Homogeneous reporting of Pavement Classification Number (PCN) in an Airport Pavement Management System

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ABSTRACT: PCN (Pavement Classification Number) reporting for the various airport pavement branches, such as runways, taxiways or aprons indicates the allowable weights for airplanes trafficking these areas. If the subgrade classification differ between these branches, determination of the allowable weight may include up to 4 interpolation calculations, which is neither practical for airline operators nor for airport administrators. This paper outlines a methodology for establishing homogenized PCN values to be reported for branches of an airport, based on PCN values for single points, determined from Super Heavy Weight Deflectometer (SuperHWD) testing and shows how it can be incorporated into GIS-based airport pavement management systems

KEY WORDS: PCN, homogeneous reporting, Airport PMS, GIS

1 ANALYSIS METHODOLOGY

The reporting of PCN is meant to provide airport operators with information enabling them to make quick decisions as to whether a specific aircraft should be allowed to operate on the airfield or parts thereof.

In this context it must be remembered that the aircraft ACN values, which should be compared to the pavement PCN value, are only reported for the discrete CBR values of 3 %, 6 %, 10 % and 15 %, and at two weight levels, the high level corresponding roughly to Maximum Take Off Weight and the low level to Operating Weight Empty. To determine the ACN value at a specific weight in between these two values and for a CBR value different from the standard reporting values therefore requires a two-step interpolation process.

In order to simplify this process, pavement PCN values should only be reported at the abovementioned standard CBR values. This will make it possible for both airport and airline operators to determine the allowable operating weight of a specific aircraft from a simple one-step interpolation between the ACN values reported at the high and low weight levels respectively.

The PCN reporting process for a trafficked area divided into branches therefore has the following separate stages:

1. Determine for each point in a branch it’s PCN-value, based on e.g. FWD/HWD measurements and analyses
2. For each point determine the allowable weight of a characteristic analysis airplane at the actual PCN value
3. Calculate mean and standard deviation of the reported weights of the characteristic analysis airplane, and select the characteristic weight percentile for reporting PCN.
4. Determine the characteristic subgrade type on the area (A to C) by choosing the most frequent type. Then back-calculate the ACN value for the characteristic airplane at its characteristic weight and report as the PCN value.

2 DETERMINING PCN

2.1 Basic Definition

The ACN-PCN system is a classification system that makes it possible to quickly determine whether it is safe to operate a specific aircraft on a given airfield. The system classifies pavements by assigning a Pavement Classification Number (PCN), including a simple subgrade strength indicator to the pavement. Any aircraft with an Aircraft Classification Number (ACN) of equal or lesser magnitude may safely operate on that pavement. The methodology is closely tied to FAA's CBR design method, and described thoroughly a.o. in Aerodrome Design Manual, Part 3 (ICAO, 1983).

The basic definition of the Pavement Classification Number (PCN) for flexible pavements is done by the following set of equations:

PCN (in 1000 kilo) = 2 × DSWL (I)

DSWL is the Derived Single Wheel Load (in 1000 kilo) that fulfills the equation

$$t = \sqrt{\frac{DSWL}{C_1 \times CBR} - \frac{DSWL}{C_2 \times p_S}} \qquad \text{(II)}$$

In this equation, the following applies:

t is the pavement reference thickness in centimeters
C1 = 0.5695
C2 = 32.035
CBR is entered in percent (i.e. CBR 10% as "10")
p_S = 1.25 MPa (contact pressure of DSWL)

The definition has its roots back in the time when many aircraft had only single-wheel main gear, whereby the PCN-value simply becomes the (approximate) weight in tons of the aircraft with a given single wheel main gear.

The one critical information that is not straightforward available is the fact that the reference thickness is the actual thickness of the pavement, designed according to the FAA CBR design methodology.

For practical purposes, equation (II) is not very operational, and unit-wise it is mathematically incorrect.

Equation (II) can, however, be used to verify a stress criterion, linking (subgrade) E-modulus to the allowable stress at the top of the subgrade under a single wheel load with a contact pressure of 1.25 MPa - the wheel load that fulfills this criterion is then the DSWL, used in the PCN definition equations.

2.2 Development of PCN stress criterion

Development of the PCN subgrade criterion is done on the basis of the ACN-values, presented in the Aerodrome Design Manual, Part 3 (ICAO, 1983), page 3-279. Here is quoted ACN (Aircraft Classification Number) for the Lockheed C-141 military transport aircraft on pavement subgrades with CBR values of 3 %, 6 %, 10 % and 15 %. These are precisely the characteristic values of the 4 sub-grade reporting classes in the ACN-PCN system. Supplementary to the ACN values are given the total thicknesses of the corresponding FAA-compliant pavements, which, according to the analysis described in section 2.1, must have PCN values corresponding to the C-141 ACN values.

In order to develop a stress criterion, it is verified that FAA-designed pavements actually match the thicknesses of the ADM3 example.

To this end the LEDFAA program (FAA, 2004) is applied for pavement design, and the subsequent critical stress determination under DSWL loading is performed with Linear Elastic Theory, LET as applied in the mePADS program (CSIR, 2001). Supplementary calculations are done with Boussinesq theory (Boussinesq, 1875) and the Method of Equivalent Thicknesses, MET (Odemark, 1949) in the traditional version and in a calibrated version, (MET enhanced), where the correction factor of 0.8 normally used for the subgrade interface (Ullidtz, 1998), is replaced with a function of the ratio between equivalent depth and load radius, increasing from 0.8 at high ratios to values well above 1 for low ratios (Busch, 1991).

For these calculations it is chosen to modify the traditional relationship between CBR (in %) and subgrade E-modulus,

$$E_m = 10\ \text{MPa} \times \text{CBR} \qquad \text{(III)}$$

For CBR values above 5 % is used a power function (Lister & Powell, 1987):

$$E_m = 17.6\ \text{MPa} \times \text{CBR}^{0.64} \qquad \text{(IV)}$$

The LEDFAA design and results from the various analyses of the DESWL subgrade reactions are summarized in Table 1.

Table 1: Analyses of subgrade stresses under C141 Starlifter loading

PCN = C141 Starlifter ACN from ADM3 example			73.53	59.3	48	41.94
Corresponding PCN definition load		(kN)	361	291	235	206
P-401 AC Surfacing	Thickness	(mm)	102	102	102	102
	E-modulus	(MPa)	1379	1379	1379	1379
P-401 AC Base Course	Thickness	(mm)	102	102	102	102
	E-modulus	(MPa)	2758	2758	2758	2758
P-209 Crushed Aggregate	Thickness	(mm)	143	143	143	102
	E-modulus	(MPa)	443	418	367	334
P-154 Uncrushed Aggregate	Thickness	(mm)	1071	623	260	122
	E-modulus	(MPa)	187	182	174	196
Subgrade	CBR	(%)	3%	6%	10%	15%
	E-modulus	(MPa)	30	55	77	100
Total LEDFAA design thickness		(mm)	1418	970	607	428
Thickness from ADM3 example		(mm)	1435	891	601	439
Ratio LEDFAA/ADM3		(-)	0.99	1.09	1.01	0.97
Subgrade vertical stress	PCN load (MET traditional)	(MPa)	0.0278	0.0662	0.1519	0.2792
	PCN load (MET enhanced)	(MPa)	0.0245	0.0519	0.0975	0.1491
	PCN load (LET)	(MPa)	0.0279	0.0584	0.1130	0.1750

The stresses calculated under the DSWL load by the different methods show some scatter, especially for the higher subgrade E-moduli, although the difference between the MET enhanced and LET are within a reasonable range, and probably could be reduced by further calibration of the f-factor function.

For the actual pavements, the stresses calculated under the DSWL indicate the allowable stress on a subgrade with that specific E-modulus, corresponding to the PCN value identical to the C141 ACN value.

The discrepancies between the calculated stresses for standard MET versus enhanced MET and LET indicates that the correction factors applied in the Boussinesq equations of the standard analyses only yield correct results for ratios between load radius and pavement layer thicknesses that are comparable to road pavement conditions. High PCN values - corresponding to large load radii – determined by this methodology are therefore not trustworthy, and only MET enhanced and LET analyses should be used.

The calculated stresses are used to develop stress criteria, linking subgrade E-modulus to allowable stress, as shown in Figure 1.

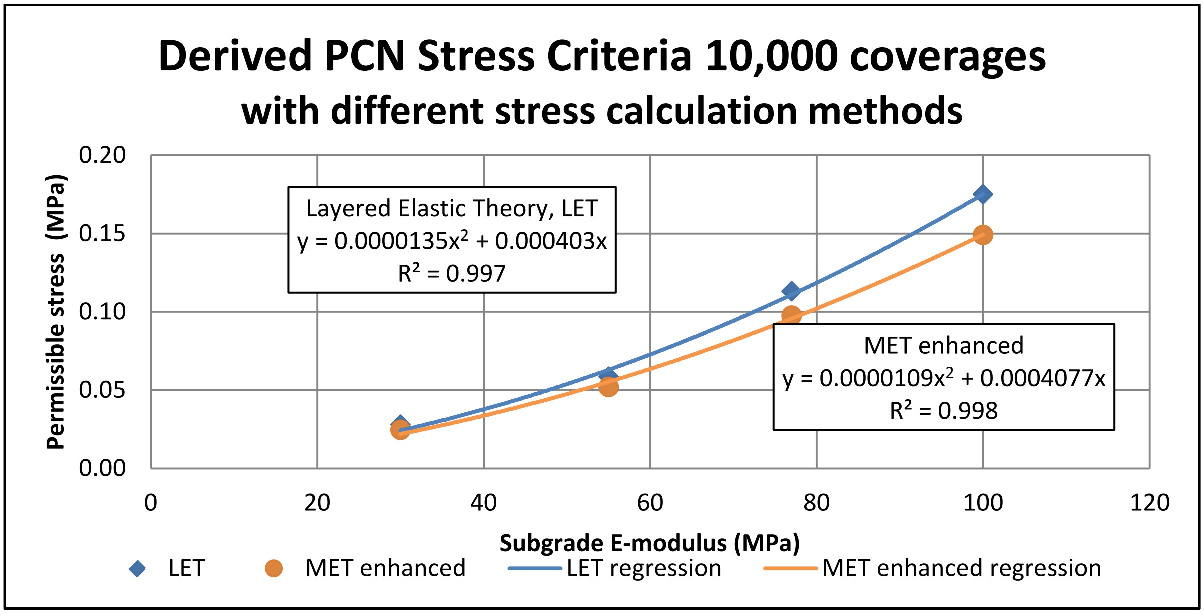

Figure 1: PCN stress criteria, applicable with different analysis methods

The LEDFAA program (FAA, 2004) applies an exponent for number of coverages, C, above 12,100 in its subgrade fatigue criterion:

$$C = \left(\frac{0.002428}{\varepsilon_v}\right)^{14.21} \tag{V}$$

For heavily trafficked airports it seems reasonable to extend the validity of this exponent downwards to the PCN definition 10,000 coverages, so that a correction factor for other PCN traffic levels may be calculated as:

$$f_{HIGH}(N) = \left(\frac{N}{10{,}000}\right)^{-\frac{1}{14.21}} = \left(\frac{N}{10{,}000}\right)^{-0.07} \tag{VI}$$

For airports with only limited traffic, the lower exponent of LEDFAA should be used, leading to the traffic level correction function:

$$f_{LOW}(N) = \left(\frac{N}{10{,}000}\right)^{-\frac{1}{8.1}} = \left(\frac{N}{10{,}000}\right)^{-0.12} \tag{VII}$$

Using the LET regression coefficients, the permissible stress equations are as follows, with both E_m and σ_{perm} entered in MPa:

$$\sigma_{permHIGH\ TRAFFIC} = (0.0000135 \times E_m^2 + 0.000403 \times E_m) \times \left(\frac{N}{10{,}000}\right)^{-0.07} \qquad \text{(VIII)}$$

$$\sigma_{permLOW\ TRAFFIC} = (0.0000135 \times E_m^2 + 0.000403 \times E_m) \times \left(\frac{N}{10{,}000}\right)^{-0.12} \qquad \text{(IX)}$$

When E-moduli and layer thicknesses are known, PCN for a given point may then be determined by an iterative process, where a single-wheel load with a contact pressure of 1.25 MPa is adjusted until the resultant stress on the subgrade meets appropriate criterion of equation (VIII) or (IX), dependent upon the traffic level. Finally, the CBR value for classification is determined from equations III or IV.

2.3 Allowable Airplane Weight and Branch PCN

The CBR value for a branch PCN point will in most cases not coincide with one of the standard PCN reporting CBR values, which are:

A. High Strength	- CBR 15 (All CBR above 13%).
B. Medium Strength	- CBR 10 (For CBR between 8% and 13%).
C. Low Strength	- CBR 6 (For CBR between 4% and 8%).
D. Ultra Low Strength	- CBR 3 (For CBR below 4%).

A PCN-value determined for an actual value, CBR_{ACTUAL} that is not corresponding to one of these four standard values should therefore be adjusted to the appropriate reporting value, CBR_{REPORT} for the interval that contains CBR_{ACTUAL}.

To achieve this objective, reverse analyses of updated ACN values (Wikipedia, 2011) are carried out. The analyses presents the ACN of commonly occurring aircraft with Dual Wheel, 4-wheel Bogie and 6-wheel Bogie as functions of the subgrade CBR.

The analyses are based solely on tabulated data and are consequently independent of pavement reaction calculation methodology.

In order to make the PCN values comparable, they are normalized, setting the value at CBR 3% to 1.

Figure 2 shows analyses for typical current airplanes of the ratios between MTOW ACN values at CBR 3 % and the values at 6 %, 10 % and 15 %. This illustrates that an airplane at a constant weight is assigned significantly different ACN values, dependent upon the reporting CBR value. Similar curves can be developed for D and 3D airplanes.

The critical parameter for a branch point with a given CBR_{ACTUAL} is therefore not the PCN but the allowable weight of a selected characteristic airplane.

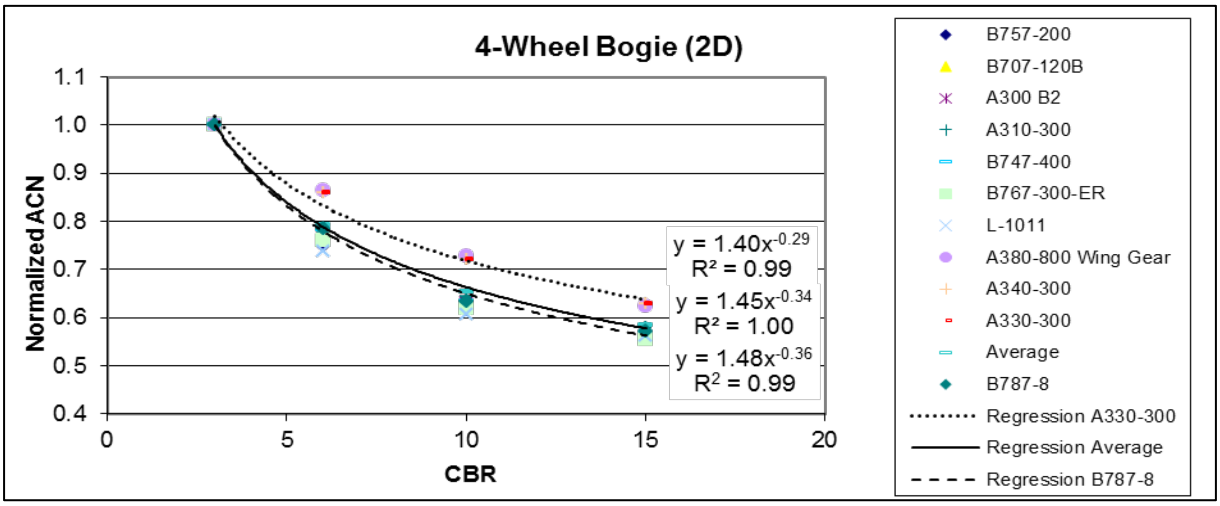

Figure 2: Example of normalized 2D gear ACN curves for constant airplane weight

The next task is to determine allowable aircraft weight at the branch points, where PCN has been determined as described in section 2.2.

To this end is selected a number of typical D, 2D and 3D aircraft. For D and 3D gear, aircraft are chosen as close to the average, the A319 and B777. For the 2D group, which is the largest and on actual airports is likely to contain the most critical aircraft, two specimens, the A330 and the B787-8 are selected in order to assess whether there is a significant difference between results calculated on the basis of one or another similar aircraft type.

Figure 3 and Figure 4 show that for the selected aircraft there are clear relationships between ACN, airplane weight (W) in ton and CBR. These relationships can be used to determine allowable weight of the selected characteristic airplane when the PCN (=ACN) and CBR_{ACTUAL} have been determined.

For aircraft representing D, 2D and 3D gear configurations the equations are:

- A319, D-gear $W\text{ (ton)} = (PCN \times 3.9)^{1/(1.13+0.0067 \times CBR\%)}$ (X)
- A330, 2D-gear $W\text{ (ton)} = (PCN \times 19.4)^{1/(1.26+0.0088 \times CBR\%)}$ (XI)
- B787-8, 2D-gear $W\text{ (ton)} = (PCN \times 21.7)^{1/(1.31+0.0092 \times CBR\%)}$ (XII)
- B777, 3D-gear $W\text{ (ton)} = (PCN \times 71.4)^{1/(1.40+0.0095 \times CBR\%)}$ (XIII)

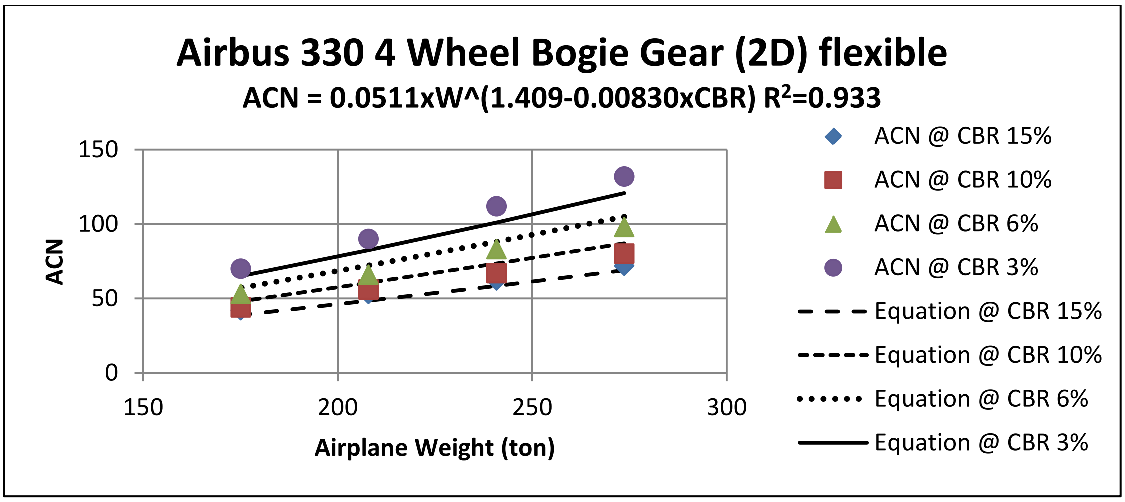

Figure 3: ACN for A330 2D-type gear for variation of Weight (ton) and CBR

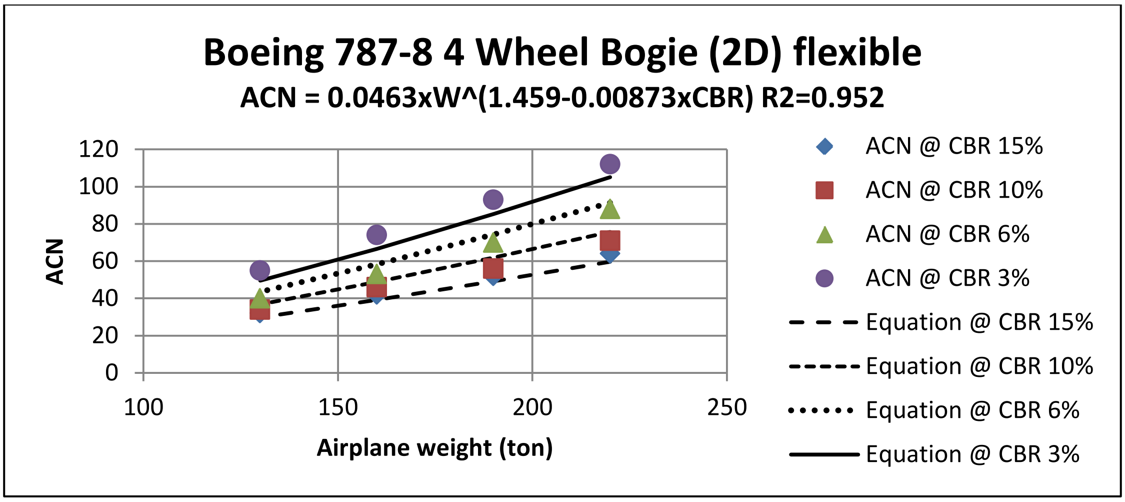

Figure 4: ACN for B787-8 2-type gear for variation of Weight (ton) and CBR

2.4 Characteristic airplane selection and PCN reporting

Allowable airplane weight in the different branch points can now be calculated from CBR-values according to (III) or (IV) and PCN-values determined as described in section 2.2. The following example, shows calculated weights for the 4 selected typical aircraft

It is noteworthy that in some instances, the calculated maximum allowable weight for an airplane is higher than its MTOW – this just indicates that the pavement PCN at that specific point is higher than the airplane ACN at that specific CBR-value.

Table 2: PCN analysis based on different characteristic airplanes, determining PCN at most-occurring CBR value (10% = Class B)

CBR	PCN	Subgrade	W_{A319}	W_{A330}	$W_{B787\text{-}8}$	W_{B777}
2.7	50	D	75	144	130	210
11.0	29	B	57	122	112	187
10.3	30	B	57	122	112	186
10.7	29	B	57	122	112	187
2.8	50	D	75	143	130	209
9.7	30	B	58	122	112	186
3.1	48	D	73	140	127	205
2.7	50	D	75	144	130	209
5.5	38	C	63	127	116	190
5.7	37	C	63	127	116	189
3.0	48	D	73	141	128	206
14.9	25	A	56	125	115	195
15.0	25	A	56	126	115	196
10.7	29	B	57	122	112	187
9.1	31	B	58	122	112	186
15.7	25	A	56	127	116	197
3.1	48	D	73	140	127	205
5.5	38	C	63	128	116	190
10.8	29	B	57	122	112	187
5.5	38	C	63	128	116	190
2.7	50	D	75	144	130	210
		Average	63	130	118	195
		StDev.	8	9	8	9
		10% pct.	53	118	109	183
Back-calculated PCN at CBR 10%		Average	33	32	32	32
		10% pct.	27	29	29	29

The calculations performed with the two 2D aircraft end up producing exactly identical branch PCN values, indicating that analysis for a single aircraft within a specific gear configuration should be sufficient.

Since the analyses are simple to carry out it is recommended in actual projects to calculate for all gear types, when they are represented in the airport traffic. For regional airports that are typically trafficked only by D-type gear aircraft, the A319 analysis will be sufficient.

The methodology for deriving branch PCN values for PCC slab pavements is exactly the same with respect to the ACN-PCN-Weight analysis. The determination of point PCN value should, however, include both calculation of critical stress in the center of slabs and at the edge, taking into account measured load transfer, and selecting the lower of the two values as point PCN

3 PRACTICAL APPLICATION

3.1 Heavy Falling Weight Deflectometer analysis

The PCN analyses are based directly on input that comes as results from bearing capacity analysis of Heavy Falling Weight Deflectometer measurements. As such, the analyses easily fits in as an add-on to the Design Life and Overlay analysis of traditional FWD software analysis packages, such as e.g. the RoSy Design Airport program.

3.2 Incorporation into Airport Pavement Management Systems

The methodology described above – including the Rigid Pavement Analysis – can easily be incorporated into Airport Pavement Management Systems.
An example is the RoSy Airport Pavement Management System that Grontmij has developed from the proven RoSy road pavement management system that is implemented on municipal, provincial and even national level throughout Northern and Central Europe as well as overseas.

3.3 GIS based analysis methods

The Airport Management System RoSy (APMS) is capable of executing advanced Spatial Analysis methods. Focusing the task 'PCN Harmonization', there is valuable functionality built into the System.
First of all, the integrated GIS shows the accurate bearing capacity measurement positions, derived from differential GPS mounted on the equipment. During the import process, all geolocations are stored in the RoSy APMS Geodatabase.

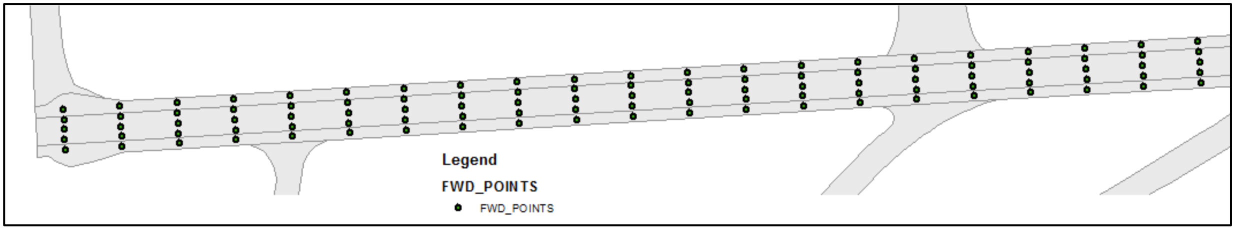

Figure 5: FWD measurement positions

After progressing in the analysis, the system will build spatially aggregated areas describing the Subgrade classes. Dimensioning of the blocks is derived from the measurement point offsets automatically.

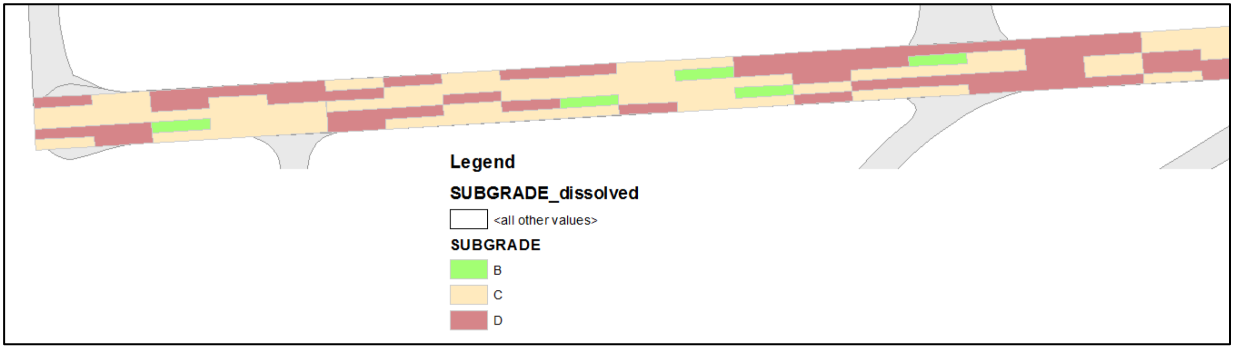

Figure 6: Analytically defined dissolved Subgrade class areas

The same kind of analysis leads to a meaningful PCN distribution Map.

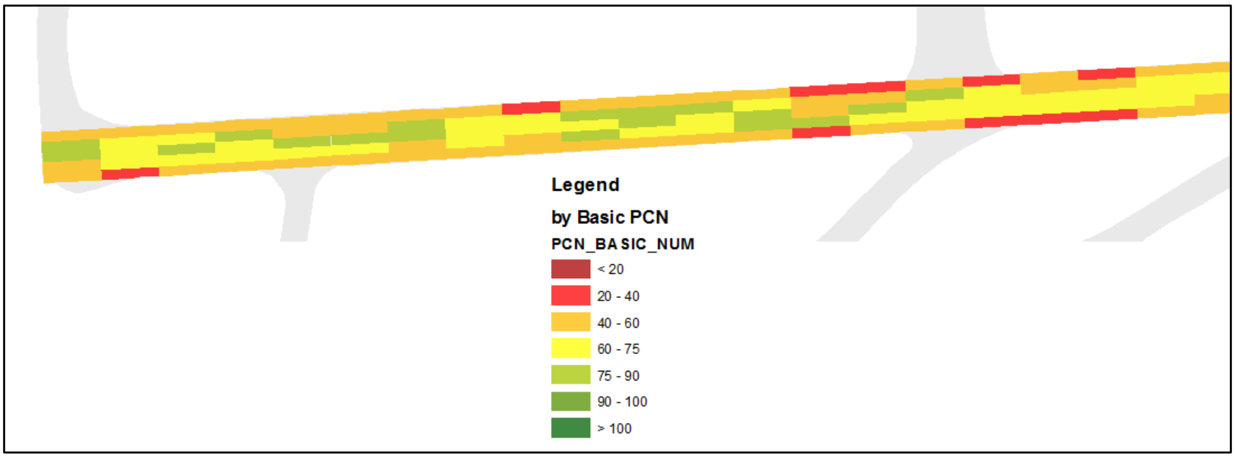

Figure 7: Analytically defined dissolved PCN range areas

Together with the view on realistic traffic loads, which could be retrieved from operational statistics, the overlay shows the relation between loads and determined PCN values per region.

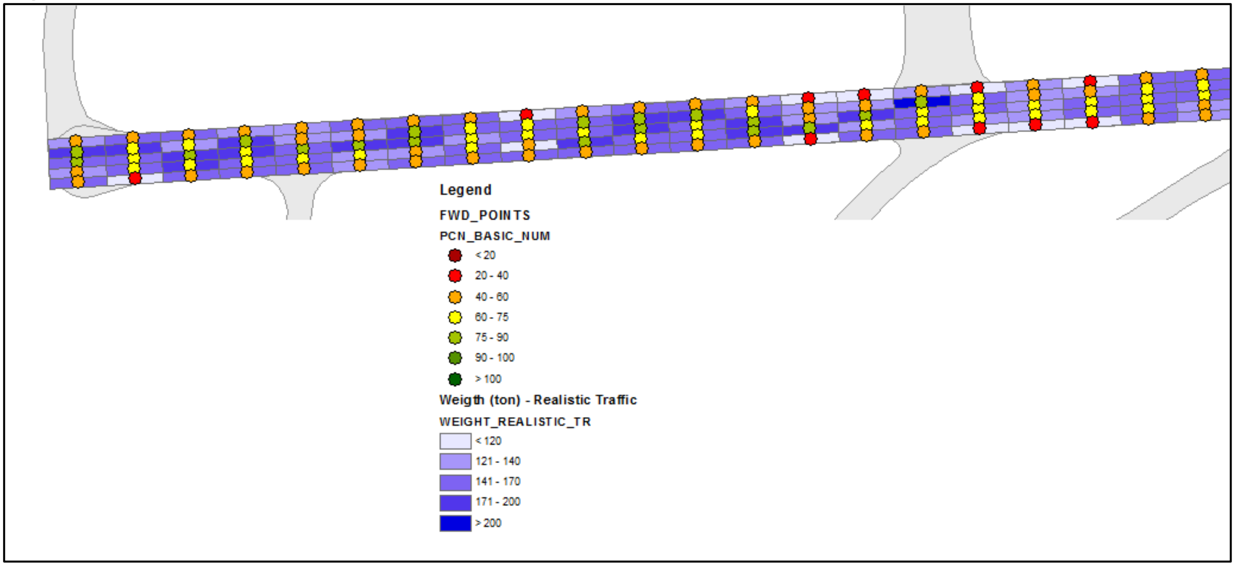

Figure 8: Overlay view – locational relation between weight and PCN

4 SUMMARY AND CONCLUSIONS

4.1 PCN calculation and Homogenization

Analyses' using enhanced MET and LET analysis has led to the development of simple, operational criteria based on FAA data for the determination of PCN from point measurements with Heavy Falling Weight Deflectometer. The analyses show that traditional MET calculation methods may lead to erroneous PCN reporting; indicating that enhanced MET or LET stress calculation should be applied.

Incorporation of the FAA design criteria exponents into the PCN criterion equations allows for a meaningful determination of PCN for both heavily trafficked areas and the low-trafficked edge sections of runways and taxiways.

The homogenization procedure facilitates the reporting of branch PCN values, and the user can easily determine which level of reliability should be employed in the determination of characteristic value.

Furthermore it allows the airport operator to apply a single subgrade category to all branches, which facilitates the determination of allowable airplane operational weight.

4.2 Airport Pavement Management System application

The inclusion of the methodology as a dynamic processing tool in an Airport Pavement Management System allows the user to select sub-areas of branches and dynamically calculate PCN-values and other pertinent pavement performance and residual life data.

Mapping and Analysis can give a comprehensive and customizable overview about the process of evaluation and the results of PCN Harmonization. This can be useful e.g. in assessing strengthening needs when designing new or upgraded taxiways that may redistribute traffic, as well as being an integral part of the maintenance planning and optimization which is the chief purpose of any pavement management system.

The user of an Airport Pavement Management System like RoSy APMS will benefit from state-of-the-art technologies in measurement, processing, analysis and presentation of Geospatial information in easily understandable Map form.

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