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Experience on the Development of a National Friction Standard for Chile

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ABSTRACT

Skid resistance is a functional characteristic of pavement surfaces that are related to safety conditions on roads. In developed countries, several studies have been carried out to define skid resistance thresholds. In contrast, developing countries usually adopt results of international experience without carrying out their own studies.

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In Chile thresholds are adopted from foreign standards because does not exist an adequate statistic of accident to find a relationship between risk of accidents and minimum skid resistance values. Also, there are not measurement standards for some skid resistance measurement devices and methods to compare different skid resistance values obtained with the devices existent in Chile.

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Considering this, the Pontificia Universidad Católica in association with the Ministry of Public Works, Concessionary Agencies, and the Found for the Promotion of Scientific and Technological Development (FONDEF), developed between 2005 and 2008 a research project. The objectives were to elaborate procedures and draft standards for skid resistance measurements, harmonization between devices, definition of thresholds values and safety analysis according to local conditions. The Transportation Research Laboratory (TRL) was contracted to give technical advisory along the study.

This paper describes briefly the development and results of the research project. The current friction control practices in Chile and the needs to improve friction standards are discussed. An integrated scheme of friction management that coordinate the different procedures developed is proposed according to the specific objectives of the project. The main characteristics of each procedure are described according to the integrated framework.

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The project approach can be replicate in any country that needs to generate or improve their friction standards, especially in the countries where accidents statistics are not available. Although for a successful implementation of standard the friction demand and friction supply behaviour at a network level should be known.

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Keywords: FRICTION STANDARDS – SKID RESISTANCE – HARMONIZATION – FRICTION THRESHOLDS – SAFETY ANALYSIS

1. INTRODUCTION

Pavement friction can be defined as the resultant of the interaction between macro texture of the pavement surface, micro texture of the aggregates, and the speed of a tire that slips on the pavement. Skid Resistance (SR) is an indicator of friction on pavement surface and represents the relationship between tangential and vertical forces that acts on a wheel, of a specific device, that slides on a wet pavement surface. It ranges between 0 and 1 and is directly related to wet weather accidents and road safety.

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It is well-known that skid resistance decreases in wet pavements. Several studies have found an inverse relationship between skid resistance and the risk of wet weather accidents (Giles et al, 1959; Schulze et al, 1976; Gothié, 1990). Consequently, the risk of wet weather accidents increases dramatically if the available skid resistance falls below a minimum value.

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A friction management system (FMS) is a tool that permits to assess pavement surfaces and to prevent wet weather accidents. The leadership in research and use of a comprehensive friction management system is United Kingdom. The objective of the UK standards is to reduce the risk of skid accidents. For this, the Highways Agency recommends flexible thresholds values for skid resistance depending on the geometrical characteristics of a road and the expected wet weather accident risk levels in each site of the roads. Recently, countries like Australia, New Zealand and Spain have adopted the UK standard philosophy and adapted to their local conditions.

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Since 1994 Chile is applying a successful method to manage the highways network based on 3P concept (public and private partnership). The objective is to achieve the higher standards of levels of service in the network where the friction management is one of the most important parameter that is considered to take decision of improve pavement surfaces.

To manage friction in this network, the current Chilean standards are based on a simple procedure, in which the skid resistance is monitored in all network. The data are compared with a single fixed standard and if skid data are below thresholds the improvement is scheduled to the investment budget of the next year.

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The current friction management system has some weakness. The thresholds are adopted from foreign standards without considers the construction pavement technology and quality of materials; does not exist measurement standards for some skid resistance measurement devices and method to compare different skid resistance values obtained with the devices existent in Chile among others. Also, in Chile does not exist enough knowledge of the behaviour of the skid resistance and macro texture in the paved network of Chile and dos not exist an adequate statistic of accident to find a relationship between risk of accidents and a minimum skid resistant values.

To update and improve the FMS currently used in Chile, the Pontificia Universidad Católica of Chile, 4 concessionary companies and the National Roads Laboratory of the Ministry of Publics Works perform a 3 year project founded by the Chilean Government through the Fund for the Promotion of Scientific and Technological Development (FONDEF). The objective of the FONDEF project was to assess in detail the weakness of the current friction management system and to propose a new system based on the life cycle of the pavement surface: design – construction - operation. On this way, the objective of the paper is to discuss the philosophy, the essential characteristics and practical issues of the Chilean experience for develop national friction standards, according to the results obtained in the FONDEF project.

2. FRICTION MANAGEMENT IN CHILE

The roads network of Chile is managed by the National Highways Agency (NHA) of the Ministry of Public Works (MOP). The trunk road network (mostly highways), are concessed roads that are managed by concessionary companies under the supervision of the NHA. The main task of the NHA is to control that the concessionary companies provide a pavement surface condition according to the national standards.

Parameters like IRI, Skid Resistance (SR), Macro Texture (MTX), routing among others are controlled. The thresholds of these parameters are established in the contract between the MOP and the concessionary firm. All this parameters are monitored year by year and the accomplishment of thresholds is mandatory for in – service pavements. In unconcessed paved road network, skid resistance and macro texture is monitored in new surfaces but not on in-service pavements.

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Minimum threshold values have been defined for both SR and MTX. The former based on SCRIM units and the last based on volumetric values obtained with the Sand Patch test. Such thresholds are single-fixed values that can be applied only in two site categories: with and without geometric singularities. If any segment of a lane shows values of SR and or MTX under the thresholds, the surface should be repaired to fulfill the required. In comparison with UK standards, the thresholds of SR used in Chile are intervention thresholds, but without considering the risk of accidents.

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The framework used in Chile to manage friction has some weakness. These can be summarized as follows.

– Threshold values of SR are based in SCRIM units but Grip Tester or British Pendulum are used for measure SR too. To compare both devices measurements, and then to compare with threshold, some companies uses IFI procedure. But it has not been calibrated to local conditions.

– Currently in Chile a standard for measurement of SR with Grip Tester does not exist. The companies that use this device perform measurements according to the manufacturer recommendation and according to general recommendations that give them the National Highways Laboratory of the NHA.

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– The fleet of Grip Tester existent in Chile are composed by 3 units. The owners of the devices apply frequently controls of the repeatability of each device but not a reproducibility check of the whole fleet. This is an important step before compare, for example, Grip Tester values with SCRIM values.

– The threshold values used in Chile are single-fixed values that not consider the risk of accidents and their relationship with different sites in the roadways. Because the thresholds are mandatory, in some cases sites with low risk accidents those have SR values below the thresholds needs to be improved. With this policy the NHA and the concessionary have not tools to assure an efficient budget allocation for pavement surfaces improvement.

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– All those weakness showed the need to update the current standards related to friction management and to develop a comprehensive framework to friction management.

3. THE FONDEF RESEARCH PROJECT

To address this challenge, a multi-lateral project named "Research and Development of Procedures for the Measurement and Control of Pavement Friction in Chile" was developed between 2005 and 2008 (De Solminihac et al, 2005). The project was conducted by the Pontificia Universidad Católica of Chile (PUC) and was supported by the Promotion of Scientific and Technological Development (FONDEF) fund of the Chilean Government, the NRH of the Ministry of Public Works, and national concessionary agencies. The research team were composed with researches of PUC and the Universidad Nacional de San Juan of Argentina. The Transport Research Laboratory (TRL) provided the technical advisory along the study.

The main objective of the research project was to develop a set of procedures and standards to manage friction as a basis for a new SR related standards for the Chilean Highways Manual. In a broad sense the main objective was classified in 5 specific objectives that were the basis of the formulation of the research project:

- To expanding the knowledge about the behaviour of skid resistance and macro texture in the paved road and highways network. This objective is related to friction supply.
- To understand driver behaviour under controlled and un-controlled braking manoeuvres and in driving in horizontal curves. This objective is related with friction demand.
- To update measurement standards of current SR devices and to develop new measurement standard for Grip Tester device.
- To harmonize SCRIM and Grip Tester measurements to provide a common basis of comparison of SR values with thresholds.
- To develop a new method to estimate SR thresholds and update the current standard for in-service pavements for the whole paved network.

Specific in-field experiments were designed to provide a suitable data base to perform technical and scientific analysis. The experiments comprised a huge amount of field measurements of SR, MTX, pavement surface temperature, weather temperature, speed of measurement devices, vehicle speed in curves and accelerations in braking conditions. All the parameters were measured in test section of the paved road network previously selected from the national road inventory and from in-field inspection.

The Ministry of Public Works provided their own SCRIM, Grip Tester, and Laser Profiler devices to make most of the field measurements. In experiments associated to harmonization procedures private companies were contracted to make SR and MTX surveys.

To fulfil the objectives described above, the project was organized in 5 work packages (see Table 1). Each one of them was associated to one single specific objective.

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Table 1. Work Packages of the project and their experiments.

Work Package	Experiment
WP1: Measurement and Quality Control	• Measurement of skid resistance with SCRIM and Grip Tester and their relationship with measurement speed, pavement temperature and weather temperature. • Repeatability and reproducibility checks for SCRIM and Grip Tester devices. • In field checks for quality control of measurements and devices
WP2: SR and MTX Behaviour	• SR and MTX evolution over the time for different pavement surfaces and traffic levels • Seasonal effects on friction supply for different pavements surfaces and MTX levels.
WP3: Harmonization	• Harmonization of measurements obtained with Grip Tester and SCRIM, considering different types of laser profilers and different levels of SR and MTX.
WP4: Thresholds	• Friction demand for different light vehicle types and pavement surfaces in braking conditions. • Friction demand of light vehicles in cornering condition, calculated indirectly with the operation speeds.
WP5: Polishing	• Polishing resistance for different types of aggregates currently used in Chile for pavement design.

A Steering Committee conformed by representatives of PUC, NHA and concessionary agencies discussed and reviewed the research, procedures and standards elaborated by the research team. The committee and the advisory of TRL was a useful mean to monitoring the technical achievements of the research and to develop scientific and practical tools to elaborate the standards.

4. DEVELOPMENT OF FRICTION STANDARDS FOR CHILE

In the FONDEF project, an approach that integrated design, construction and operation concepts was used to construct the framework of the system of procedures that lead to the finally proposed standards.

4.1 CONCEPTUAL FOCUS FOR FRICTION MANAGEMENT SYSTEM

A friction management system should be able to recognize the factors that explain the variability of friction demand and friction supply, and to define how to integrate it.

Friction demand is defined as the friction required for a driver-vehicle system to carry out manoeuvres safely. It can be classified into longitudinal friction demand in braking condition and side friction demand to ensure dynamics stability in horizontal curves.

In most roads, the drivers are quite heterogeneous, therefore the friction demand can not be considered as a single fixed value. Friction demand is associated to a percentile of the probability distribution of longitudinal or side accelerations which depend of drivers´ behaviour in braking or cornering condition. The percentile of accelerations, usually 85 or 99, represent a certain level of risk of wet weather accidents.

Modelling friction demand makes possible to define design friction values, and also friction thresholds for several kinds of road infrastructure considering the population of driver's variability. In this approach, design friction values represent a comfort condition for

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drivers in controlled situations while friction thresholds represent a safety condition for driver in an emergency situation. Thresholds values are consistent with the design friction values since both are obtained of the distribution of friction demand that characterizes the drivers. Friction Thresholds represent the minimum value of friction supply that should be provided by the pavement.

Friction Supply is defined as the friction provided by the pavement at a specific slip speed, measure with a specific device. Friction supply is also variable, changing along time. Usually, after new construction or surface rehabilitation, the pavement surface provides the highest skid resistance values, but SR decreases along time, reaching in some years an equilibrium value (Echaveguren, 2008). Friction equilibrium value provided by the pavement in the equilibrium stage should be higher than the friction thresholds defined according to friction demand.

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If the evolution of friction supply along the time can be expressed at network level in terms of mathematical models, the corresponding values of friction at the initiation of the pavement surface life can be estimated applying back-calculation and reliability concepts for different traffic levels. Following this approach, friction thresholds for new or rehabilitated surfaces can be defined for paved local roads or highways.

An appropriate knowledge of friction demand and friction supply for different situations in a road allows defining realistic design and thresholds values considering the driver behaviour and the pavement surface condition about materials characteristics, traffic levels and construction technologies available in the country.

Though the approach considers design, construction and operation, only the standards for in-service pavements have been developed. The standard for design and construction are in development. The in-service pavement standards are described in next section.

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4.2 FRICTION STANDARDS ON A FRICTION MANAGEMENT SYSTEM

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As a group of final products of the FONDEF project, friction procedures and standards for in-service pavement were elaborated following an integrated approach among skid resistance measurement, harmonization, thresholds specification and safety analysis. The integration of friction standards can be diagrammed into a whole system for friction monitoring and assessment (See Fig. 1) which has been organized in four components:

- **Skid Resistance Measurement Standards:** include indications for device calibration, measurement method, data processing, need of harmonization among different devices and delivers as output a measurement report.

- **Harmonization Standards:** include indications for harmonization of Grip Number Coefficients (GNp) to SCRIM Equivalent Coefficient (SFCe) in the case of the measurement was done with Griptester.

- **Thresholds Specification Standards:** include skid resistant thresholds for different sites, according to geometrical and operational conditions. Consider Study Thresholds and Intervention Thresholds for different levels of friction demand.

- **Safety Assessment:** establishes indications for data analysis according to the sites categories, segmentation of data, construction of a skid resistant profile, evaluation of thresholds and delivers as output an assessment report.

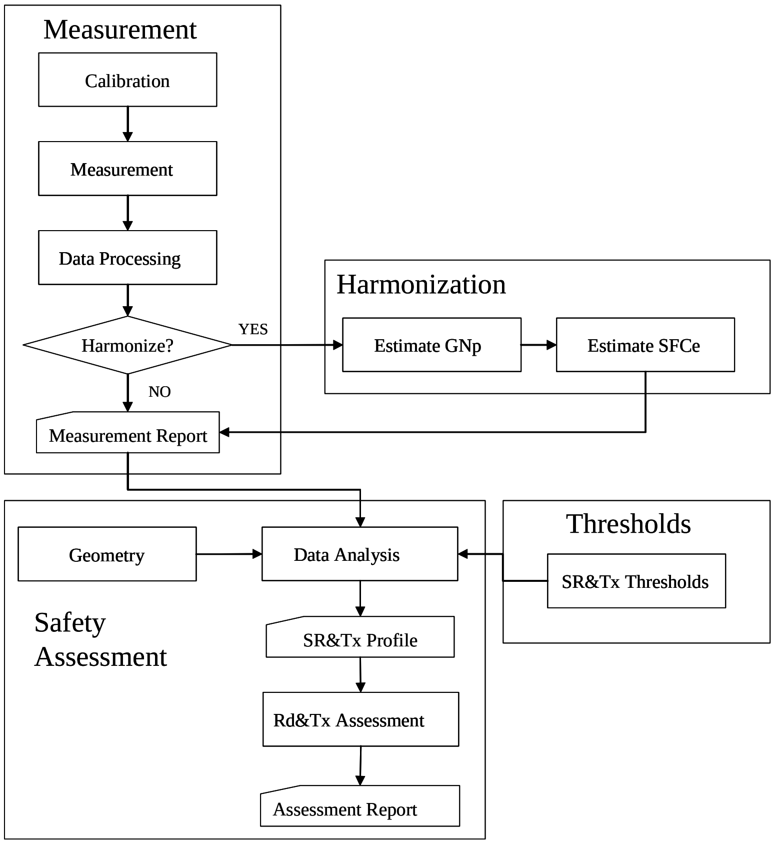

Figure 1. Integration of friction standards into a friction management system

The main objective of such system is to check if the friction supply falls below the thresholds defined for a given road geometry. The different components are organized in a logical sequence, starting with the calibration of the measurement devices and ending with an assessment report. The main characteristics of each standard as a component of the monitoring and evaluation system are described in the following specific sections.

4.3 THE STANDARDS PROPOSED

4.3.1 Skid Resistance Measurement Standards

The SR measurement standards had the objective of update the current standard for the SCRIM device and to develop a new standard for the Grip Tester device (See Fig 2). The standards include the subjects: calibration of each device, a step by step method for field measurements and first processing of collected data.

Calibration procedures are focused to standardize the kind and frequency of calibration checks and mechanical adjustments that have to be made in each device prior to the measurement campaigns. Specific issues for measurements such as recommended measurement speed, test line, test lane was proposed.

Figure 2. SCRIM and Grip Tester devices used to measure skid resistance in Chile (Source: Tomas Echaveguren with permission of NHL).

The proposals for data processing consists in a preliminary assess of raw collected data, to built a database of SR measurements. It considers discarding of invalid data, and the use of speed and temperature adjustment factors to standardize the SR measurement to a specific speed of 50 Km/h and weather temperature of 20 °C. The use of these adjustment factor permits to compare SR measurements obtained from different in-field conditions with the thresholds.

4.3.2 Quality Control Standard

A collateral work was to develop tools for quality control of the devices. The procedure developed was the basis of the repeatability and reproducibility (R&R) standard for SCRIM and Grip Tester devices. A detailed description of all these procedures can be seen in De Solminihac et al (2007a; 2007b).

The standard defines the mathematical procedures to estimate repeatability of each measurement device and reproducibility of a fleet of devices. Threshold for R&R values were proposed. It was based on the history of repeated measurement developed in the FONDEF project, and on the international experience.

4.3.3 Harmonization Standards

The harmonization standard includes equations to convert Grip Tester measurements (expressed as Grip Number, GN) to SCRIM-equivalent units (Side Friction Coefficient, SFC). To develop the harmonisation equations the EFI principle was used, considering as a free parameter the reference speed. In the Chilean case, the value of the reference speed that minimizes the error of the calibration was calculated in 25 Km/h.

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Because the Grip Tester has different behaviour depending on the macro texture, the standard propose equations for high (> 1mm) and low (< 1 mm) macro texture. The value that defines the low and high levels was based on statistical analysis of the macro texture data survey carry on the project.

The standard proposes general guidelines to calibrate the coefficients of the harmonisation putting emphasis in the need that the devices and the fleet of devices must to accomplish the measurement and quality control standards. Some guidelines are also indicated to update such coefficients in some cases, for instance when a new type of device is incorporated for measurement purposes. A more detailed description of the procedure can be reviewed in De Solminihac et al (2007c).

4.3.4 Threshold Specification Standards

The thresholds standard defines a mixed scheme of study and intervention threshold for skid resistance based on SCRIM values measured at 50 km/h. Study thresholds are SR values below which the risk of accident could be increasing and a study of occurrence of accidents and macro texture should be carried out to evaluate if an intervention on the site is necessary. Intervention thresholds are minimum SR values below which the risk of accident increasing and an intervention on the pavement surface is required to increase the skid resistance and macro texture.

Both kinds of thresholds were established considering three site categories according to the risk of wet weather accidents:

- Main line, with free-flowing traffic, which was subdivides in two subcategories according to dual or single carriageways.
- Stopping Zones such as junctions, crosswalk, railroad crossing and toll areas.
- Horizontal Curves, which was subdivided in five sub-categories according to the radius of curvature and the speed limit.

The study and intervention threshold for each site were calculated according to friction demand probability distribution. These values are dependent of the selected level of reliability, expressed in terms of a specific percentile of friction demand. Typical percentiles used were 99th and 85th for study and intervention thresholds respectively. These friction demand percentiles represent different risk levels of accidents.

The study and intervention thresholds calculated by friction demand were similar to values obtained according to the risk accidents approach used in UK and other countries.

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4.3.5 Safety Assessment

This standard uses the information provided by the measurement and harmonization procedures, and takes into account the defined threshold values, to assess if the current situation in each site involves a degree of unacceptable risk from a safety viewpoint. It is intended to evaluate the eventual need to carry out a study in the site, apply some corrective measures like improving pavement friction or traffic controls, or if nothing has to be done.

Safety Analysis is comprised of four steps (De Solminihac et al, 2007d): Data Analysis, Skid Resistance Profile (SRP), Thresholds Evaluation, and Intervention Profile (See Fig 3).

Data Analysis is a procedure that permits to identify skid resistance outliers (singularities) and structural changes in mean values inside each site of the road. Outlier detection is based on the statistical leverage test, and structural changes detection is performed using the Change Point Theory, in order to define a segmentation of measured data in each site (de Solminihac et al, 2008). This process can be systematized in a computational application so that the final outputs of data analysis are the mean value and standard deviation of SR, for each segment according the structural changes detected.

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Using the mean values of SR obtained from data analysis, the *Skid Resistance Profile (SRP)* is constructed. This profile is a graphic representation of the road that contained the main geometric characteristics of the road, the sites categories, the final data segmentation in each site, and the mean value of skid resistance obtained for each segment. In base of this profile is possible evaluate the skid resistance thresholds easily and finding the sites that need study, intervention or do nothing.

The data presented in the SRP are therefore assessed through the *Threshold Evaluation Procedure.* This is a systematic method that describes the steps to compare the average values of skid resistance against the "study" or "intervention" thresholds already defined in the corresponding standard. Figure 3 shows the flowchart of this evaluation methodology.

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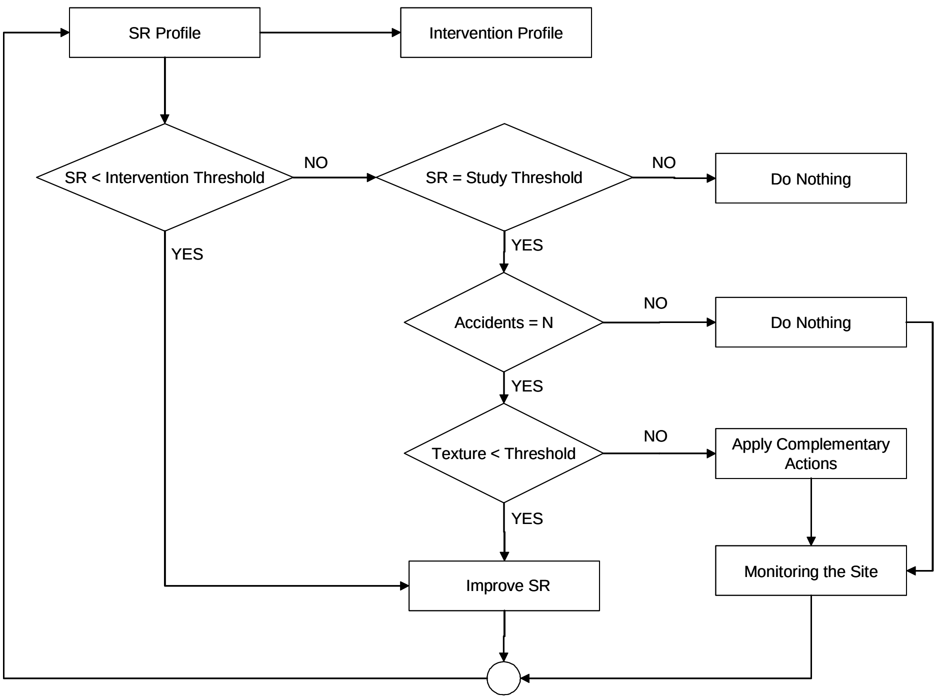

Figure 3. Conceptual structure of the Safety Analysis Procedure

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As it is shown in Fig. 3, the mean of SR in each segment is compared against the respective intervention and study thresholds. If SR is below the intervention threshold, surface friction directly needs to be improved by surface restoration or rehabilitation. If SR is above the intervention threshold but below the study threshold a more detailed study of accidents history and macro texture in the segment has to be performed, to decide if the surface needs intervention to increasing friction values, apply complementary actions or need to be monitored. If SR is above the study threshold, nothing has to be done.

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The final output of this procedure is the *Intervention Profile* which is a graphic representation of the road that includes the following information:

- Red Sectors: Segment or group of segments requiring an intervention to improve skid resistance and macro texture.

- Yellow Sectors: Segment or group of segments that do not require immediate intervention, but need further evaluation and monitoring. In these sectors, complementary actions should be performed to reduce the risk of accidents, like improvement of limit speed signs, traffic control, etc.

- Green Sectors: Segment or group of segments in which nothing has to be done, because skid resistance is higher than study thresholds.

The Safety Analysis Procedure can be implemented in software in which the inputs are the skid resistant data, geometrical characteristic of the road, site categories, and skid resistant thresholds. The output of the procedure is the Intervention Profile, which is a practical tool for pavement maintenance and monitoring.

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5. CONCLUSIONS

This paper described the main procedures that support draft standard for friction measurement, control and management, elaborated during the FONDEF D03I-1042 research project carried out in Chile between 2005 and 2008. This project was developed for Chilean condition but the procedures can be adapted or used as a good base to develop standards in other countries.

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The individual procedures for in-service pavements were linked to establish a systematic methodology that includes measurement, harmonization, threshold specification and safety analysis. The cores of this methodology system are friction demand and supply mathematical models, validated with field experiments and calibrated to Chilean conditions.

Developed procedures for skid resistance measurement update and improve the current standards mainly in the treatment of temperature and speed effects and quality control checks.

Harmonization procedure permits to compare measurement done with SCRIM and Grip Tester devices. The method considers the macro texture effects in the skid resistance values obtained with Grip Tester. This method can be generalized for any device, therefore is possible to incorporate new devices in the future and the measures can be translated to SCRIM equivalent values and compared with skid resistance thresholds.

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A new method for skid resistant thresholds specification was developed based on friction demand-supply approach. Study and Intervention thresholds were proposed which represent different risk levels of wet weather accidents. The thresholds values obtained on this approach are similar to thresholds values found in the international experience.

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This new philosophy in thresholds estimation needs a decisional procedure more detailed that the current procedure used in Chile. The new decisional procedure called Safety Analysis Procedure identify those segments of the road where is necessary increasing de skid resistance, applying complementary measures or doing nothing, to fulfil skid resistance thresholds.

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The subsequent implementation of these standards into the current practices of friction control and management in Chile is the actual challenge. A transition scheme should be developed to help the highway authorities and personnel of road administrations during that process of implementation, because the new standards are clearly more demanding than the existing ones. It requires a strong direction and frequent interaction and dialogue between researchers, public authorities and private concessionaires, to achieve success at the end of this process.

In that way, the development of specific assessment tools, like a software package including most of the automated procedures incorporated in the standards for data collection, processing and analysis, quality verification and safety evaluation could be very helpful to accomplish such purposes.

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