Pavement performance specifications: case study

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Abstract

In a context in which many projects have been executed in public-private partnership (PPP) mode in recent years, it makes sense to explore the various pavement performance criteria used by agencies for recent road projects developed in Canada.

After describing the various types of criteria used for pavements, such as ride quality, rutting, surface distress, skid resistance, structural capacity and frost susceptibility, their individual target values are reviewed. Adaptations of the performance criteria to enhance the effectiveness of the specifications for each of the parties concerned are suggested. Finally, the impact of the criteria and target values on the intervention cycles is analyzed in terms of technical constraints and life cycle maintenance cost aspects.

Introduction

Numerous projects have been executed in recent years in Public-Private Partnership (PPP) mode, in Canada and elsewhere in the world, and the trend seems to be continuing. Executing a project in PPP mode implies the transfer of some or all of the financial, construction, operation, maintenance and rehabilitation responsibilities for a specified period of time to a private sector company or consortium. The company is entrusted with these responsibilities and their associated risks in exchange for remuneration through the term of the transfer that will cover all of the costs and generate a profit. To ensure a minimum service level for users of the contracted road, the contracts call for respect of specified limits for selected pavement performance indicators.

This paper discusses the performance level that the contracted road must maintain during the contract period and at the time of its handback to the government agency. First the various performance indicators used are described, followed by a comparative analysis of the prescribed levels in different projects, in order to illustrate the trends in terms of target objectives. Finally, the impact in budget and technical terms of the specified target values on the contractor during the term of the contract is discussed.

Performance indicators

The types of assets whose management is entrusted to the private company as part of a PPP contract are generally the following:

- roads (roadways, shoulders, ramps);
- structures (bridges, supporting walls);
- electrical system (lighting, digital displays, telesurveillance);
- right-of-way (grading, fences, noise-abatement walls);
- safety (guard rails, marking, impact absorbers, signage);
- drainage (ditches, culverts).

Some of these elements, especially those with safety implications, are subject to daily surveillance by a patrol system, and the response time must be virtually immediate. Other elements receive occasional monitoring, especially in relation to constraints of an operational nature, such as grass cutting, drainage maintenance and winter snow removal. Finally, functional components like the condition of the road surface and structural components generally receive annual inspection, and the planning of maintenance and refurbishment activities for these components is controlled by an asset management system. This paper deals specifically with the pavement.

The condition indicators that are commonly or sporadically included in performance specifications, listed in order of occurrence, are the following:

- ride quality (International Roughness Index (IRI));
- rutting (depth of the rut);
- surface distress (cracking and default);
- skid resistance;
- structural capacity;
- frost susceptibility

Ride quality (IRI)

The longitudinal profile is measured to identify the deformations that affect user comfort and safety as well as vehicle operating costs. Ride quality assessment is associated with the functional performance of the roadway and is a characteristic directly perceived by road users. The quality indicator generally used for ride quality is the IRI (International Roughness Index). The IRI index is calculated for each of the wheel tracks but is generally presented in terms of the average of 2 tracks and expressed in m/km. The index may be compiled over variable distances but the preferred interval is usually 100 metres. In some projects, the specified interval is 50 metres, while others prescribe a distance of 1.000 metres. The longer the selected interval, the less impact occasional deformations will have on the calculated index. The ride quality indicator IRI is specified in most if not all projects executed in mode PPP.

Rutting

Depending on the amplitude of the transverse deformation of the road profile from the creation of ruts, major user safety problems can occur, especially aquaplaning during raining conditions. The presence of ruts also makes driving uncomfortable and can result in the driver making an undesirable change in a vehicle's trajectory in order to avoid driving in the ruts. Rutting is calculated as the maximum depth measured from the deepest point in the deformed wheel path to the top of the surface beside the wheel path, using a reference length of 3.0 m. This depth is expressed in millimetres. Generally, the measurement is made for each of the wheel tracks at an occasional frequency, at an interval of between 10 and 100 metres. Both the average of the two tracks and the maximum value can be compiled. Like the ride quality index, rutting is a criterion widely used as performance indicator in projects executed in PPP mode.

Surface distress

The source of the degradation of the surface, i.e. from the action of traffic (wheel track cracking, alligator cracking), the environment (transverse and meandering cracking) or construction (paving joint, stripping, patching) can orient the diagnosis toward structural problems or quality of materials. Unlike ride quality and rutting indices, which are internationally recognized (IRI) or unequivocally measurable (ruts), there are many protocols used to quantify and qualify surface distress. Most methods, however, have in common the characterization of distress by type, description of the extent in terms of length, surface or numbers, and qualification by degrees of severity. In a number of cases, distress is weighted and combined or associated with deduction curves in order to calculate an overall surface distress index. Data on surface distress can be compiled by intervals of variable lengths. The most common intervals are in the order of 100, 500 and 1,000 metres. The surface distress criterion is not systematically included in all projects executed in PPP mode. In certain cases, only manifestations of specific problems are monitored, such as the presence of potholes, peeling or flushing.

Skid resistance

The skid resistance of a pavement reflects the friction forces between the pavement surface and the wheels of vehicles, especially when they break and change direction. Skid resistance is thus an important characteristic in road safety, especially on a damp pavement. The skid resistance of a pavement is described by measuring either the friction of a test tire on the pavement or its texture or a combination of both methods. For texture, both macrotexture (0.5 to 50 mm horizontally, 0.2 to 10 mm vertically) and microtexture (< 0.5 mm horizontally, < 0.2 mm vertically) are measured. The World Road Association, after a 1992 study, proposed an International Friction Index (IFI) calculated from texture and friction tests. Few projects so far include skid resistance criteria but the trend could grow in the near future.

Structural capacity

The capacity of a road to support traffic loads and distribute them across its structure is a characteristic that promotes pavement longevity. Structural capacity is determined by deflexion tests that identify the maximum deformation from the effect of a standardized load and thus make it possible to estimate either residual life or reinforcement needs. Few projects executed in PPP mode call for respect of structural capacity criteria through the term of the contract. However, in certain cases, the conditions for rehabilitating a road at the end of the contract include a structural capacity criterion, in order to ensure that there is a minimum period in which no major work on the road structure will be required once the road is again the responsibility of its owner.

Frost susceptibility

The susceptibility of a road to frost action can on one hand generate differential displacements, promoting the development of surface distress, and on the other, reduce winter riding quality. The frost behaviour of a pavement can be assessed visually from distinctive signs, such as the presence of transverse cracks and differential deformation zones, or analytically, from a comparison of roughness surveys made during the summer and near the end of winter, often expressed in terms of IRI index difference. Inclusion of frost susceptibility criteria in projects executed in PPP mode is rather rare but may occur in specific projects where such problems have already been identified.

Performance criteria

The execution of projects in PPP mode using contracts for more than 20 years offers companies an opportunity to work in a context that allows some flexibility, making it possible to establish a strategy that includes innovative measures and focuses on sustainable development.

However, within this framework, contractors must ensure a minimum service level for road users at all times. Contracts thus generally include performance criteria to be respected (KPI: Key Performance Indicators) based on an annual assessment of the condition of the roadway. As discussed above, ride quality (IRI) and rutting are the criteria most commonly encountered in the performance specifications of recent projects. Some contracts also require a specific distribution of results on a performance indicator measurement scale. Figure 1 shows an example of a distribution curve associated with the IRI index that was included in the project to build the William R. Bennett floating bridge in British Columbia. Use of this type of control is intended to ensure continuous maintenance during the term of the contract and thus avoid a situation in which the condition of a large proportion of the structure reaches the limit imposed by the performance criteria within a short period.

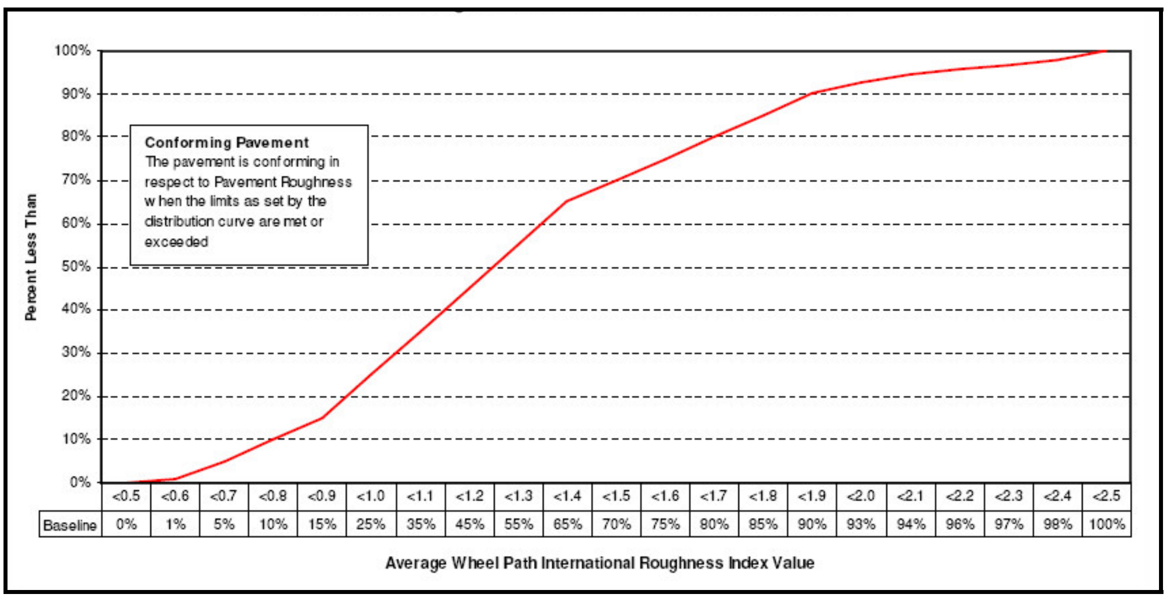


Figure 1 – IRI index distribution curve, William R. Bennett bridge in B.C.

A review of PPP projects recently completed or now under way mainly in Canada has allowed a comparison of prescribed performance indicators. Table 1 presents a synthesis of this review.

The information appearing in the table clearly indicates the diversity of the prescribed limits, especially of the intervals at which the indicators are measured. In the case of the IRI index, the compilation interval has a strong influence on the results produced and caution is called for when comparing criteria based on different intervals.

Table 1
Synthesis of performance criteria from various PPP projects

General information						
Project		Fredericton-Moncton Highway	Trans-Canada Highway - Route 2	Sea to Sky	North Edmonton Ring Road	A25
Location		New Brunswick	New Brunswick	British Columbia	Alberta	Québec
Commissioning		2002	2005	2010	2011	2011
Performance criteria						
IRI (m/km)	**Limit**	< 2.5	< 2.28	< 2.5	(4) < 1.9 | < 2.9	< 2.2
	Interval	100 m	100 m	50 m	1000 m | 100 m	100 m
Rutting (mm)	**Limit**	< 20	< 20	< 20	< 14 mm | < 19 mm	< 8 mm
	Interval	50 m	100 m	50 m	1000 m | 100 m	100 m
Surface distress	**Description**	(1) SDI > 7.9	SDI > 7.9	(3) PDI < 7	NA	(6) < 75 m cracks
	Interval	500 m	100 m	50 m		100 m
Skid resistance	**Description**	NA	NA	NA	IFI (F60) > 30	CFT > 55
	Interval					100 m
Structural capacity	**Description**	FWD def. < 600 μm (2)	NA	NA	At the end of the contract (5)	NA
	Interval	200 m				
Frost susceptibility	**Description**	NA	NA	NA	NA	IRI< 3.0 (m/km)
	Interval					100 m
Distribution curves		No	Yes	Yes	No	No and yes (7)

(1) SDI: Surface Distress Index – from 1 (very bad) to 10 (excellent). Calculated according to the procedure used by the New Brunswick Department of Transport (NBDOT)

(2) The limit varies as a function of the traffic. The 600 μm value is a representative value for the whole project.

(3) PDI: Pavement Distress Index – from 1 (excellent) to 10 (very bad). Calculated using the procedure used by the British Columbia Ministry of Transport.

(4) The limit values of 1.9 m/km and 2.9 m/km apply to traffic lanes in which the base speed is greater than 110 km/h. Other values are used by speed class less than 110 km/h.

(5) The criterion used specifies that when returning the road to the owner, an intervention (rehabilitation, resurfacing, etc.) lasting 10 years must not require a thickness of asphalt greater than 50 mm.

(6) The criterion specifics a maximum length for cracks whose width exceeds 25 mm.

(7) Limit of 2 to 4 non performing sections is tolerated before penalties are considered.

Technical and budget considerations

The performance criteria specified in projects executed in PPP mode relate to both the service level offered and user safety. However the values used for intervention limits must remain realistic in terms of the technical and financial resources available. The target service level should correspond to that offered for road sections with a similar purpose for which the government agency is responsible. Maintaining a road section at a higher service level is inevitably associated with a higher level of investment.

It should be possible to exercise flexibility in a contract with a long enough term to provide an adequate service level by the application of effective performance criteria. Each of the performance indicators describe above has its place in the context of a PPP type contract but adjustments could be made to improve their effectiveness, both for the contractor and the government agency.

Ride quality

The IRI index is a very good performance criterion for representing the service level offered. In most cases, a single value is specified. Certain projects adjust the target value as a function of the base speed of the roads involved, and this approach deserves more attention. Likewise, highway entry and exit ramps should receive adapted treatment because of the transition between the highway and the ramp, with its lower base speed, particular geometric configuration and deceleration zones. The joints associated with structures ought also to be the subject of special clauses because they have a direct effect on measured ride quality.

Rutting

Because the presence of ruts can generate problems for user safety, rutting constitutes an important criterion. The limit value of 20 mm over a length of 100 metres seems appropriate. Bus and heavy vehicles at weigh stations and rest areas with stopping sectors ought however to be excluded or treated differently.

Surface distress

Often the criterion used in the case of surface distress is a quality index calculated by weighting the types of distress, their extent and their degree of severity. However, in the case of highway projects in particular, non-severe distress does not have a real impact on the service level offered. Accordingly, certain actions may be deemed necessary because of a quality index below the prescribed limit even if the roadway does not show significant distress. It would be appropriate to specify specific forms of distress of a severity deemed adequate to trigger action rather than prescribing an overall quality index.

Skid resistance

Skid resistance evaluation is still a subject with undergoing development. Measurements are often made on an occasional basis at locations deemed potentially dangerous or of segments of roads where a number of accidents have been reported. Skid resistance performance criteria are more easily applicable when measurements can be made as part of a network evaluation or when the scope is limited to some specific locations.

Structural capacity

The structural capacity of a roadway is an important characteristic when determining the type of intervention to carry out and it plays a decisive role in the changes that occur in surface conditions over the mid and long term. The use of structural capacity as a performance criterion is thus relevant as a condition for handback of the road at the end of the contract. Respect for this criterion assures the government agency of a minimum performance level for the road for a specified period after responsibility has been returned back to it and avoids the execution of purely cosmetic actions at the end of the contract.

Frost susceptibility

It is relevant for projects executed in northern environments to provide a performance criterion associated with deformation caused by frost. While the roadway design stage ought to take into account the possibility of frost heaves, the transfer of responsibility often includes road segments that already exist where a frost-related problem may be present. The use of the IRI index difference between summer and winter conditions offers an advantage over a fixed limit when considering changes in ride quality over time.

Budget considerations

The contract must estimate pavement construction, maintenance and rehabilitation costs for the term of the contract in a way that respects defined performance criteria. The value used as intervention limit for certain criteria has an undoubted influence on roadway design and maintenance planning. For example, a relatively strict value for skid resistance can diminish the opportunity of using a concrete pavement because of recurring activities required to maintain surface texture. On the other hand, a lower limit value for rutting can favour the choice of concrete paving to reduce the frequency of required interventions.

The specification of distribution curves for certain performance criteria makes planning more difficult in the long term and requires good road condition lifecycle models for each criterion specified. This problem is even greater when the project includes a large proportion of new construction whose lifecycle will accordingly be relatively uniform.

In many projects, there are specific criteria to be met at the end of the contract. Generally, the values for these criteria are stricter than those prescribed during the term of the contract. In addition, some specifications provide a maximum period, 5 years for example, between the last maintenance action and the end of the contract. This measure assures the government agency that no major intervention will be required for a given period after handback of the road. Planning of these elements must be considered in the contract in order be sure to have the resources required to respect the requirements.

Finally, when a performance index value does not meet the prescribed limit, the correction must be made within a period generally not exceeding the year during which the measurement was made. While this requirement is reasonable in the case of user safety criteria , a longer period, e.g. before the end of the following year, would allow the contractor to engage in more effective technical and budget planning of maintenance without significantly reducing the service level offered.

Case Study

When working on PPP project, the target for pavement design is not to find the best or the most durable pavement but is to find the lowest present value cost over the duration of the contract. This is done through Life Cycle Cost Analysis (LCCA) of different pavement design with their associated pavement maintenance costs which are directly influenced by the performance criteria.

Such an analysis cannot be undergone without a very good knowledge of pavement's performance evolution.

To better explain this approach, we will go through an example and this case study is related to the approach that we used for Highway 25 in Montreal Region. We will also see other examples of highway network performance behavior.

As shown in Table 1, the Highway 25 in Montreal Region has the following performance criteria

IRI (m/km)	< 2.2 m for 100 m section
Rutting (mm)	< 8 mm for 100 m section
Surface distress	< 75 m of crack for 100 m section
Skid resistance	CFT > 55 for 100 m section
Frost susceptibility	IRI (winter) < 3.0 for 100 m section

For the purpose of this case study, we will look only at the IRI and rutting performance indicators. This PPP project has a specification that stipulates that each non performing 100 m section will get 4 "non performing" points for IRI and 8 "non performing" points for rutting.

Fifteen non performance points are tolerated over which a deduction (penalty) is applied has shown in table 2.

Table 2
"Non performing" points vs deduction

NON-PERFORMANCE POINTS PER DAY	DEDUCTION ($ / POINTS / DAY)
0-15	0
16-25	250
26-50	375
51-75	500
> 76	750

This means that 2 non performing sections regarding rutting or 4 sections for IRI (or a combination of 1 for rutting and 2 for IRI) will bring a deduction in payment of $4 000/d. This can represent a huge financial impact on the project.

Since they will be around 210 sections in this project, these 2 to 4 non performing sections correspond to about 1 % of total project. This means that when about 1 % of the pavements will be non performing, the contractor will have to intervene on these sections. But, since maintenance work carried out to correct rutting or IRI on these non performing sections could diminish the performance of adjacent sections, especially for the IRI, a more global approach was retained to maintain the pavement. Resurfacing work would be applied on 1 to 2 km section to correct non performing sections.

To evaluate the life cycle of this type of intervention, we must look at the evolution of key performance indicators and also at the scatter (or standard deviation) of these parameters (IRI and rutting). If we do not want any penalties (deduction), we are aiming at less than 1 % of non performing section before our first resurfacing.

If the indicators values has a normal distribution, this would mean that the maximum average value should be less than the performance criteria subtracted by 2.38 x standard deviation, to respect 1 % non performing proportion. In other words, if the standard deviation of rutting on a given network is 0.9 mm, the maximum average rut value of the network should not reach more than 5.8 mm (8.0 mm – (2.38 (0.9 mm))) before 1 % of network is more than the performance criteria of 8 mm.

So, if we assume that the ruts of a network evolve at a rate of 1.00 mm/year, our first 2 (or more) non performing sections would appear after only 6 years.

To get a better understanding of the evolution of IRI and rutting and there standard deviation to establish a more accurate life cycle cost analysis (LCCA), a performance survey of different types of pavement (rigid and flexible) was carried out in the Montreal region with Qualitas multifunction vehicle. The results are shown in table 3.

From this survey, the following conclusion can be mentioned for asphalt pavement.

1) The sections #11 and 12 (A-25) are the most representative sections regarding rutting of asphalt mixes under a similar traffic. These results show that the 8 mm rutting limit will be reached on some 100 m sections (< 1 %) within a 12 years period.
2) The IRI value of sections 11 and 12 shows that the IRI performance limit of 2.2 will be reached within an 8 years period, for some 100 m sections.

TABLE 3

Surveys results														
	section	location	road	lane	length (m)	year	AADT (2002)	IRI			Rut (mm)			
								mean	std dev.	99%	mean	std dev.	99%	∆ rut/year
Asphalt pavement	11	Montréal	A25	right	1 100	7	50 000	1,29	0,40	2,2	3,7	0,7	5,3	0,53
	12	Montréal	A25	left	1 100	7	50 000	1,27	0,27	1,9	3,7	0,6	5,0	0,52
	13	Repentigny	A40	right	3 481	4	65 000	0,96	0,18	1,4	7,4	1,5	11,0	1,86
	14	Repentigny	A40	left	3 476	4	65 000	0,96	0,13	1,3	4,7	0,5	5,8	1,19
	15	New-Brunswick	-	right	200 000	4	5 500	1,07	0,18	1,5	4,2	0,8	6,1	1,06
	16	New-Brunswick	-	right	200 000	6	5 500	1,22	0,23	1,8	5,6	1,6	9,3	0,94

As it can be seen, we cannot use only mean values and evolution rates to establish a proper LCCA. We must look at the type of maintenance intervention that will be used, and a statistical approach with interval of confidence is needed.

Now, let's see how other networks behave is real life.

Figure 2 shows the evolution of IRI of highway network "A" between age 6 and 7. As it can be seen, the progression rate of IRI is about 0.1 m/km per year with significant scatter or deviation between one year periods (6 to 7 years).

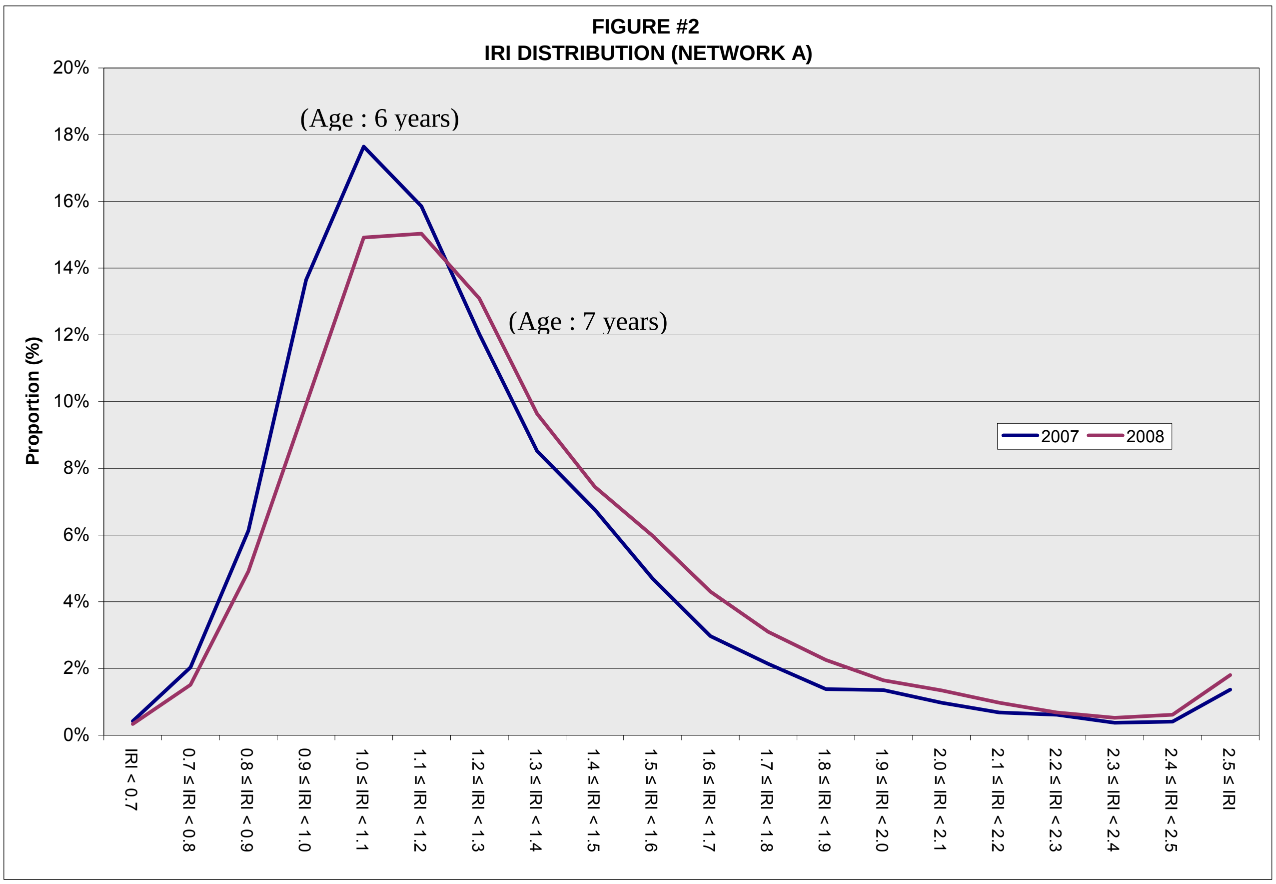
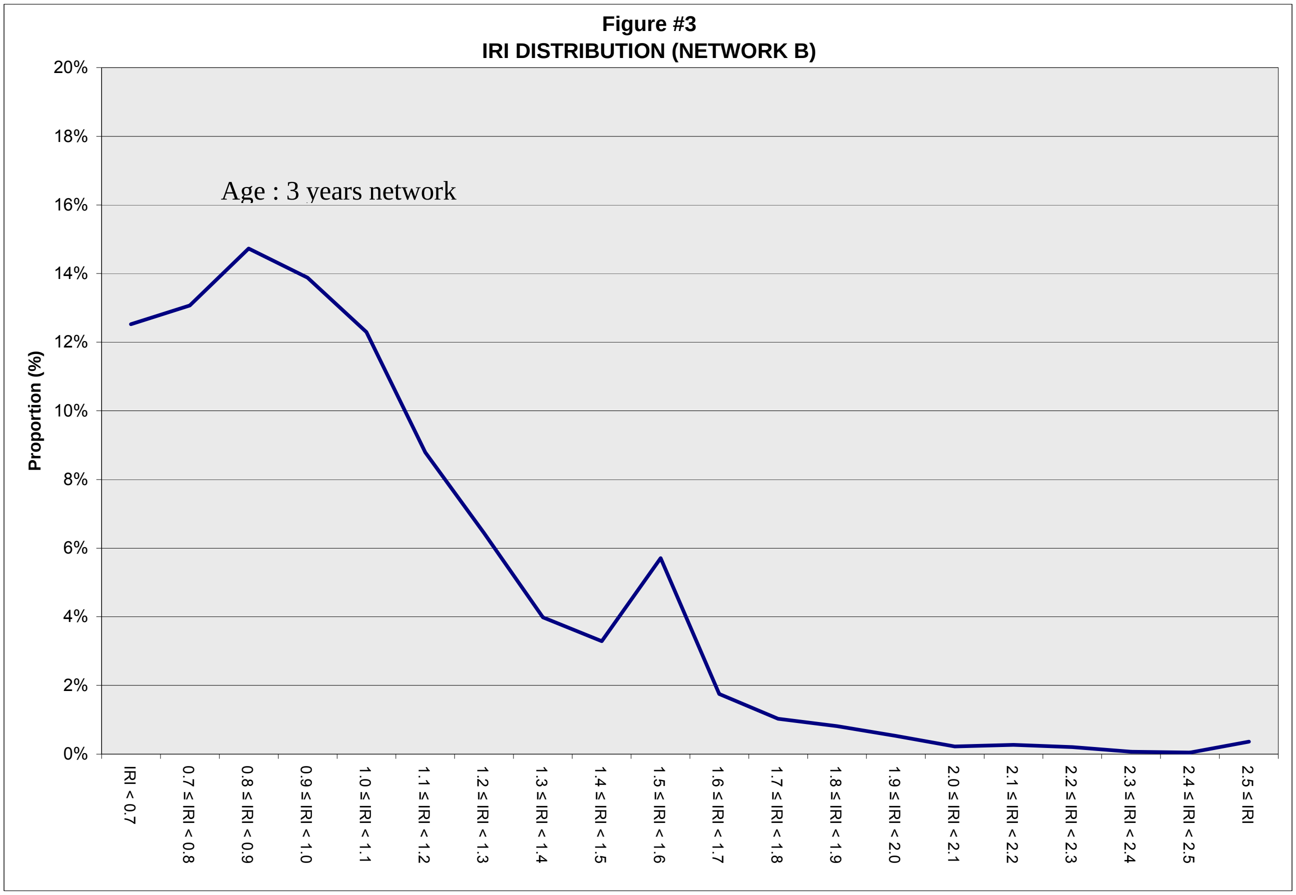
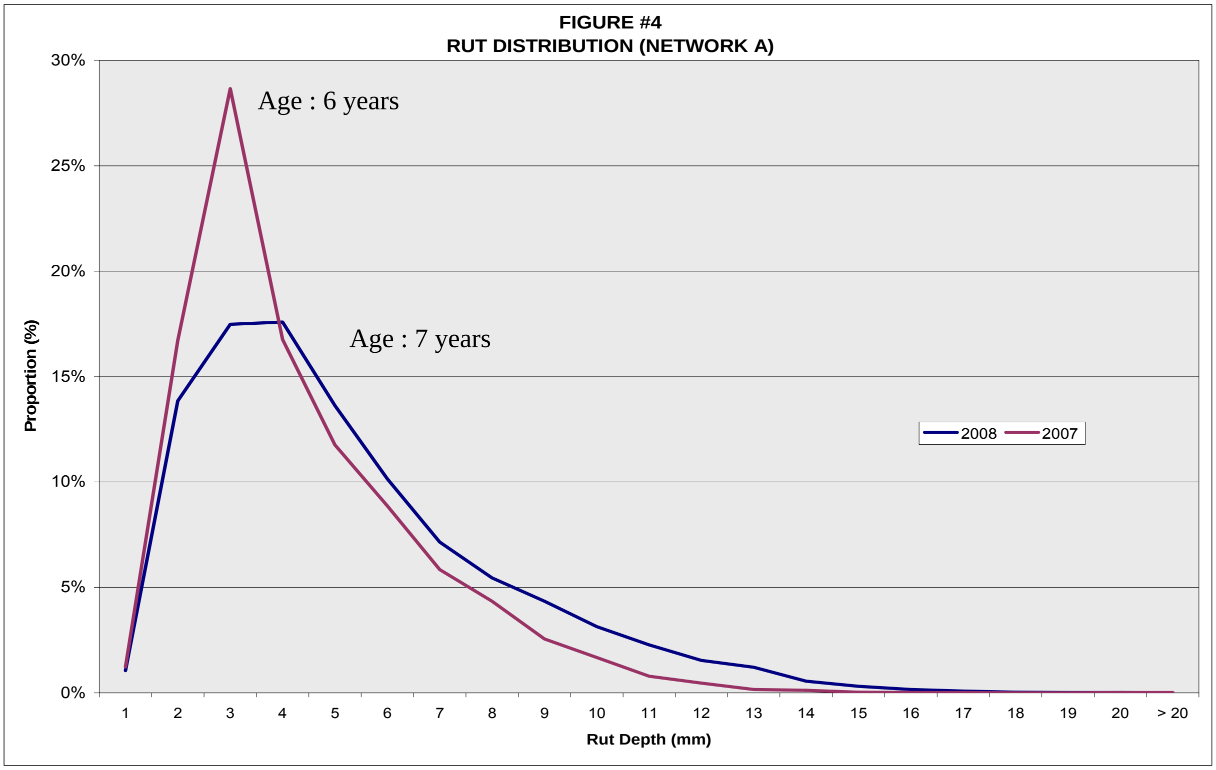
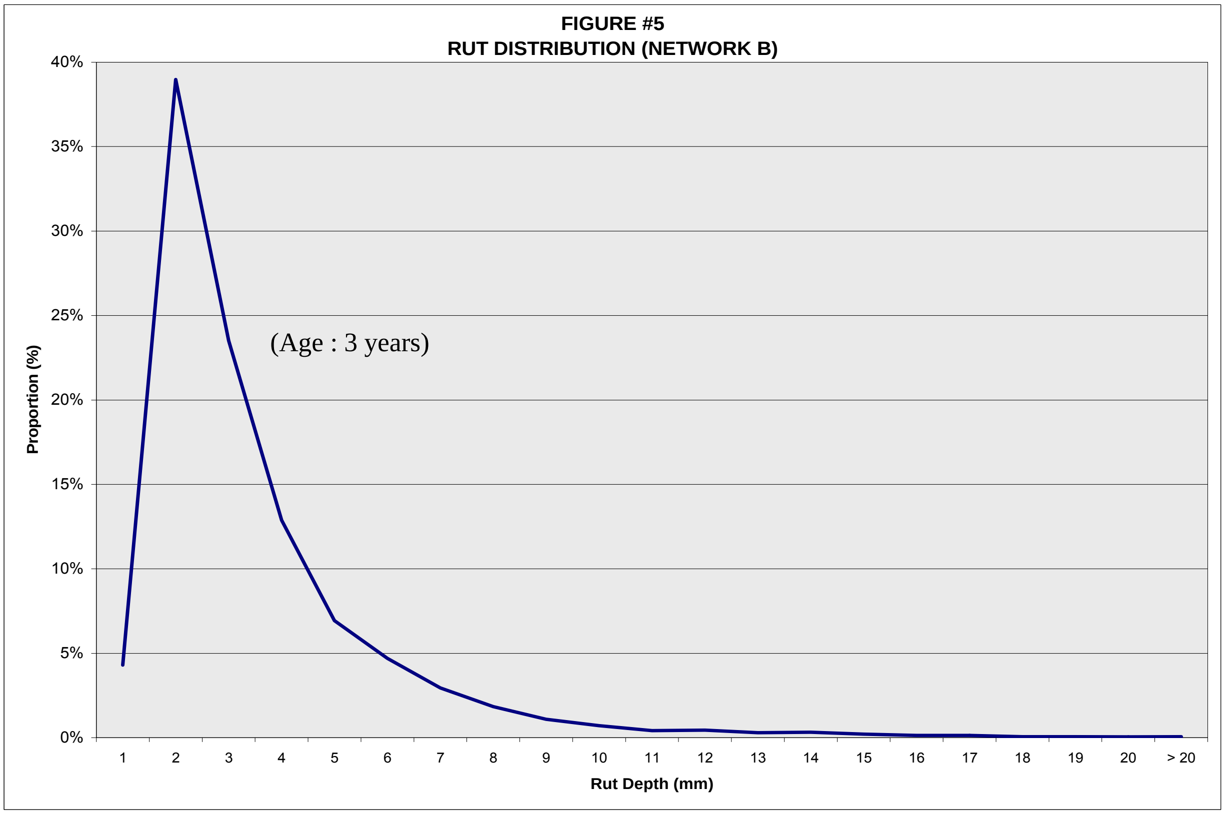


Figure 3 shows the IRI distribution of network “B” of age 3 where there is a proportion of (previously existing) older sections presents in the network causing the increase of number of sections with higher IRI around IRI values of about 1.5 to 1.6.



Figures 4 and 5 show the rutting distribution for these two networks (A and B).





As we can see, performance indicators of these networks are not distributed as a normal distribution. Caution must be exercised when a statistical approach is used. For example, if we use a normal distribution for rutting on network A, we would find following numbers.

AGE	RUT (mm)		
	AVERAGE	STANDARD DEVIATION	99 % INTERVAL OF CONFIDENCE
6	4.3	2.2	9.5
7	5.2	2.8	11.9

But, if we look at figure 4, we can see that the 99 % interval of confidence would be around 11 mm at age 6 and 14 mm at age 7, which is not the case, as shown on figure 4.

Conclusion

PPP project have pushed pavement engineers to look at pavement design in a new way. LCCA approach has proven to be the best way to look at pavement design for these projects.

This type of analysis cannot be carried out without a very good knowledge of pavements performance evolution, including the variation of these performance indicators. Good understanding of a statistical approach to these pavements will prove to be the way to go in most projects.

Also, each of the performance indicators described in this text has its place in the context of a PPP type contract but flexibility should be exercised in these contracts to permit contractors to provide an adequate service level in an effective way.

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