuracy, the reporting frequency, report scheduling, and the criteria for issuing new reports.

The current ICAO SNOWTAM format and related directions for its completion should be updated to bring them in line with current definitions and condition reporting requirements for consistency and clarity.

Norway has instituted direct electronic issuance of SNOWTAMS by RIs from the runway inspection vehicle, including data verification. Although checks are provided by the ANS through an intelligent computer program, air traffic controllers and flight service specialists are not required to handle the reports. This has resulted in SNOWTAMS being published within 20 seconds of the RCR being filed, which is a major improvement in timeliness. Sweden is currently trialing the process.

4.3 Technologies for Runway Condition Measurement

4.3.1 Summary of Findings

At present, there is a strong need for accurate reporting of the runway condition itself, with respect to parameters such as the contaminant type, the contaminant depth, cleared width, etc. This is evident from various sources, including the surveys done by questionnaire in this project (which are described in Volume 2). The TALPA ARC recommendations, if enacted, will produce an even stronger need for accurate reporting of the runway surface conditions, as they are recommending that RCR emphasis be refocused from friction measurements to observations of physical condition parameters.

The ICAO FTF agreed that a common global reporting format is required but could not reach consensus regarding the most appropriate path for achieving this goal. There was a divergence of views within the FTF regarding the role of ground friction measurements.

The accuracy and reliability of reported condition values will be enhanced if RIs are equipped with measuring tools and processes. Measurements rather than estimates of conditions would increase the accuracy and reliability of reports without sacrificing the ability of RIs to enhance reports with their observations and alerts to specific concerns. The "common sense" approach to condition reporting is currently (and is likely to remain) the foundation of the most valued condition evaluation and reporting systems.

Currently, there are few if any tools available to airports to assist them in quantifying runway conditions. The only measuring tools at present are crude instruments such as rulers or threshold gauges to measure contaminant depth. Consequently, a long time is required to make measurements, which makes this approach unsuitable at a high-volume operational airport. As a result, practically all information related to the runway surface condition is estimated visually at present.

The credibility of the runway surface condition assessment process would be improved if equipment were available that could identify the contaminants on the runway and that could quantify the contaminants in terms such as depths, cleared widths, contaminant patches, etc.

A technology review was conducted. No off-the-shelf equipment was found that would allow the important runway surface condition parameters (contaminant type, contaminant depth, cleared width, contaminant location, cleared width offset, area coverage, etc.) to be measured with sufficient accuracy and rapidity to fulfill operational runway condition reporting requirements.

With regard to availability of systems related to condition measurement and reporting, with few exceptions, the historical practice has been for manufacturers to independently develop a product that they consider would be beneficial to airports. This product would then be field-tested by staff at airports to determine the effectiveness and usefulness of the product. The result is typically a product which works to some extent. It is perhaps time for airports and the aviation community to clearly define requirements and work jointly with the manufacturers in development of new products.

A number of relevant research programs have recently been conducted, which offer potential (Table 4.1). These should be monitored and perhaps encouraged.

Table 4.1: Potential Applicability of Sensing Technologies

	Maintained Path Width	Maintained Path Offset	Contaminant Type	Contaminant Location	Contaminant Depth
Spectral analysis imaging (SPAR)	Yes	Yes	Yes	Yes	
Near infrared imaging (Vaisala DSC111)	Yes	Yes	Yes	Yes	
Infrared temperature sensing (Vaisala DST111)			Yes	Yes	
Lateral laser scanning (IST ALASCA)	Yes	Yes	Yes	Yes	Yes
Vehicle mounted radar (IST or similar)	Yes	Yes		Yes	
Differential GPS (COTS)		Yes		Yes	
Stereo polarization imaging (IST Road Eye sensor or similar)	Yes	Yes	Yes	Yes	
Contaminant Impact energy measurement (Vestabill modified Mu-meter)			Yes		Yes
Forward Looking Interferometer (NASA/Georgia Tech/Hampton University)	Yes	Yes	Yes	Yes	
Laser Depth Profiling (SnowMetrix)					Yes

4.4 Friction Measurements and Friction-Related Information

4.4.1 The Friction-Related Information that is Reported

Countries differ with respect to the type of information that is provided to pilots, as shown in Table 2.6 in Section 2. Some countries provide the measured friction values to pilots while others only provided them with general indications of braking action according to the ICAO scale. It is noteworthy that the results from the questionnaire survey assigned a lower priority to general braking action indications compared to the measured friction values themselves.

The AIPs of many countries contain warnings regarding the limitations of ground friction-measuring devices. It is generally recognized (a) that they are most suitable for “solid” surfaces (such as compacted snow and ice) and (b) that they are unreliable for “liquid-type” surfaces (water, slush, de-icing chemicals, wet snow, etc.).

PIlot REPorts (PIREPs) were also identified during the questionnaire survey as important information with high priority. PIREPS provide good information on the aircraft’s ability to brake on that particular surface. These reports, however, are aircraft and time dependent. The TALPA ARC has recognized the value of PIREPS formally, albeit not as a primary information source, but as information that can be used to downgrade assessments based on the surface conditions.

4.4.2 General Views of the Aviation Community Regarding Friction Measurements

There is a divergence of views regarding the role that friction measurements can or should play for operational applications:

(a) The TALPA ARC initiative is trending towards de-emphasizing friction measurements, and instead, is recommending that RCR efforts be focused on defining the runway surface itself for operational evaluations of aircraft performance.

(b) The ICAO FTF could not reach consensus regarding the most appropriate role of ground friction measurements for operational applications, although it agreed that a common reporting format is required.

(c) Some airlines utilize ground friction measurements as an important input for making operational assessments of aircraft performance. It is noted though that these airlines use the friction data in an advisory role only. Also, they only include one device, and they limit their usage to data on surfaces where the readings are considered to be reliable. This leaves a gap as the current devices are not suitable for all surfaces.

In summary, many stakeholders are reluctant to accept friction measurements as a primary information source (under regulatory or certified regimes), or as a useful information source. On the other hand, some pilots, carriers, and regulators consider friction measurements from a single device family to be of significant value.

It should be noted that this situation refers to friction measurements as they are performed at present. This should not necessarily be construed to mean that friction measurements are not useful potentially.

4.4.3 Past Test Programs Related to Operational Friction Measurements

The Joint Winter Runway Friction Measurement Program (JWRFMP) was the most extensive test program conducted to date for winter surfaces although prior tests were done by NASA.

(a) The JWRFMP showed that the presently-available devices produced different friction numbers when operated on the same contaminated surfaces at the same time. A common reporting index (i.e., the International Runway Friction Index – IRFI) was established for the devices for a limited range of surfaces (i.e., compacted snow and ice) although it contained scatter.

(b) The JWRFMP showed that a ground friction measurement could be related to aircraft braking performance although the correlations contained scatter. The scatter from the JWRFMP tests was generally similar to that seen from the previous NASA tests.

(c) The JWRFMP also identified serious issues with the present ground friction-measuring devices, related to: (a) the limited number of surfaces on which they can provide reliable data; (b) the repeatability and reproducibility of the devices, and the device families; and (c) the stability of the device readings over time, etc.

Until such time that these concerns are addressed, questions will remain regarding the utility of these devices for operational friction measurement.

(d) Although the JWRFMP contributed greatly to the state-of-knowledge, the results from the JWRFMP have only been implemented in a regulatory capacity to a limited extent. The IRFI produced during the JWRFMP has not been used widely, partly because the infra-structure for it is lacking at present.

4.4.4 General Issues Affecting the Application of Operational Friction Measurements

The presently-available friction devices are at best, only satisfying the needs of some of the groups within the aviation community (aircraft manufacturers, air carriers, civil aviation authorities, etc). There are many groups that question the role that friction measurements can play for operational applications, although it must also be stated that others presently make use of operational frictional measurements. Until such time that this changes, there will continue to be strong resistance to any attempt to have them relate a ground friction number to aircraft braking performance, particularly in a regulatory capacity.

There are many issues limiting the application of operational friction readings, including:

(a) The regulatory and certification framework;

(b) Issues associated with the technical performance of the friction-measuring devices;

(c) Complexities regarding the process of friction measurements; and

(d) Lack of high-level performance criteria for friction-measuring devices

4.4.5 Regulatory and Certification Framework

4.4.5.1 Certification Requirements

Aircraft manufacturers are only required by regulators to specify aircraft performance with respect to basic runway surface conditions as summarized briefly below:

(a) EASA: The requirement is to supply data for certification for dry, wet, ice, snow, slush, and standing water surface conditions.

(b) FAA: The requirement is to only supply data for certification for dry and wet surfaces.

No requirement is imposed by either EASA or FAA for aircraft manufacturers to provide certified aircraft performance data in relation to the friction readings from ground vehicles.

4.4.5.2 Methods Used by Airlines to Establish Operational Aircraft Performance Data

In the absence of certified data, airlines develop additional information to define aircraft performance on specific surfaces. As part of this process, aircraft manufacturers can and do supply aircraft performance information to air carriers upon request as advisory material. Table 4.2 summarizes information received during this study from airlines regarding the methods by which they make operational aircraft performance assessments.

Table 4.2: Sampling of Methods Used by Airlines to Establish Aircraft Performance

Question[1]	Listing of the Five Responses Received (Numbered 1 to 5)
What information is contained in the AFM?	1. For new certification aircraft (A320/A330 and E190), the wet runway takeoff performance data are included in the AFM. For our older aircraft (B737/B757/B767), the engine-inop wet takeoff performance is found in the Operations and Performance Engineers Manuals. The contaminated runway data for takeoff are found as non FAA-certified data. Certified wet landing performance is found in the AFM for all aircraft. Operational landing performance data (not certified by the FAA) are found for all runway conditions for all aircraft within the Operations Manuals and QRH. 2. We are flying Boeing 737Classics and 737NG. The classics are certified on dry runways only, as the NGs are certified on dry, wet and wet skid resistant runways. For operation on contaminated runways, Boeing has published “Advisory Information”. Boeing has also published aircraft databases that includes this advisory information, and we are using these databases in our electronic flight bag (EFB). 3. The respective AFMs include information only needed for certification. 4. The Airbus Aircraft Flight Manual states that for the "Determination of Performance" at Takeoff, Final Takeoff and Landing Performance, the Performance Engineering Program/AFM Approved (OCTOPUS) Flight Manual Modules are used which use the stated approved aircraft database. Note that only the PC version of this program is approved. Furthermore the Performance Engineers Program provides some further guidance on the Tire/Runway Friction coefficients used for the performance calculations. Information for an A319 is listed below. The data differ of course for each aircraft type and Flight Manual (i.e. whether it is an OCTOPUS Flight Manual or not). <u>Dry runways</u> On a dry runway an ETA MU is the result of the modelling of the flight test data. (ETA) represents the anti-skid efficiency. <u>Wet runways</u> The WET braking coefficient is defined in compliance with CRI F4012. The WET braking friction coefficient is based on ESDU (Engineering Science Data Unit) data. It is determined with 200 PSI tire inflate pressure, UK wear limit, runway surface effect intermediate between B-type and C-type runways and ETA = 92% antiskid efficiency (demonstrated through flight tests). _ WET = _ WET (ESDU) and Airbus provides the _ WET (ESDU) equation used in the program. Contaminated runways On standing water and slush, the braking friction coefficient results from an amendment based on flight test campaign defined in CRI F4012. The SNOW braking coefficient = 0.2 The ICY braking coefficient is = 0.05. The aquaplaning phenomenon is taken into account. A graph is also provided which plots mu vs. ground speed (m/s) for the 3 rwy conditions for each aircraft type. 5. The AFM contains the data required to comply with EU-OPS for operations on contaminated runways.

Question[1]	Listing of the Five Responses Received (Numbered 1 to 5)
Contaminant types on which aircraft performance assessments are based.	1. Dry, wet, wet snow and/or slush in ¼-inch increments, dry snow in 1-inch increments, ice 2. We use DRY, WET, STANDING WATER, SLUSH, SNOW and DEGRADED BRAKING ACTION. We differ between contaminants that give roll-resistance in takeoff (Standing water, slush, snow) and contaminants that give no roll-resistance (ice, compact snow). On landing we only use slippery data – i.e., no roll-resistance in addition to DRY and WET. When using roll-resistance we need to input how thick the layer is in addition to a braking action value (3 mm slush, braking action MEDIUM). 3. Performance calculations are based on the most critical contaminant type covering the runway. The options available in their performance software are Dry, Wet, Compacted snow, Ice wet, Standing water (mm), Slush (mm), Snow (mm), Loose Snow (mm), Reported friction. For take-off the most critical contaminant is usually a thick contaminant, and for landing usually slippery runway. 4. The flight crew use the onboard computer (Less Paper in the Cockpit) to carry out the Takeoff performance calculations. The following contaminants are available for use in the calculations: Dry, Wet, Water ¼ inch, Water ½ inch, Slush ¼ inch, Slush ½ inch, compacted snow and Icy. 5. All contaminants
Are performance assessments based on ground friction readings?	1. We do not provide performance based on readings from ground friction vehicles. 2. “Yes” and “No”. The National Airport Authority uses friction readings as an aid for estimating braking action. However, their AIP advises that friction readings are not accurate under certain conditions. 3. Yes, in most cases the runway condition is given as reported friction, based on reading provided by Skiddometer BV 11 equipment. Also when runway friction is given as Braking Action (BA), the runway inspector usually uses the readings obtained in measurement with Skiddometer equipment for his/her estimation of friction level (BA). When we are given BA, the ICAO BA-friction table is used to get corresponding friction value for BA level (the most conservative friction value for each level is used). 4. FODCOM 200906 states that CAP 683 has been revised to warn aerodrome licence holders NOT to promulgate friction readings in periods of runway contamination, whilst paragraph 4 explains the limitations of operational use of Continuous Friction Measuring Equipment and friction readings, also relevant to aeroplane operation. We have included similar instructions in our SOPs for crews NOT to use if provided any runway friction coefficient readings. In cases of slippery when wet runways we instruct crews to reduce rwy length accordingly and then calculate takeoff performance. 5. “If these are available”
Source of aircraft performance data	1. It is not provided by the manufacturer. 2. Boeing uses braking action 0.05 for poor, 0.1 for medium and 0.2 for good. The airline defines a friction vehicle value .20 to be poor (0.05) and value .30 to be medium (0.1) and finally value .40 to be good. They do not use values above .40 and below .20. They define all other values linearly between these points. They also point out that the airport authority no longer reports the measured friction value, and only provides the SNOWTAM format (1-5) or the phrasing GOOD, MEDIUMtoGOOD, MEDIUM, MEDIUMtoPOOR, and POOR.

Question[1]	Listing of the Five Responses Received (Numbered 1 to 5)
	3. The manufacturers have provided only dry/wet/water covered rwy/compacted snow and ice wet runways. The sources for development of reported friction calculation has not been provided by manufacturers. The friction model has been developed by Antti Puronto, TopPOY. (toppoy@dnainternet.net<mailto:toppoy@dnainternet.net>, Mob. +35850 3935186) and the sources for development have been JAR OPS 1 AMC; NPA friction model; ICAO Doc 9137; experimental research at EFHK, EFTP, EFTU and EFOU and Transport Canada-JAA-NASA friction program results. 4. See previous answers. 5. Supplied by the manufacturer.
Is there an onboard computer for calculating landing or takeoff performance?	1. No. Data adjusted by Dispatch are used to calculate performance. 2. Yes. We are now introducing the EFB in our aircraft. For the aircraft not yet having the EFB, we are using gross weight charts. These charts are produced by the same software used in the EFB. 3. Yes, all aircraft are using an onboard cockpit computer for performance calculations as well as for mass and balance calculations. All performance calculations are done for the actual take-off weight/landing weight in actual conditions (OAT, QNH, wind, lineup, runway, obstacles, de-ice fluid effects, flap setting, engine rating etc) considering the actual runway condition (dry/wet/water/slush/snow/loose snow/BA or reported friction). The program used (EGAR, provided by TopP Oy) is fast to use and calculations can be made during line-up using up-to-date contamination information. The program calculations optimum speeds to be used with a safety-centric logic; a low V1 speed for slippery runways and a high V1 speed in relation to the optimized V2 speed for runways covered by a thick contaminant. 4. We have the Airbus' Less Paper in the Cockpit (LPC) concept implemented across our Airbus fleet; The Flight Operations Versatile Environment (FOVE) software runs amongst other Takeoff & Landing applications that flight crew use to carry such calculations. Our Boeing fleet uses paper Takeoff Performance Manuals. 5. No. All our calculations are done by a ground based application that is available to connect to from the aircraft using ACARS.

Note:

1. See Appendix A, Section A.4, in Volume 2 for a listing of the questions that were asked.

As a result, airlines are forced to make their own assessments at the time of landing. The information-gathering conducted in this project showed that there is considerable variability among airlines with respect to the methods used for determining landing distance requirements as illustrated by Table 4.2. The methods used by the airlines generally ranged between those based on: (i) ground friction readings; (ii) surface condition information, principally contaminant type and depth; or (iii) a combination of the two information sources.

In many cases, particularly for commercial airlines, the flight crew evaluates aircraft performance based on the reported contaminants, and policies based on the guidance and directions from the airline. This may or may not include aircraft performance data provided by the aircraft manufacturer.

4.4.5.3 Outcome of Regulatory and Certification Framework

The friction measurements from ground vehicles are not included as part of the certification process, which assigns lower importance to them.

This situation reflects a reluctance on the part of the aviation community to make friction measurements part of a regulatory process. The evidence shows, however, that there is general support for the view that friction readings are useful as advisory material, as an input for determining aircraft performance in an operational manner. Of course, the correlation and overall performance requirements are considerably more stringent if the readings from GFMDs are to be used as part of a regulatory process.

4.4.6 Complexities of Friction Measurement

Probably, the most important item to recognize is that the friction coefficient is a "system" measurement rather than an intrinsic property of, say, the pavement, the tire, or the material on the surface of the pavement. The result of a friction measurement is governed by the interaction of all the components of the system which include the tire, the pavement, the material on the pavement, and the atmospheric conditions.

This may be manifested in various ways. Examples follow:

(a) The material on the surface may fail, by shear for example, thereby limiting the tractive forces that can be developed. This process is most likely to occur for solid contaminants such as compacted snow or ice.

(b) Metamorphosis of the material on the surface – as an example, experience has shown that in some cases, "dry" snow may become "wet" under the pressure exerted in the contact zone, which has a significant effect on the frictional forces that can be developed. This is more likely at higher pressures, such as those for an aircraft tire, and less likely for the lower pressure tires used for ground vehicles.

(c) Contaminant drag – loose contaminants (such as slush or snow) are likely to cause contaminant drag forces to be developed, which affects the measured friction coefficient. Some ground friction-measuring devices, such as locked-wheel testers or side-force testers, are more susceptible to contaminant drag than others that "process" the contaminant more effectively by rolling over them.

(d) Liquid contaminants may cause thin film lubrication, leading to partial or full hydroplaning. This interaction is significantly affected by the degree of drainage that occurs from under the tire. The degree of hydroplaning depends on the tire pressure and perhaps the tire aspect ratio as well. It also depends on the viscosity of the contaminant as viscous contaminants (such as slush or solutions with de-icing chemicals in them) are more likely to cause hydroplaning. It is well known that the onset of hydroplaning is related to the tire pressure. Tire pressures vary among the devices, and all of them are considerably less than those for an aircraft. This variation can lead to significant differences among ground vehicles and with respect to an aircraft for many contaminants such as slush, de-icing chemicals and also thin layers of loose snow which may or may not be penetrated to reach the pavement below.

The available devices differ widely with respect to practically all design parameters, including the measurement principle, the tire used, and the vertical load and tire contact pressure. All of the devices differ significantly from an aircraft. This variation causes differences with respect to the interaction process(es) that are dominant in the tire-surface-pavement contact zone. This leads to differing parameter dependencies among the devices with respect to factors such as: (a) speed; (b) contaminant type; (c) contaminant depth; and (d) physical properties of the contaminant such as shear strength, density and viscosity.

This limits the degree of correlation that can be achieved from an empirical process (which is the method used so far) as has been seen from the various correlation attempts that have been made to date.

4.4.7 Technical Performance of Devices

The issues related to the technical performance of the devices include the following:

(a) Different devices give different readings when operated on the same surface. Although previous harmonization attempts have shown that it is possible to develop a common scale (i.e., the IRFI), the IRFI was limited to only “solid” surfaces (compacted snow and ice), and it contained scatter.

(b) The devices are not reliable on all surfaces of concern. Warnings to this effect are present in the AIPs of many countries. Generally, friction-measuring devices are considered to be reliable on “solid” surfaces (compacted snow, ice, etc.), and to be unreliable on “loose” or “liquid-like” surfaces (loose snow, wet snow, slush, de-icing chemicals, etc.).

(c) The calibrations of the devices changed with time over the course of the JWRFMP.

(d) Individual units of the same device family (for three different device families) provided significantly different results when operated at the same time on the same surface, on artificially-wetted surfaces.

4.4.8 Need for High-Level Criteria for a Device for Operational Friction Measurements

Except for decelerometers, the current ground friction measuring devices were initially designed to assess surface friction characteristics for runway maintenance purposes. The attempts to date have focussed on utilizing these existing devices for operational use for correlation with aircraft performance on contaminated runways.

Experience has shown that this approach is not producing acceptable results for many stakeholders. For friction measurements to be generally accepted, a fresh approach is needed starting with “first principles” with the objective of producing a device that would correlate well with an aircraft on the full range of contaminated surfaces of concern.

A high level definition of requirements (performance specification) for a continuous-measuring ground friction device specifically targeted for operational friction measurement would be beneficial for advancing the current state of the art. This is presently lacking; and as a result, equipment suppliers develop improved designs using their best judgments. A high-level performance requirement would provide direction regarding the most suitable device type for correlation with an aircraft. It is believed that given this direction, equipment suppliers would probably respond cooperatively.

Research and investigation is required to develop a high-level performance specification for a device intended to correlate with an aircraft. The performance specification should, address the following at a minimum:

(a) The measurement principle, starting with the GFMD type (fixed-slip vs. variable slip vs. side force vs. locked-wheel tester, etc.). As well, the JWRFMP tests showed that different readings were produced on some surfaces (mainly loose snow) from devices that used torque measurements versus ones that used force measurements.

(b) The tire design (tread and ribbing, carcass design, properties, etc.). Also, investigation is needed to establish whether or not an aircraft tire is required as the measurement tire.

(c) The vertical load on the tire, the tire inflation pressure, and the tire contact pressure – the results presented in this section suggest that a contact pressure in the range of about 750 kPa is probably required, although it is cautioned that more detailed testing is necessary.

(d) The slip ratio(s) and the slip speed(s) that is (are) required.

(e) The requirement for an anti-skid system that has similar performance to those on aircraft also needs to be investigated.

5 RECOMMENDATIONS

5.1 Overview of Framework of Agencies and Initiatives

5.1.1 General Review

An understanding of this issue is required to assess which agencies are best-suited to evaluate and possibly act upon the recommendations being put forward in this project. Of course, this affects which recommendations should be directed to whom. The main agencies which have interest in the recommendations being put forward in this project are ICAO, EASA and the National Civil Aviation Authorities of the EASA-member states.

ICAO is responsible for creating and updating as necessary, universal standards and recommended practices for international civil aviation. It is important to note though, that ICAO does not have regulatory powers.

EASA and State Civil Aviation Authorities do have regulatory powers however. They are responsible for developing specific regulations for their state, or group of states, and in doing so, for determining the extent to which ICAO Standards are to be adopted.

Both ICAO and EASA are involved with research and development, with both being governed by a board comprised of state representatives who meet and establish priorities, and budget levels. Thus the agency best suited to deal with or action the recommendations being put forward are essentially both. The factors that each agency would have to take into account would be their priorities, time, resources and the availability of funding that may be necessary to action the recommendations.

As this research project was initiated by EASA, it is suggested that EASA: (a) first review the recommendations; (b) then list the recommendations in order of importance; and (c) finally meet with ICAO to determine which recommendations ICAO would be willing to support, action and fund.

5.1.2 Presently-Active Initiatives

The initiatives of primary interest to this project are the TALPA ARC and the ICAO FTF. These have been considered to a large extent in this project and are important for two main reasons:

(a) They represent a broad spectrum within the aviation community; and

(b) They are forums through which, potentially, some of the recommendations made in this project could be implemented.

5.1.3 Focus of Recommendations

As this project has been sponsored by EASA, the recommendations made here have been developed keeping this as the primary focus, while making an attempt at the same time to consider the overall aviation community, and its need for a global reporting format.

Consequently, two types of recommendations are provided:

(a) Recommendations that EASA should consider enacting – these are presented in Sections 5.2, 5.3, and 5.4. For clarity, these recommendations have been divided into three categories:

(i) General issues, such as taxonomies and definitions – these are presented in Section 5.2.

(ii) Functional friction assessments – these are presented in Section 5.3.

(iii) Operational friction assessments – these are presented in Section 5.4.

(b) Recommendations of a more general nature that would require other groups (than EASA) to action, or that would require a collaborative effort – these are presented in Section 5.5.

5.2 Recommendations for EASA – General Issues

5.2.1 Recommendations – Monitoring of Other Initiatives

Because the recommendations being proposed by TALPA ARC, if implemented by regulation, will have a significant impact on current runway condition reporting practices in the USA and other countries duplicating or emulating the process, it is recommended that all aspects of the TALPA ARC process be monitored, and appropriate assessments be undertaken to determine applicability of the TALPA ARC process to European operations. The monitoring and assessments should include but not be limited to the following:

(a) Obtaining and reviewing all available background material (technical reports, meeting minutes, etc.) that formed the basis for the TALPA ARC's recommendations.

(b) EASA should review the logic used within the TALPA-ARC regarding the values assigned to PIREPs, and if appropriate, quantify its role in adjustment of aircraft performance on contaminated runways. Depending on the results of this evaluation, EASA should cooperate with other agencies in building a PIREP value reference database.

(c) Monitoring the field tests that will be conducted by the FAA at various US airports during the 2009-2010 winter regarding the TALPA ARC reporting process.

(d) Depending on the results of the initial field evaluations at airports, EASA may wish to consider conducting parallel evaluations related to the TALPA ARC's recommendations at some European airports to enable the European aviation community (airports and airlines) to determine the appropriateness of the changes to their operating environment and to develop positions and policies.

(e) Maintaining close contact with the FAA staff responsible for evaluating and implementing the TALPA ARC's recommendations.

(f) Because an essential part of the TALPA ARC process is to have the aircraft manufacturers provide information in the flight manuals that link the proposed codes to aircraft braking performance, consultation with aircraft manufacturers is recommended to verify that this data will be in place should the TALPA ARC approach be enacted.

The ICAO Friction Task Force (FTF) may have significant input as well. The work being done by the ICAO FTF should be monitored closely and should include reviewing the various ICAO FTF reports in detail.

With the above information, appropriate evaluations should be made by EASA of the impact that these changes would have on the European aviation community.

5.2.2 Recommendations – Harmonization of Definitions and RCR Approaches

The most suitable basis for harmonization is relating runway surface conditions descriptions to aircraft performance. Because the TALPA ARC's recommendations have been developed on this basis, it is believed that they should provide an appropriate foundation for harmonization. It should be noted though that, because testing related to the TALPA ARC's recommendations will be undertaken during the 2009-2010 winter, some of the recommendations made here should be considered to be preliminary.

Because the TALPA ARC system does not address the question of how materials not specifically named as contaminants are to be classified, this should be investigated further, starting with a detailed review of the supporting basis for the TALPA ARC's recommendations.

5.2.3 Recommendations - Taxonomies and Definitions

5.2.3.1 Runway States and the Definition of a Contaminant

These are discussed in section 10 of Volume 2. The fundamental definitions are:

(a) The runway state - the aviation community is trending towards a three-level definition, in that a runway is either: (i) dry; (ii) wet; or (iii) contaminated. Although different organizations employ different definitions for the various runway states, there are many more similarities than differences among them. The current EASA definitions (in CS-25) employ a three-level definition, and it is recommended that EASA maintain this.

(b) The definition of a contaminant – the only difference of significance is which contaminants are specifically named or listed. EASA CS-25 provides a list for the purposes of aircraft certification. This list is incomplete as other contaminants also occur, which will introduce uncertainties regarding runway condition reporting. It is recommended that EASA expand the list in CS-25 as appropriate, based partly on the results from other initiatives such as the ICAO FTF and the TALPA ARC.

(c) Runway coverage producing contaminated conditions – EASA CS-25 defines the criterion as being 25% coverage of the reported runway length and width. This is in general agreement with most definitions. The definition in ICAO Annex 15 is one exception, and it is recommended that EASA review this variation.

(d) Damp – some aircraft performance standards, including EASA CS-25, require the definition for a "damp" surface, although, based on the above general runway state categories, a "damp" runway would be classified as "wet". It is recommended that a definition for damp be retained until consistency is achieved among the associated aircraft performance standards.

5.2.3.2 Detailed List of Recommended Taxonomies and Definitions

Recommendations are provided in Table 5.1. It was recognized that there should be harmonization between the definitions used for defining aircraft performance and those used for describing the runway surface condition. Accordingly, a three-column table of recommendations was produced regarding:

(a) The values and relevance to aircraft performance evaluations (Column 2); and

(b) The characteristics that would be used by runway inspection personnel to describe the runway surface condition (Column 3).

In many cases, there was no technical reason that would favour one definition over another as they all have the same intent. For the purpose of establishing the recommendations listed in Table 5.1, priority was given to:

(a) The definitions in ICAO Annex 14, Volume 1, to maintain consistency with past definitions; and

(b) The classifications and definitions in the TALPA ARC system, as this system has been developed taking aircraft performance into account.

(c) Technical and logical descriptions that would facilitate harmonization and field observations.

It is recognized that definitions are also required for other parameters such as cleared width, contaminant depth, etc. Definition lists for these other parameters are contained in Volume 2.

Table 5.1: Listing of Recommended Definitions

Frozen Contaminants		
Term	**For Aircraft Performance**	**Recognizable Characteristics**
Slush	Assumed SG: 0.85 (source: EASA CS25.1583)	Water-saturated snow with a heel-and-toe slapdown motion against the ground will be displaced with a splatter (source: ICAO)
Frost	Higher friction than Ice (source: BMT Project Team)	A condition where ice crystals formed from air borne moisture condense on a surface whose temperature is below zero. Frost differs from ice in that the frost crystals grow independently and, therefore, have a more granular texture (source: TC)
Loose Snow	Assumed SG: 0.34 (source: ICAO)	Sometime called "Dry" snow. Snow which can be blown if loose or, if compacted by hand, will fall apart upon release (source: ICAO & EASA CS25.1583). Snow that is not bonded to the AMS and will compact under vehicular traffic (source: BMT Project Team)
Wet Snow	Assumed SG: 0.5 (source: EASA CS25.1583)	Snow that will stick together when compressed but will not readily allow water to flow from it when squeezed (source: EASA CS25.1583)

Frozen Contaminants		
Term	**For Aircraft Performance**	**Recognizable Characteristics**
Compact Snow	Assumed SG: 0.8 (source BMT Project Team)	Snow which has been compressed and will not compress further under vehicular traffic or aircraft wheels, at representative operating pressures and loadings (sources: EASA CS25.1583 & BMT Project Team)
Ice	Lower friction than Frost (source: BMT Project Team)	A frozen liquid with a continuous surface and includes the term "black ice" and the condition where compacted snow transitions to a polished surface with the density of ice (sources: Transport Canada & EASA CS25.1583)
Non-Frozen Contaminants		
Damp	Required in various standards	A surface is Damp when it is non-reflective and moisture is present (source: TC & BMT Project Team)
Wet	Liquid depth no more than 3mm	A Wet surface has liquid present and is reflective (Source: EASA CS25.1583 & BMT Project Team)
Standing Water	Liquid depth greater than 3mm (source: EASA CS25.1583)	Sometimes called 'Flooded'. Includes localized and continuous surface coverage, whether during precipitation or not (source: BMT Project Team)

Notes:

1. SG: Specific Gravity
2. Transport Canada is the only agency that has a definition for frost at present. The Canadian training material includes the following explanatory notes, which should be considered to be part of the definition for frost.
3. Caveat: to date, NO technical documentation has been published regarding the rationale that led to the TALPA ARC's recommendations, and definitive recommendations can NOT be made regarding the TALPA ARC's recommendations. The TALPA ARC's recommendations are presented in Table 11.1 in recognition of the fact that they have been developed by a large group with representation from aircraft manufacturers, airlines, and regulatory bodies. EASA is strongly advised to obtain as much supporting material as possible regarding the TALPA ARC, and to review it in detail in formulating positions and policies.
4. Frost is differentiated from ice and compact snow by its refraction of light giving it an opaque presentation. The crystalline nature of frost is readily apparent to the viewer because it does not uniformly reflect light, presenting instead a "sparkle" or "glitter" effect. This is true of all forms of frost and for all depths.

5.2.3.3 Gaps in the Present Set of Definitions

The most serious gaps in the present set of definitions are considered to be:

(a) Layered contaminants – a multitude of cases are possible. The need for accurate definitions of layered contaminants will become more acute if the current trend towards de-emphasizing friction measurements is continued. A system of definitions and classifications has been proposed in section 2 of Volume 4. Guidance should be developed on the reporting of specific underlying contaminants. This should be evaluated with field-testing.

(b) Frost – This is a significant gap in the present set of definitions, given that frost has been recognized as an important contaminant (by TALPA ARC – see section 4 in Volume 2); and presently, suitable definitions are generally not available. Although a definition for frost has been recommended in this project (in Table 5.1, and also in Volume 2), this should be evaluated with field testing.

5.2.4 Recommendations – Certification and Training

EASA should institute training programs for:

(a) Pilots – a training program should be developed and implemented for pilots regarding how to use the information provided from runway condition reporting. This need is will become more acute given that EASA and FAA both intend to close the gap that a pre-landing assessment is presently not required by regulation.

(b) Runway inspectors (RIs) - Certification requirements are required for Runway Inspectors (RIs), and for staff issuing RCRs and/ or NOTAMS directly affecting aircraft operations. Requirements should be established for minimum RI trainer qualifications, competency-based training, certification expiration, and maintenance of training records.

A process should be commenced to harmonize the training for runway inspectors. This might take the form of first establishing a working group of runway inspection trainers from different countries with the objective of establishing a common set of training guidelines (course notes, representative photos, etc.). Following that, these common training guidelines should result in a common approach to training runway inspectors.

5.3 Recommendations for EASA – Functional Friction Assessments

5.3.1 Recommendations – Objectives of Functional Friction Measurements

There is a fundamental variation between the objectives for functional and operational friction measurements. Correlation to aircraft performance is of much more concern for operational friction measurements. This difference should be taken into account in formulating policies for each application.

It is recommended that work related to functional friction measurements focus on developing standardized procedures, including calibration and harmonization, for the devices, with desired correlation to aircraft as a secondary goal. This will facilitate quicker realization of effective and stable functional friction measurement.

5.3.2 Recommendations – Testing Procedures and Specifications

Earlier attempts for harmonization and the underlying processes/models did not include sufficient quality requirements for accuracy, consistence, uncertainty, and frequency. There are no thresholds values defined that are necessary for the Friction-Measuring Devices (FMDs) to fulfill to be accepted for functional friction characteristic measurement or to be able to be harmonized.

Ideally, a collaborative effort should be taken to address this need, and EASA should participate actively in it. This is described in Section 5.5. The work should include the following:

(a) A comprehensive set of technical specification should be developed and incorporated in civil aviation regulatory standards. The development of the comprehensive set of technical specifications should be based upon the technical criteria and base specifications identified in this study (in Volume 3).

(b) A comprehensive set of technical specification should be developed and incorporated in civil aviation regulatory standards. The development of the comprehensive set of technical specifications should be based upon the technical criteria and base specifications identified in this study.

(c) Strict uncertainty limitations for individual device repeatability and device family reproducibility should be established. The procedures for the measurement of the uncertainty limitations and the setting of the threshold limits for uncertainty shown in this report are recommended.

(d) Every friction measuring device should be tested to ensure compliance with repeatability and reproducibility requirements. Only those friction measuring devices that comply with the technical specifications should be used for harmonization testing.

(e) A timely plan for harmonization testing is recommended for periodic calibrations, and this should be enforced. Device constants should be compared annually and only those devices that are within the threshold limits should be considered acceptable for functional friction measurements.

(f) The process identified in this report for the dynamic calibration of the reference device and for the harmonization of surfaces should be adopted. This should include the quality control requirements for harmonization testing that are recommended in Volume 3.

(g) The use of the European Friction Index (EFI) or the equivalent IFI harmonization model is recommended.

5.3.3 Recommendations – Reference for Calibrations and Harmonization

The reference device for friction measurements should be the DF tester and for texture measurement the reference device should be the CT meter. See Volume 3 for descriptions of these devices and for the rationale for these recommendations.

5.3.4 Recommendations – Revisions to Table A1 of ICAO Annex 14 Supp A

It was concluded that, at this point, only the established harmonization methods such as the ESDU model, the EFI, or the IFI, with their already-developed device constants would provide a sufficient platform to amend Table A1 of ICAO Annex 14 Sup A. However, due to limitations associated with the time stability of the harmonization models, the application of any of these models would produce a significantly different equivalency table depending on the year that the harmonization trial was carried out. Of course, this is not acceptable.

Therefore, at this point, it is not recommended that the ICAO device equivalency table be amended. Instead it is proposed that a harmonization test based on the requirements and design parameters suggested in this report be carried out and the harmonization values obtained be used to amend the ICAO table.

5.4 Recommendations for EASA – Operational Friction Assessments

5.4.1 Recommendations – General

There is a divergence of views within the general aviation community regarding the emphasis that should be placed on observations of the runway surface condition itself versus ground friction measurements. Some groups are suggesting that friction measurements should be downgraded in importance while others are reluctant to change the status quo.

It is recommended that fundamental decisions be made by EASA regarding:

(a) Whether to parallel the trend (being exhibited by a large part of the aviation community) towards de-emphasizing friction measurements for operational purposes or not;

(b) Whether to focus runway condition reporting on the surface condition of the runway itself;

(c) Whether to pursue a parallel path of improving condition assessment and monitoring advancements in friction measurement with a view to improved operational applications;

(d) The most appropriate position and policy regarding format, relevance, value and application of ground friction measuring device readings; and

(e) Clear differentiation between measured runway friction and aircraft braking action in regulatory and associated texts.

The initiatives being undertaken by the ICAO FTF and the proposed TALPA ARC system should be monitored closely before determining items the above.

Also, it is noted that runway friction measurements generated using a single operational friction measurement and reporting system are considered to have credibility in some specific jurisdictions, and are valued by the respective CAA and air carriers. The differences between these systems (instrumentation, procedures, regulatory regime, etc.) and others should be investigated and identified to determine their pros and cons.

5.4.2 Recommendations – Friction Measuring Devices

It is the opinion of the project team that friction-measuring devices have an important role to play, potentially, for operational friction assessments. However, the limitations associated with present friction-measuring devices, as documented in this report series, must be addressed in order for them to have an important, unequivocal role for operational friction assessments.

Because all of the presently-available devices have significant limitations, none of them should be a priori selected at present as being suitable, or the “best” device. Furthermore, the currently available information is inadequate for making such an assessment.

There is a need for high-level criteria for a friction-measuring device that is intended to correlate with an aircraft. This requires a collaborative effort and it is recommended that EASA participate actively in this initiative. This is discussed further in Section 5.5.

5.4.3 Recommendations – Analyses of Aircraft Data in Near Real-Time

Emerging technologies for determining the friction coefficient in near real-time based on analyses of aircraft data collected during previous landings should be monitored and perhaps encouraged.

5.4.4 Recommendations – Runway Condition Assessment, Measurement and Reporting

EASA should take a lead role in updating the current runway surface condition assessment and reporting process:

(a) Direction and advice should be provided to airport operating authorities regarding interpretation and accuracy in assessing contaminant criteria, as recommended in Table 4.1 of Volume 4. This should also include evaluations and recommendations regarding the definition of a “significant change”, which would trigger the need for an updated runway condition report. Preliminary criteria regarding a “significant change” are provided in Section 4 of Volume 4. These should be evaluated by comparing them against field situations.

(b) Guidance should be provided to runway inspectors regarding processes for estimating average depths, relative locations, percentage coverage, windrow width and other contaminant parameters.

(c) Auditing of airports’ runway inspection instructions and procedures should be included in airport regulatory compliance inspections.

(d) Input into runway condition assessment processes should be sought from the aviation community (aircraft manufacturers, air carriers, civil aviation authorities, airports, etc.).

(e) A committee should be established to update the RCR process. It is recommended that the ICAO SNOWTAM format be updated (described in section 5.5) and EASA should participate actively in this.

(f) An independent person or group should be appointed to act as facilitator for the committee to ensure that all technical inputs are provided as needed.

Human factors and the availability of runway occupancy time have a significant influence on the reliability and accuracy of condition reports. EASA should develop policies to:

(a) assist airports in mitigating the influence of human factors on the accuracy of condition reports.

(b) provide direction to air navigation service providers and airports to ensure adequate runway access and occupancy time for completion of runway condition inspections.

(c) provide direction in the case where RIs are not granted access to runways and other aircraft movement surfaces.

Reference should be made in regulation to requirements with respect to:

(a) Contaminant definitions;

(b) Assessment frequency, including the definition of a "significant change";

(c) Runway Inspector qualifications;

(d) Estimating techniques for reportable conditions;

(e) Training and testing of RIs; and

(f) Auditing of airports' runway inspection instructions and procedures.

Airport operating authorities should receive guidance in and be advised of condition reporting requirements as detailed in Volume 4.

5.4.5 Recommendations – Runway Closure

In regard to the need to close contaminated runways for maintenance purposes, a policy decision should be made by EASA to either:

(a) regulate the closing of runways for maintenance when predetermined contaminant thresholds are reached; or

(b) to recognize that airports' responsibilities are limited to accurately reporting conditions with which carriers and pilots will make aircraft movement decisions.

5.4.6 Recommendations – Measurements of the Runway Surface Condition

There is a need for equipment and technology which can identify and quantify contaminants on runway surfaces. This need would become more critical should the trends being advocated by various groups (to de-emphasize friction measurements) become enacted. The aviation community should be encouraged to work together closely to identify the requirements for such devices, in order to ensure that the technology developed fulfills the reporting requirements stated in Volume 4. This should be a collaborative effort as described in section 5.5, and EASA should participate actively in this.

5.4.7 Recommendations – Runway Condition Information Transmission

The impact on flight operations and performance of the Norwegian runway inspection computerized NOTAM transmission process should be assessed. If initial positive results are confirmed in wider use the advantages should be documented and publicized and the process should be formalized and encouraged through establishment of equipment and procedural standards and regulatory commentary.

5.5 Recommendations for Others or That Require Collaborative Effort

5.5.1 Recommendations – ICAO Documents

There is inconsistency in some of the key ICAO documents such as:

(a) Annex 6 does not cross-reference Annex 14, Volume 1, Annex 15, and the Airport Services Manual with respect to items such as the definition of a contaminated runway and the definitions for the contaminants themselves.

(b) There is inconsistency between ICAO Annex 15 and the other ICAO documents with respect to the area coverage threshold for defining a contaminated runway.

EASA should recommend to ICAO that these inconsistencies be addressed.

5.5.2 Recommendations – Updates to ICAO SNOWTAM

Revision of the ICAO SNOWTAM format is recommended to facilitate harmonization of reporting practices. Guidance and recommendations are provided in section 4 of Volume 4.

EASA should recommend to ICAO that the SNOWTAM form be updated, and offer to participate actively in this process.

5.5.3 Recommendations – Functional Friction Harmonization Trials and Development of Consistent Standards

A stepwise method for conducting a calibration and harmonization trial has been developed. A pilot study should be done to evaluate the proposed approach.

This requires a collaborative effort for maximum benefit, and EASA should participate actively in this. Consideration should be given to approaching ICAO to form a committee to oversee and direct the trials and further developments that are appropriate. Regulatory bodies (e.g., EASA, FAA, other State National Aviation Authorities, etc) should be encouraged to participate.

The final step in this process should be the updating of Table A1 (device equivalency table) in ICAO Annex 14 Supp A.

5.5.4 Recommendations – High-Level Criteria for a Friction-Measuring Device

There is a need for high-level criteria for a friction-measuring device that is intended for use in operational correlation with aircraft performance. This requires a collaborative effort and it is recommended that EASA participate actively in this initiative.

This should include the following steps:

(a) Essential support and technical input into establishment of the design/performance criteria for friction measuring devices should be obtained from Airports, Aircraft manufacturers, Airlines and Civil Aviation Agencies. This could potentially be a role for ICAO, through a committee to control the development process.

(b) Research and investigation should be undertaken to develop high-level overall design criteria for a friction-measuring or aircraft ground deceleration emulation device capable of correlating with aircraft ground braking performance on all types of contaminated surfaces. The work should address but not necessarily be limited to, the issues identified in this project, in Volume 4.

(c) Following the establishment of design requirements, equipment manufacturers should be encouraged to undertake detailed design and prototype development.

(d) If the development of a set of high-level criteria is to be pursued, consideration should be given to having an independent person or group assume the role of facilitator in order to consult with the aviation community and to obtain the necessary technical information.

5.5.5 Recommendations – Technology for Observing Runway Surface Conditions

A committee should be formed to develop a performance specification for a device(s) or for technology (technologies) that would meet operational runway surface condition reporting requirements. As a guideline, direct sensor data or values derived through analysis of sensed data from one or more runway condition measurement sensors should provide values with minimum accuracies as summarized in Volume 4.

Potentially, ICAO could take the lead on this although EASA should participate actively in this process.

EASA and ideally others as well (for maximum benefit and acceptance of the technology developed), should evaluate and where appropriate, encourage or foster development of surface contaminant condition measurement technologies as detailed in Volume 4. This recommendation applies equally to those technologies described in these reports and to other applicable existing and emerging technologies.

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