NON-NATIONAL ROADS – PAVEMENT CONDITION AND PAVEMENT MANAGEMENT STUDIES

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ABSTRACT

A major study of the Non-National road network in Ireland was carried out for the Department of the Environment, Heritage and Local Government in 2004. The objectives were to determine the existing pavement condition and remedial works required both nationally and at county level, and to recommend a pavement management system to be used to manage the non-national road network.

Over 8,000 kilometres of non-national road were surveyed and assessed as part of the study. Visual distress and ride quality parameters were used to report and to determine remedial works requirements. The results have provided a basis for allocation of funding on a needs basis, and will have significant implications for local authority roads funding in the future.

The review of pavement management practices in the local authorities indicated a low current level of usage. After extensive review, recommendations were made on a structured process for the development and implementation of Pavement Management Systems. It was recommended that these be integrated into an existing systems and that the MapRoad system developed by Local Government Computer Services Board (LGCSB) should be considerably enhanced to provide a suitable system.

DEHLG REQUIREMENTS

The Department of the Environment, Heritage and Local Government (DEHLG) commissioned RPS Consulting Engineers and PMS Pavement Management Services Ltd to carry out a pavement condition study on the Non-National roads. The main objectives of the 2004 Pavement Condition Study were:

- To establish, by county and nationally, the lengths and areas of various categories of non-national roads requiring remedial works, and
- To review existing pavement management systems and recommend a system suitable for use on the non-national road network.

Another stated requirement was that comprehensive information on the current status of regional and local roads should be obtained from the 2004 Pavement Condition Study. This information is required both to quantify the current status of road conditions within counties and nationally, and to provide a benchmark measurement against which the future actual road conditions can be compared, both within counties and at a national level.

In response to the DEHLG requirements for the road condition study, the consultancy team carried out the following steps:

1. Developed a statistical sampling approach to ensure the required accuracy.
2. Identified a survey methodology

- that was consistent, repeatable and accurate
- that was implementable within the timeframe specified

- that could deliver the expected outturn (quantification of remedial works types), determine actual road conditions and provide a basis for comparison with previous and future surveys if required.

- that relies on proven technology to produce the required outputs

- that provides a permanent record of the road condition at the time of survey in a suitable format and file size compatible with the Local Government Computer Services Board (LGCSB) MapRoad system.

3. Put in place a system of data collection and data processing to

- ensure that the survey was being carried out correctly

- allowed auditing of the survey results at a reasonable cost and in a short time period

- allowed simultaneous data collection at many locations throughout the country

- allowed easy, low-cost independent inspection by DEHLG if required

- maximised the subsequent utility of data collected to DEHLG and local authorities

4. Developed survey tools, manuals, forms, equipment to maximise the uniformity and consistency of approach, while retaining the survey procedures and recording of results at the simplest and quickest possible level. Put in place training courses, follow-up site visits and ongoing auditing of data collection and data processing to ensure maximum consistency and accuracy of data.

SAMPLING METHODOLOGY

An essential requirement of the brief is that the sampling method and size shall be sufficient to achieve an outturn accuracy in the lengths of road requiring remedial works of at least +/- 10% at the 95% confidence level for each county. In order to achieve these confidence levels, the following approach was adopted.

The Engineering Area was chosen as the base unit for sampling, with roads in all 4 road classes selected in every Engineering Area in the country. Road segments as defined in each local authority road schedule were selected randomly, and each 100 metre length within a road segment was treated as a separate sample unit. All sample units in a road segment were surveyed. Stratified random sampling methodology was used to determine required sampling sizes. The target sampling rates and lengths are shown in Table 1 below.

Road Class	Kilometres	Recomm. %	Survey Km
Regional (R)	11349	15	1702
LP (Local Primary)	23611	9	2125
LS (Local Secondary)	32021	6.25	2001
LT (Local Tertiary)	20169	9.75	1966
Total	**87150**		**7795**

Table 1 – Lengths to be surveyed

ROAD CONDITION DATA COLLECTION EQUIPMENT

The survey methodology proposed is a modified version of the PCI windshield survey method used in the 1996 DOE Pavement Condition survey. The 1996 methodology provided an accurate and repeatable measure of visual distresses on each surveyed road section.

Over 70 teams of local authority personnel, surveying roads simultaneously in each local authority, carried out the 1996 survey. Surveying and data entry typically took 4 to 6 weeks in each local authority and was carried out in July, August and September 1996. The consultants in 1996 audited c. 10% of the surveyed roads to ensure consistency across the many teams of surveyors.

In the 2004 survey, the consultants were the primary data collectors. Notwithstanding the difference in manpower resources available, it is desirable to measure the road condition parameters in all counties within a relatively short time period to give an accurate countrywide snapshot of road condition. Accordingly, a data collection methodology to maximise the speed of data collection in the field was developed.

The methodology relies on high-definition digital video to capture the road surface condition. The video is both chainage-referenced and geo-referenced for ease of post-processing. This ensures maximum compatibility with the LGCSB MapRoad package (where the underlying data storage is chainage-based) as well as full compatibility with any GIS. A very accurate DMI (Distance Measuring Instrument) is attached to the vehicle and connected to the hardware interface. A high-specification GPS device is also attached to the vehicle and connected to the hardware interface. The video camera outputs a high-resolution digital video (DV) stream to the hardware interface. Each video frame is stamped with road segment id, date, time, chainage and GPS co-ordinates, and the frames are compressed using state-of-the-art compression algorithms to retain maximum definition at minimum storage space. The video frames and associated information are then written to a high-speed hard disk. All of the data capture is in real time.

In addition, a further condition parameter, the ride quality of each pavement section, was recorded in the 2004 survey. Two bump integrators are attached to the vehicle, one in each wheelpath. The output from the bump integrators is calibrated to produce International Roughness Index (IRI) values for each 100 metre sample unit. The bump integrator outputs are also processed through the hardware interface in real time, and the IRI values can also be stamped on the video if required.

A total of almost 8000 kilometres of roadway was surveyed in the 2004 Pavement Condition Survey. The video/ride quality data collection can be carried out at normal driving speed, and is typically carried out at 10-50 km/h depending on road condition and road geometrics. Each video van is operated by a single operator, reducing the costs of field data collection significantly.

Copies of MapInfo with underlying base maps and a layer showing the road segments to be surveyed for the 2004 survey were loaded onto the data storage computer in each van, and a feed from the GPS device was also connected to the data storage computer. A flat screen monitor was connected to the computer so that the driver could check on his position in real-time. This real-time navigation speeds up the location of the start and end of the road segments significantly, and also ensures that the correct road segments are being surveyed.

The video data is stored in compressed .AVI files using an MJPEG format to maximise the quality of each video still and to allow subsequent playback of the video in a chainage-based (eg. MapRoad) or georeference-based (eg. within a GIS) system. Using this setup, c. 8000 kilometres of video can be stored in just over 100 gigabytes, making it entirely feasible to load all of the video into a server for display purposes. All of the video data can be handed over on a single external data drive. Average daily data collection rates of 50 to 60 kilometres were achieved, in spite of the survey being carried out from late January to early May when weather conditions were poorer and daily hours of light were significantly shorter than the summer months.

Once the data is collected in the field, all of the remaining post-processing can be carried out indoors, and is completely independent of weather conditions. Very considerable research, field trials and completed projects have been undertaken into the use of the video PCI (VPCI) as a suitable replacement for the windshield PCI used in 1996. Use of video for condition evaluation has some clear advantages over a manual windshield inspection:

- The rater can concentrate completely on distress identification – in the manual survey, the distress identifier is usually the driver as well
- Multiple raters can be used in the post-processing phase to expedite the duration of processing
- Inspection and identification is carried out in safe and comfortable surroundings
- Auditing of the distress identification process is very straightforward and much less costly than field auditing
- A permanent record of the road condition is saved and can be subsequently re-processed if required for other uses, eg. Presence/absence of road markings, road signs, number of junctions, edge drainage etc.
- DEHLG or local authority personnel can view the video at any subsequent time for any required purpose
- The video files can be subsequently attached to the road segments in MapRoad and can be viewed from within MapRoad in conjunction with the road condition data derived from the video and ride quality measurement devices.

PAVEMENT CONDITION INDEX (PCI)

A visual inspection of the pavement condition, identifying pavement distress types, quantities and severities is an invaluable aid in the evaluation of a pavement's performance. There has been extensive use of the Pavement Condition Index (PCI) system in Ireland over the past 16 years. A new pavement (theoretically distress-free) has a PCI of 100. For each distress measured, there are deduct values depending upon the nature of the distress, its severity and quantity. The deduct values are summed, adjusted to take into account the total number of distresses identified, and then subtracted from 100 to give the PCI index for the pavement.

The power of the PCI inspection system revolves around the provision of a defined index between 0 and 100 that all pavements must lie between. In addition, all of the detailed distress data is available on a section and sample unit basis so that the engineering manager is not reliant upon the PCI alone when deciding what maintenance action to pursue for a specific section. A rough breakdown of pavement classification by PCI is

PCI Range	Pavement Condition
85 to 100	Very Good
65 to 85	Good
50 to 65	Fair
40 to 50	Poor
20 to 40	Very Poor
< 20	Failed

This section PCI can then be used to compare sections with one another, to monitor pavement performance over time for that section, and to show a picture of the entire network condition by examining the number of sections in each PCI range. In addition, relationships between PCI and cost can be established, making budget estimation and prediction more accurate and easier to perform.

Further modifications to the windshield PCI methodology were developed through research to allow estimation of distress types and quantities from high definition video. Ten distresses were retained for the 2004 survey, as they are by far the most common distresses encountered on Irish non-national roads. The distresses can be grouped into four categories as follows:

Surface Defects:

Bleeding

Ravelling

Patching

Openings in Surface

Potholes

Road Disintegration

Cracking:

Alligator Cracking

Edge Breakup

Cracking - Other

Pavement Deformation:

Rutting

Depressions

For each distress type as shown above, there are one, two or three severity levels defined, depending upon the particular distress type. Bleeding, for example, has only one severity level defined, while Potholes and Patching have three severity levels. A detailed pavement inspection manual has been produced specifically for Irish road conditions, with descriptions of each distress type, how to distinguish between severity levels, and full colour photographs for every distress type/severity combination.

The pavement distress definitions have been improved and modified to ensure maximum consistency across teams of raters. Deduct curves from the Corps of Engineer manual PCI system have been adopted, with some minor changes based on Irish conditions, as these curves have been developed, refined and validated based on engineering experiences worldwide over the last 25 years. In particular, there has been a high level of satisfaction in the Irish local authorities that have implemented the PCI system with the relative rankings of roads based on the PCI deduct curves.

As the estimation of quantity of the distress defects is based totally on visual assessment from the video, it was found that it was most consistent and reproducible to give the pavement inspector ranges of magnitude (<1, 1-5, 5-10 etc), of the estimated percent area of the distress to choose from. The value of the ranges vary by distress. Use of the ranges has worked out well in practice, with good levels of repeatability in surveying sections with different teams of inspectors.

INTERNATIONAL ROUGHNESS INDEX (IRI)

Road roughness has been defined as the variation in surface elevation that induces vibration in moving vehicles. In particular, the International Roughness Index (IRI) is a scale for roughness based on the response of a standardised motor vehicle to the road surface. The IRI simulates response to the surface profile, and also considers the effect of vehicle suspension. Roughness or ride quality is important as numerous studies have shown that there are strong correlations between motorists's subjective ratings of ride quality and the ratings derived from measurement of IRI. In fact, the road user's view of satisfactory or unsatisfactory road condition is primarily influenced by roughness or ride quality.

There are a number of different ways to measure ride quality, but the IRI has become the standard international scale. The IRI was developed in the late 1970's and early 1980's based on initial research in the United States and subsequent research sponsored by the World Bank. The IRI can be measured by an extensive range of equipment from rod and level through response-type meters to very accurate laser-based profilometers.

The IRI is expressed in units of metres per kilometre, with low values indicating smooth roads, and high values indicating rough roads with poor ride quality. There is also significant correlation between IRI and the maximum speed at which a road user is comfortable. Table 2 shows a rough description of IRI scale translated into likely road defects and maximum speed with comfortable ride. The table is based on ASTM standard E1926-98, Standard Practice for Computing International Roughness Index of Roads from Longitudinal Profile Measurements.

IRI Value	Comfortable Ride Speed	Description
2	over 120 km/h	Very Smooth
4	100 to 120 km/h	Smooth
6	70 to 90 km/h	Perceptible movement
8	50 to 60 km/h	Some Swaying and Wheel Bounce
10	40 to 50 km/h	Significant Swaying
12	30 to 40 km/h	Consistently Rough
14	< 30 km/h	Very Rough

Table 2: IRI Scale

In the 2004 Pavement Condition Survey, each video van was fitted with 2 roughness response meters to measure the ride quality in the left and right wheelpaths. The results are stored for each wheelpath, and post-processed using specialised software to determine the average IRI value for each wheelpath over every 100 metres travelled. The average value of IRI from both wheel tracks is reported, as this is considered a better measure of road surface roughness than the IRI for either individual wheel track.

Response meters are significantly less expensive than laser profilometers in measuring IRI, and are also substantially more robust on rougher roads which was a key factor in their choice for the 2004 survey. However, it is possible for the response meters to go out of calibration over time if there are changes to the vehicle suspension, tyre pressures etc. Frequent calibration and checking is required when response meters are used for IRI measurement.

Calibration sites were established in Galway and Cork using very accurate laser profilometer measurements, and the IRI values for the calibration sites were established from the profilometer measurements. The roughness meters in each van were then calibrated so that the IRI outputs from the roughness meters matched the IRI values determined from the profilometer measurements. IRI measurements were carried out on the calibration sites whenever a test van left to do data collection or returned from data collection. In this way, consistency in IRI measurement was controlled across all of the county road samples. Initially, there were some problems with shearing of connecting pins in the roughness meters. This was addressed prior to the main data collection phase, and the response meters proved to be very robust and repeatable over the course of the data collection phase.

ROAD SCHEDULE SAMPLING

A full road schedule, listing all of the road sections in each local authority using a standardised road numbering system, was supplied by each local authority. Table 3 shows the total lengths of road, in kilometres, in each local authority. The lengths are shown by road classification.

County	R	LP	LS	LT	Total
Carlow	158	328	337	284	1107
Cavan	399	710	1352	396	2857
Clare	598	1094	1407	807	3906
Cork-North	374	913	1390	707	3384
Cork-South	531	1354	1979	735	4599
Cork-West	401	900	1490	799	3590
Donegal	688	1978	2071	1259	5996
Dun L/Rathdown	103	96	87	310	596
Fingal	197	273	211	273	954
Galway	762	1390	2474	1429	6055
Kerry	449	1183	1035	1554	4221
Kildare	388	332	1043	324	2087
Kilkenny	313	790	1350	397	2850
Laois	281	620	600	445	1946
Leitrim	334	680	579	515	2108
Limerick	463	1005	1413	512	3393
Longford	151	416	508	347	1422
Louth	196	293	468	190	1147
Mayo	579	1220	1673	2295	5767
Meath	476	549	765	1115	2905
Monaghan	290	526	575	975	2366
North Tipp	338	906	750	460	2454
Offaly	339	493	556	450	1838
Roscommon	343	1106	1570	982	4001
Sligo	214	601	963	771	2549
South Dublin	99	106	456	46	707
South Tipp	426	921	891	462	2700
Waterford	353	889	1012	228	2482
Westmeath	229	509	893	366	1997
Wexford	439	968	1218	572	3197
Wicklow	424	466	904	170	1964
Total	**11335**	**23615**	**32020**	**20175**	**87145**

Table 3 Total Length (kilometres) by Road Class and Local Authority

A random sample of road sections was selected from each road schedule, using the Engineering Area as the base unit. Road sections were chosen randomly from the road schedule for each engineering area. The sampling rate was chosen to give the desired confidence level of 95 percent in the out-turn lengths, as specified in the consultancy brief.

The list of selected road sections in each engineering area of the local authority was sent to the local authority. The local authority then produced maps showing the locations of all chosen road sections, with copies being provided to the consultants. Generally, the local authorities were able to provide electronic maps linked to the LGCSB MapRoad package. Local Government Computer Services

Board developed software and provided training to the consultant's staff to enable the selected sample of road sections to be displayed through MapRoad/MapInfo.

When all of the files for each local authority were ready, they were loaded into a Microsoft Access database. Effectively, there are three key tables. The first table contains the distress data for every sample unit derived from the video condition survey. The second table contains the processed PCI results for each sample unit. The third table contains the IRI results for every sample unit. There are a total of 76,538 sample units with PCI, IRI and distress data in the final database. The process of uploading the data was extremely straightforward, and customised queries of the data tables were then defined within Microsoft Access to form the basis for the analysis, tables and figures set out in the remainder of this report.

DESCRIPTION OF REMEDIAL WORKS CATEGORIES

The remedial works categories specified in the consultancy brief were Surface Restoration, Road Reconstruction and Restoration of Skid Resistance. Surface Restoration was defined to include improvement of drainage, pothole patching, restoration of road width and strengthening of road edges as well as localised surface dressing of the repaired areas. Road Reconstruction was defined to include reconstruction of existing road pavements, overlaying of existing road pavements with bound or unbound materials surface dressed, and raising of road levels to prevent flooding with provision of drainage. Restoration of Skid Resistance covers the application of a surface treatment to restore adequated skid resistance. A fourth category, Routine Maintenance, was defined by the consultants to include road section lengths not requiring any of the three remedial work types defined above. Road sections in this category would be in very good existing condition.

ALLOCATION OF SAMPLE UNITS INTO MAINTENANCE CATEGORIES

As previously described, the PCI rating, a structural index and a surface index were computed and stored in the database for every sample unit (100 metre stretch) surveyed. The Structural Index reflects the percentage contribution of structural distresses (potholes, rutting, alligator cracking, edge cracking, road disintegration) to the overall PCI deduct value calculated in each sample unit. The Surface Index reflects the percentage contribution of surface-related distresses (bleeding, ravelling) to the overall PCI deduct value of each sample unit.

The initial assignment of each surveyed sample unit to one of the remedial work types, or to the routine maintenance category, is based on a combination of Video Pavement Condition Index (VPCI) brackets, and particular values of Structural Index and Surface Index as outlined below.

If the VPCI value of the sample unit is greater than 85, the sample unit is deemed to be in very good condition, and is assigned to the Routine Maintenance category.

If the VPCI value of the sample unit ranges from 51 to 85, there are two brackets into which the sample unit may fall. If the structural index is > 50%, (structural distresses are causing more than 50% of the total VPCI deduct value), then the sample unit is assigned to the Surface Restoration work type. If the structural index is less than or equal to 50%, the sample unit is assigned to the Restoration of Skid Resistance work type on the basis that the VPCI is being influenced primarily by surface distresses which can be addressed by this work type.

If the VPCI value of the sample unit ranges from 41 to 50, there are three brackets into which the sample unit may fall. If the structural index is > 75%, the sample unit is assigned to the Road Reconstruction category as there is clearly significant structural damage causing the VPCI to be in this bracket. If the structural index is less than or equal to 75%, and the surface index is > 40%, the sample unit is assigned to the Restoration of Skid Resistance work type on the basis that the surface distresses are significantly influencing the VPCI and may be addressed by this work type. Otherwise, the sample unit is assigned to the Surface Restoration work type which covers a range of treatment types between Restoration of Skid Resistance and Road Reconstruction.

Finally, if the VPCI value of the sample unit is less than or equal to 40, the sample unit is assigned to the Reconstruction work type.

In this way, every sample unit can be uniquely assigned to one of the available work type categories. The remedial work category allocation strongly reflects the methodology used in 1996, with modifications to the categories based on the VPCI outputs rather than the manual windshield PCI outputs.

In the 2004 study, the ride quality data is also used to modify the results derived from the visual survey. In particular, road segments with poor or very poor ride quality characteristics are moved into the Road Reconstruction category, notwithstanding relatively low levels of visual distress. This reflects the reality that a road may be in need of reconstruction or overlay due to pavement deformation, particularly for example on peat foundations, while the pavement surface has been relatively well maintained through Surface Restoration or Restoration of Skid Resistance activities. Only the Road Reconstruction activities can restore the ride quality of the pavement section to an acceptable level.

The intervention levels based on IRI are customised for each road class, with a lower intervention level for regional roads than for local tertiary roads. This reflects the higher traffic volumes, speeds and level of comfort expected by the road user on higher road classes. Values used in this report are:

Road Class	Road Reconstruction indicated if IRI value is greater than
Regional Roads	8
Local Primary Roads	11
Local Secondary Roads	14
Local Tertiary Roads	17

Table 4: IRI Intervention Levels for Road Reconstruction

GENERAL STATISTICS

Over 8,000 kilometres of roadway were actually surveyed, but not all of the data was useable due to impassable road conditions, sample units where PCI could not be carried out due to lighting conditions (into direct sunlight after a rain shower), mismatches between road schedule names etc. A total of 76,538 valid sample units, each 100 metres in length, were available for analysis.

Class	Length (km)	Width (m)
R	1724	6.1
LP	2007	4.6
LS	2324	3.8
LT	1598	3.3

Table 5: 2004 National Summary; Lengths and Widths

Table 5 shows the national average road width by road class based on data supplied by Local Authorities. It can be seen that there is a clear downward progression in average road width as the road class decreases, from 6.1 metres on regional (R) roads to 3.3 metres on Local Tertiary (LT) roads.

Class	PCI	IRI
R	68	5.3
LP	60	7.7
LS	55	9.3
LT	50	11.8

Table 6 2004 National Summary; Condition Parameters

Table 6 shows the average PCI and IRI by road class. It is clear from Table 6 that there is a consistent downward progression through the road classes in average PCI, from 68 on R roads down to 50 on LT roads. The IRI ride quality average values show a similar trend. The smoothest roads (lowest IRI) are on the R roads with an average value of 5.3 m/km, while the LT roads show the highest average valu PCI and IRI b

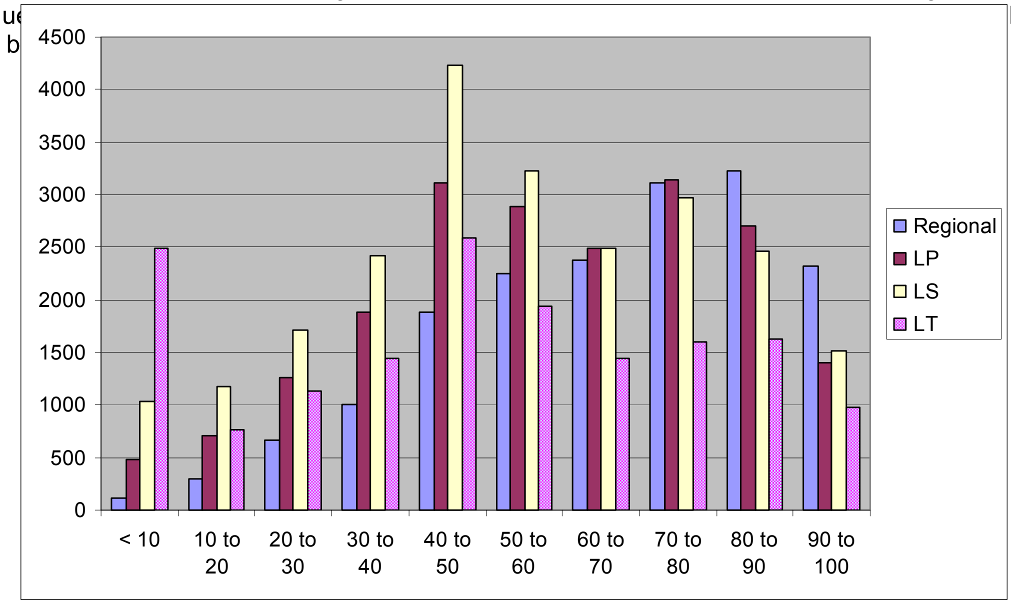


Figure 1: PCI Frequency Distribution by Road Class

Figure 1 shows the distribution of sample units in each bracket of 10 PCI points for the four road classes. The Regional road distribution is the smoothest, with relatively low numbers in the lower PCI brackets, and the number in each bracket increasing up to a maximum in the 80 to 90 bracket. The LP distribution follows a similar pattern up to a maximum in the 40 to 50 bracket, then begins to decline in higher brackets. However, there is a second rise in numbers at the upper end with another peak in the 70 to 80 bracket. This “double-peak” distribution reflects the impact of expenditure on improving road conditions in recent times.

The LS distribution follows a similar pattern to the LP distribution, but the maximum peak in the 40 to 50 bracket is significantly greater than the second peak in the 70 to 80 bracket. Finally, the LT distribution is most noticeable for the high number of sample units in the PCI less than 10 bracket. Otherwise, the LT distribution increases smoothly to a peak in the 40 to 50 bracket, and then decreases smoothly in the higher brackets. The second peak in the 70 to 80 bracket is much smaller in relative terms compared to the other three road categories.

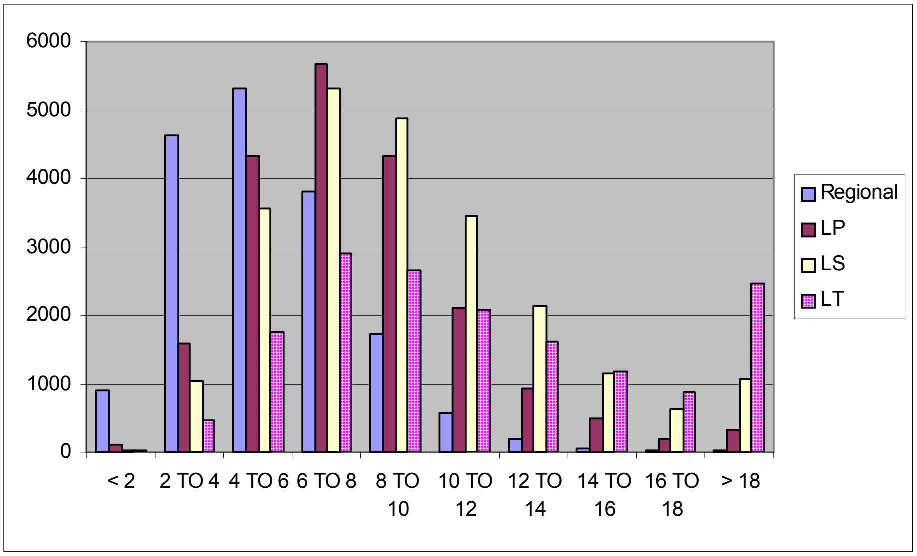


Figure 2: IRI Frequency Distribution by Road Class

Figure 2 shows the distribution of sample units in each bracket of 2 IRI points. In contrast to the PCI distributions, there are no double peaks for any of the 4 road classes. The Regional road distribution is the most desirable, with a relatively narrow distribution (very few sample units with an IRI of greater than 10) and a peak in the 4 to 6 IRI bracket. The LP distribution is similar but the peak is shifted to the 6 to 8 IRI bracket, and the distribution is noticeably wider. The LS distribution also peaks in the 6 to 8 bracket, but has a much longer tail in the higher IRI brackets. Finally, the LT distribution is clearly the widest distribution with the peak in the 6 to 8 bracket quite similar to the numbers in the 8 to 10 and 10 to 12 brackets. There are also many sample units in the IRI > 18 bracket for LT roads, mirroring the pattern seen in the PCI distribution where there was a large number of LT sample units with a PCI of less than 10.

DISTRESS DATA SUMMARY

Table 7 shows that Ravelling occurs much more frequently than any other distress. Rutting is the second most frequently occurring distress. This is significant as rutting is a structural distress, carrying a relatively high deduct value, and having implications for the maintenance requirements of the section. Patching and Bleeding have a similar rate of occurrence, significantly higher than Edge Breakup. Potholes, Alligator Cracking and Depressions have a relatively low rate of occurrence, with Road Disintegration and Other Cracking having a very low rate of occurrence.

Distress Code	Distress Type	Number of Occurrences
2	Ravelling	66199
5	Rutting	36171
4	Patching	26832
1	Bleeding	23430
10	Edge Breakup	16705
3	Potholes	10338
8	Alligator Cracking	8827
6	Depression	8447
7	Road Disintegration	3692
9	Other Cracking	2800

Table 7: Distresses Sorted by Occurrence

In terms of quantity of distress, Ravelling, also has the highest average quantity when it occurs of almost 25% of the surface area of the sample unit. Road Disintegration occurs very infrequently, but when encountered it takes up a relatively large percentage of the sample unit area. Bleeding, another surface distress, covers 13% of the surface area, when it occurs. Rutting, a relatively frequently occurring distress, also covers a significant percentage of the pavement area when it occurs as does Patching.

In relation to average deduct value, the structural distresses dominate. Road Disintegration clearly showed the highest average deduct value. Rutting, Alligator Cracking, Potholes (High Severity), Patching (High Severity) and Edge Breakup all have relatively similar high average deduct values. Ravelling, although occurring very frequently and over relatively large areas when it occurs, has a relatively low average deduct value. This is because Ravelling and Bleeding are surface defects that do not have significant structural maintenance implications.

COMPARISONS OF 1996 AND 2004 SURVEY RESULTS

There has been a substantial increase in the occurrence of Ravelling in 2004 compared to 1996. The percentage occurrence of Bleeding is lower in 2004. These differences may reflect the difference in the time of year when the survey was carried out. The 1996 survey was carried out in late Summer/early Autumn when the surface dressing programme would be complete and ground temperatures are relatively high. The 2004 survey was carried out in spring, when ground temperatures are much lower and the incidence of Ravelling is typically higher after the winter season.

There has also been a substantial increase in the occurrence of Rutting between 1996 and 2004. This reflects the much larger traffic volumes, and in particular the much heavier and wider commercial vehicles using the road network over the past 8 years. The economic boom has yielded a very significant increase in the development of towns, villages and one-off housing developments, and heavy commercial vehicles are used to supply materials to these developments. Larger and heavier agricultural vehicles have evolved, and there has been a very significant increase overall in commercial traffic volumes in line with economic growth. The historic pavement structures in place would have been relatively thin layers of granular material, with one or more surface dressings. These structures were barely adequate for light traffic and light commercial vehicles/cars, but are inadequate for the much heavier loadings being imposed by traffic in 2004.

Without the strengthening programme which was put in place since the mid 1990's, the rate of occurrence of all structural distresses in 2004 would have been much higher than in 1996. In fact, the rate of occurrence of Potholes and Road Disintegration has effectively halved over the period from 1996 to 2004, while the rate of occurrence of Patching is also substantially reduced. This reflects the significant investment in the road network with priority obviously being applied to road sections with surface breaks.

The average deduct values for Potholes and Road Disintegration have dropped significantly, and in conjunction with the substantial drop in the rate of occurrence of these distresses, the maintenance investment programme is clearly succeeding in dealing with these surface break distresses notwithstanding the much heavier traffic using the network.

Distress Code	Distress Type	1996	2004
1	Bleeding	11.1	11.9
2	Ravelling	14.8	15.1
3	Potholes	23.2	17.8
4	Patching	20.0	34.0
5	Rutting	39.7	41.0
6	Depression	8.8	20.5
7	Road Disint.	94.0	76.7
8	Allig. Cr.	32.2	31.2
9	Other Cr.	7.6	11.6
10	Edge Cr.	13.1	28.1

Table 8: Average Deduct Value, 1996 and 2004

Overall, the distress comparisons show that the Non-National network is very significantly better in 2004 in reducing the incidences of surface breaks (Potholes and Road Disintegration) that produce high levels of road user dissatisfaction. This reduction has occurred in the context of much heavier and more frequent loadings on all road classes of the Non-National network. However, this greater loading has increased the amount of rutting on the network substantially, and this has significant implications for the structural maintenance budgets required going forward.

CHANGES IN NETWORK LOADING CONDITIONS, 1996 TO 2004

Table 9 shows some relevant Irish network statistics based on 2001 data. There were almost 1.4 million cars registered in Ireland in 2001, almost 190,000 light goods vehicles (LGV) and just over 32,500 heavy goods vehicles (HGV). Cars and LGV travel, on average, between 19,000 and 20,000 kilometres per annum. However, HGV travel, on average, almost 74,000 kilometres per annum, thus having a major impact on the road network well out of proportion to the impact implied by the number of vehicles alone. A 2001 National Road Authority study on vehicle-kilometres of travel in Ireland indicated that the Non-National road network carries 59% of all car travel, 56% of all LGV travel, and 43% of all HGV travel, clearly showing the importance of the Non-National road network in the Irish context.

Category	Number	km per vehicle	National %	Non-National %
Car	1,384,700	19864	41	59
LGV	186978	19275	44	56
HGV	32536	73980	57	43

Table 9: National Traffic Patterns, 2001

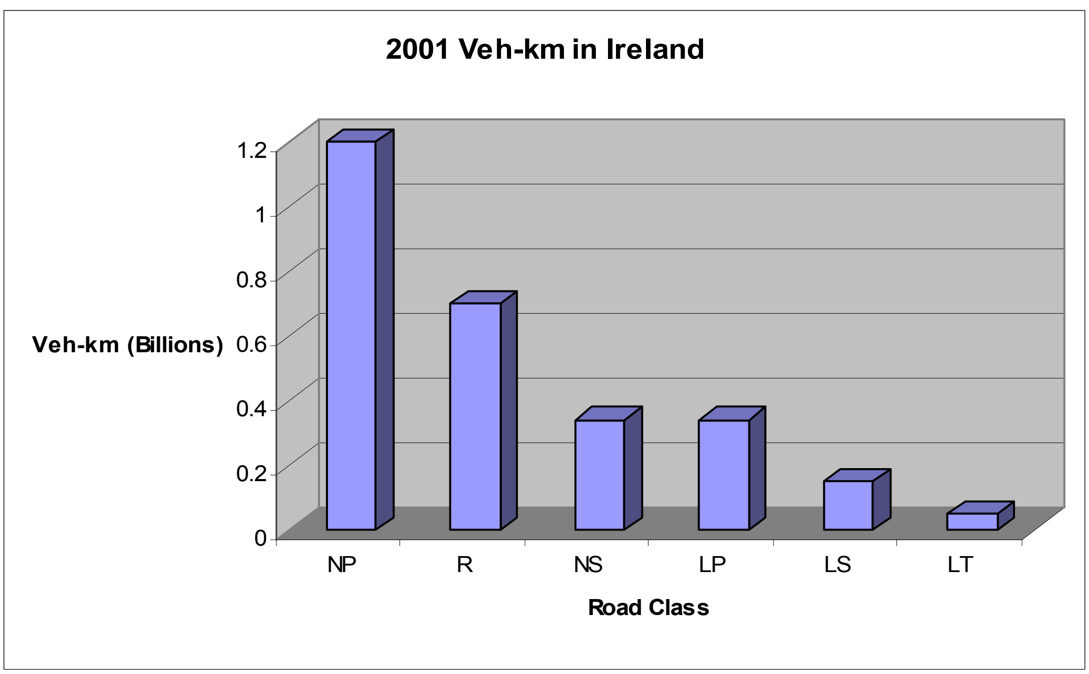


Figure 3: Total Vehicle-kilometres of travel by Road Class, 2001

Figure 3 shows the breakdown in Vehicle-kilometres of travel by road class. The National Primary road network carries the largest share of travel. The Regional road network carries the second highest proportion, over twice as much as the National Secondary and LP networks which are very similar.

The relative importance of the three local road classes is clear in Figure 3, with the LP network carrying roughly twice as much as the LS network, and the LS network in turn carrying roughly three times as much as the LT network.

Table 10 shows the growth in HGV numbers between 1976 and 2005. It can be seen that there has been a very large growth in HGV numbers since 1995. The HGV numbers grew on average by 6% per annum since 1995. Taking LGV and HGV together, there was an annual growth of 7.6% over this period, exactly the same as the average GDP growth rate of 7.6% per annum from 1996 to 2003.

Year	Number of HGV
1976	15,000
1985	19,000
1989	19,500
1995	23,000
2001	32,536
2005	39,159

Table 10: Growth in Heavy Good Vehicle Numbers 1976 to 2005

Figure 4 shows the changes in the distribution of HGV unladen weights between 1995 and 2005. It is very clear that there has been a noticeable shift in the distribution towards heavier vehicles. The number of vehicles in the lower weight categories have grown between 1995 and 2005, but the numbers are still quite close. However, from the 10,000 kg category and above, the 2001 numbers are very significantly higher than the 1995 numbers, and the 2005 numbers are very much higher again. In conjunction with Table 10, it can be seen that there has been a large annual increase in the number of HGV, and this increase has been predominantly in the provision of much larger and more damaging HGV. The combination of growth in numbers and damaging power has dramatically increased the structural loading on the network between 1995 and 2001.

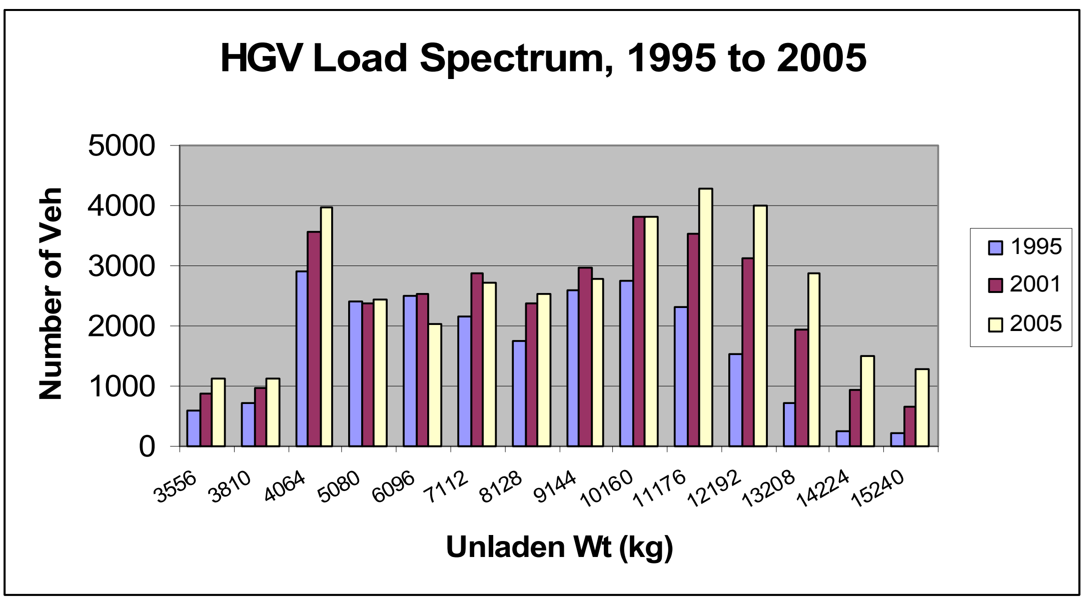


Figure 4: Distribution of HGV Unladen Weights – 1995 to 2005

Figures 5 and 6 further emphasise the impact of the changes in vehicle numbers and load capacity on the road network. Figure 5 shows the growth in tonnage of goods carried on Irish roads, based on

Central Statistics Office (CSO) data. The total tonnage carried has grown from 85 million tonnes in 1995 to almost 304 million tonnes in 2005. Almost 160 million tonnes, over 50% of the total tonnage carried in 2005, is derived from delivery of goods to roadworks or building sites. or almost 2.5 times the 1995 level. Vehicles with unladen weights of between 10T and 12.5T form 16% of the truck fleet, but carry 41% of the total tonnage. Vehicles over 12.5T in unladen weight make up 11% of the truck fleet, but carry 37% of the total tonnage. Thus, the largest trucks, though relatively few in number, are carrying almost 80% of the total tonnage on Irish roads. This has very serious implications for the health of the road network system going forward.

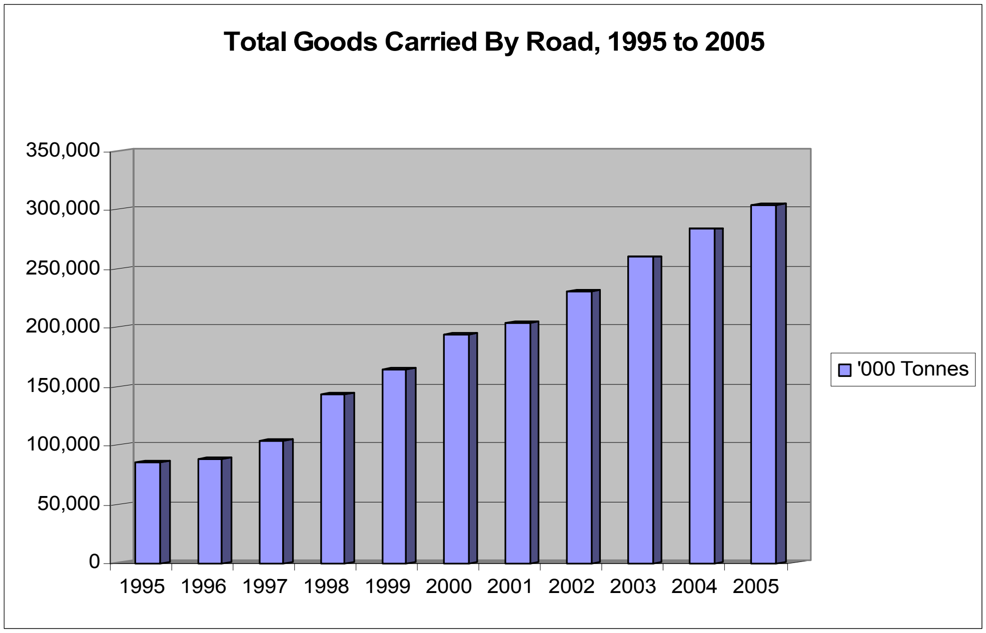


Figure 5: Total Goods Carried by Road, 1995 to 2005

Figure 6 shows the growth in the number of house completions per annum between 1995 and 2005. This can be used as a surrogate measure of the impact of the economic growth on the road network, given the requirement to transport materials to service the completion of the houses. Over the 10 year period, the annual number of house completions grew from just over 30,500 to just over 80,000. This translates into an annual average growth rate of 10.5%, again well in excess of the GDP growth rate. Overall, it can be concluded that the economic boom in Ireland since the last condition survey in 1996 has fundamentally changed the loading regime on the Non-National road network, with much higher and more frequent loadings by much heavier vehicles being the norm in 2004. This pattern has continued up to the present.

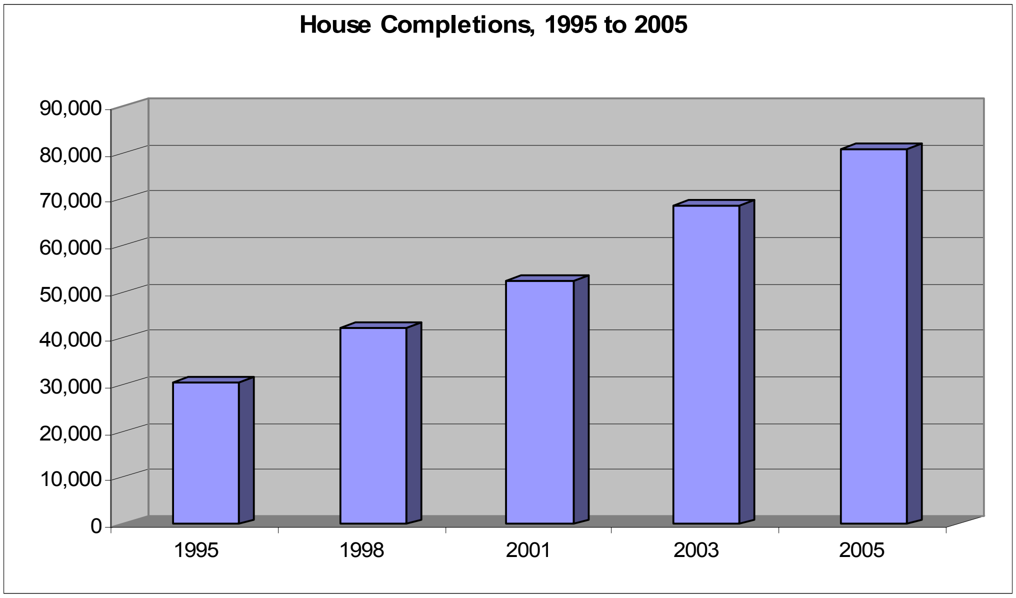


Figure 6: Number of House Completions, 1995 to 2005

GENERAL STATISTICS BY COUNTY

Table 11 shows the average road width by road class in each local authority. Cork is treated as being made up of 3 divisions, reflecting the internal road management structure in Cork. This is also consistent with the reporting of results from the 1996 survey. It can be seen that average road width by road class varies substantially across the local authorities, with the 3 Dublin road authorities of Dun Laoghaire-Rathdown (DR), Fingal (F) and South Dublin (SD) having higher average widths than other counties.

Table 12 shows the average PCI and IRI based on length and weighted by area for Regional roads in each county. Table 13 shows similar average values for Local Primary (LP) roads. Similar tables for Local Secondary and Local Tertiary roads are contained in the Condition Study report.

It can be seen from the tables that there are significant variations in average road condition as measured by PCI and IRI across the local authorities.

County	R	LP	LS	LT
Carlow	6.6	4.6	4.2	3.2
Cavan	6.3	4.5	3.6	3.2
Clare	5.8	4.1	3.3	3.1
Cork-North	6.3	5.2	4.0	3.8
Cork-South	6.6	5.0	3.7	3.2
Cork-West	6.5	4.4	3.2	2.9
Donegal	5.8	4.2	3.7	3.5
Dun L/Rathdown	8.7	7.5	7.7	5.8
Fingal	7.1	5.9	4.0	4.8
Galway	5.6	4.2	3.2	3.0
Kerry	5.1	4.3	3.9	3.6
Kildare	6.3	4.7	4.0	3.8
Kilkenny	6.2	4.8	4.0	3.3
Laois	6.8	4.9	4.5	3.8
Leitrim	6.1	3.8	2.9	2.8
Limerick	5.6	4.4	3.9	3.1
Longford	6.7	4.6	3.5	2.8
Louth	7.1	5.2	4.3	3.2
Mayo	5.6	4.4	3.5	3.3
Meath	6.3	4.5	4.2	3.5
Monaghan	6.2	4.9	3.8	3.1
North Tipp	5.9	4.2	3.9	3.4
Offaly	6.1	4.4	3.6	3.5
Roscommon	5.7	4.2	3.3	2.9
Sligo	6.2	4.0	3.3	3.4
South Dublin	7.2	8.0	5.9	7.0
South Tipp	6.0	5.0	4.3	3.3
Waterford	6.8	5.1	3.8	4.3
Westmeath	7.1	5.0	3.8	3.2
Wexford	6.0	4.7	4.2	3.6
Wicklow	5.8	4.9	3.9	2.9

Table 11 Average Road Widths by County (metres)

County	PCI	IRI
Carlow	66	3.9
Cavan	77	4.6
Clare	67	6.3
Cork-North	66	5.5
Cork-South	56	6.1
Cork-West	66	6.7
Donegal	70	6.6
Dun L/Rathdown	77	4.2
Fingal	70	4.3
Galway	63	4.9
Kerry	67	5.2
Kildare	74	4.2
Kilkenny	76	4.2
Laois	66	5.1
Leitrim	71	4.1
Limerick	76	5.4
Longford	73	4.8
Louth	65	3.8
Mayo	69	5.9
Meath	61	5.3
Monaghan	79	3.4
North Tipp	74	6.3
Offaly	58	5.5
Roscommon	73	6.4
Sligo	53	6.2
South Dublin	73	4.0
South Tipp	64	5.2
Waterford	74	5.6
Westmeath	65	4.0
Wexford	53	5.7
Wicklow	67	5.5

Table 12 Condition Parameters - Regional Roads

County	PCI	IRI
Carlow	64	6.8
Cavan	68	6.7
Clare	62	7.8
Cork-North	76	7.0
Cork-South	60	8.4
Cork-West	58	8.5
Donegal	64	11.3
Dun L/Rathdown	59	4.7
Fingal	65	5.7
Galway	58	5.4
Kerry	58	6.9
Kildare	64	6.3
Kilkenny	71	6.1
Laois	53	6.8
Leitrim	49	8.7
Limerick	70	7.1
Longford	68	6.5
Louth	51	6.5
Mayo	62	7.8
Meath	62	6.8
Monaghan	58	6.7
North Tipp	57	8.2
Offaly	41	7.3
Roscommon	58	8.7
Sligo	40	8.0
South Dublin	64	4.6
South Tipp	56	8.0
Waterford	61	8.8
Westmeath	48	5.7
Wexford	45	8.0
Wicklow	66	8.5

Table 13 Condition Parameters - LP Roads

REMEDIAL WORKS - NATIONAL REQUIREMENTS

The basis for assignment of road sample units to the different remedial works categories based on VPCI and IRI criteria has already been set out in this paper. Table 14 shows the percentage of total pavement area assigned to each of the 4 remedial work categories by road class using both the VPCI and IRI criteria. Effectively, additional road lengths have been included under the Road Reconstruction category if the IRI on the sample unit exceeds a maximum threshold level, even though the VPCI criteria would not have assigned the sample unit to the Road Reconstruction category ordinarily. Only Road Reconstruction remedial works will improve the IRI under the DEHLG remedial works category definitions.

It should be noted that the percentage length identified as needing restoration of skid resistance (Skid Resist.) in Table 14 is based on visual identification of surface defects. Additional sections may also require restoration of skid resistance on the basis of low surface friction values, but are not included as surface friction was not a parameter measured in the 2004 survey.

	Remedial Work Type Percentages			
Road Class	Routine Maint.	Skid Resist.	Surf. Rest.	Reconstruction
R	24.7%	29.6%	21.7%	23.9%
LP	14.4%	28.1%	25.5%	31.9%
LS	12.6%	23.2%	29.3%	34.9%
LT	12.4%	18.1%	25.7%	43.9%

Table 14: Remedial Work Types - VPCI plus IRI thresholds

The maximum threshold levels applied in this report vary by road class, reflecting the reality of a higher level of expectancy of comfortable ride speed by the road user on different road classes. The use of IRI in this way is common internationally, and is also used by the National Roads Authority in the management of the national road network, but it is an innovation in the management of Non-National roads in Ireland. Accordingly, reasonably loose standards are applied initially. The threshold levels that were applied are shown in Table 15.

Road Class	Road Reconstruction indicated if IRI value is greater than
Regional Roads	8
Local Primary Roads	11
Local Secondary Roads	14
Local Tertiary Roads	17

Table 15: IRI Intervention Levels for Road Reconstruction - Present

It is recommended that tighter IRI standards should be aimed for and applied over time to have a specific, measurable performance parameter reflecting road user expectations. It is proposed that over time, the maximum threshold levels should move towards the following standards, shown in Table 16.

Road Class	Road Reconstruction indicated if IRI value is greater than
Regional Roads	6
Local Primary Roads	8
Local Secondary Roads	10
Local Tertiary Roads	12

Table 16: IRI Intervention Levels for Road Reconstruction - Future

Ultimately, application of these maximum threshold levels would lead to significant improvements in the overall ride quality levels on all road classes, and could also form a basis for further improvements in the future.

REMEDIAL REQUIREMENTS BY COUNTY

Table 17 show the percentage of total pavement area assigned to Local Primary roads for each local authority based on both the VPCI and IRI criteria. Similar tables for all road classes are contained in the Road Condition Survey final report.

Figure 7 shows a thematic diagram for Local Primary roads. The percentage of surface area for each local authority in the Road Reconstruction category was obtained from Table 18, and sorted in increasing order. There are a total of five groupings, with the 6 counties having the lowest percentage of surface area in the Road Reconstruction category being placed in grouping 1, the next 6 counties in grouping 2 etc. A similar process was followed for Local Primary roads in the Surface Restoration and Restoration of Skid Resistance categories. The Road Condition Survey final report contains similar thematics for Regional, Local Secondary and Local Tertiary roads respectively.

	Remedial Work Type Percentages			
County	**Routine Maint.**	**Skid Resist.**	**Surf. Rest.**	**Reconstruction**
Carlow	14.8%	17.7%	47.9%	19.6%
Cavan	18.1%	54.4%	14.2%	13.4%
Clare	18.9%	27.0%	29.4%	24.7%
Cork-North	35.8%	26.0%	22.0%	16.2%
Cork-South	13.0%	29.2%	25.8%	32.1%
Cork-West	10.6%	31.6%	22.1%	35.7%
Donegal	24.5%	13.0%	6.7%	55.9%
Dun L/Rathdown	18.1%	28.7%	19.9%	33.3%
Fingal	28.9%	31.0%	18.1%	22.1%
Galway	7.0%	29.5%	42.7%	20.8%
Kerry	14.6%	22.0%	30.4%	33.0%
Kildare	18.2%	28.0%	32.7%	21.1%
Kilkenny	26.2%	44.9%	18.0%	10.9%
Laois	11.4%	23.2%	31.8%	33.6%
Leitrim	5.0%	22.8%	35.6%	36.6%
Limerick	24.0%	22.5%	40.4%	13.1%
Longford	16.2%	61.3%	13.7%	8.8%
Louth	8.8%	18.4%	25.3%	47.6%
Mayo	13.4%	33.7%	20.0%	32.9%
Meath	11.1%	18.9%	49.8%	20.2%
Monaghan	8.9%	43.8%	19.8%	27.5%
North Tipp	4.9%	53.1%	16.4%	25.6%
Offaly	1.4%	17.5%	24.5%	56.5%
Roscommon	6.9%	39.6%	24.5%	28.9%
Sligo	0.6%	23.1%	20.5%	55.8%
South Dublin	17.9%	44.6%	20.1%	17.4%
South Tipp	11.0%	27.0%	24.3%	37.7%
Waterford	21.7%	26.9%	17.5%	33.9%
Westmeath	1.9%	25.6%	42.4%	30.0%
Wexford	8.2%	8.1%	25.5%	58.2%
Wicklow	11.5%	15.6%	46.7%	26.2%

Table 17: % area of LP Roads requiring each remedial work type based on VPCI and IRI criteria

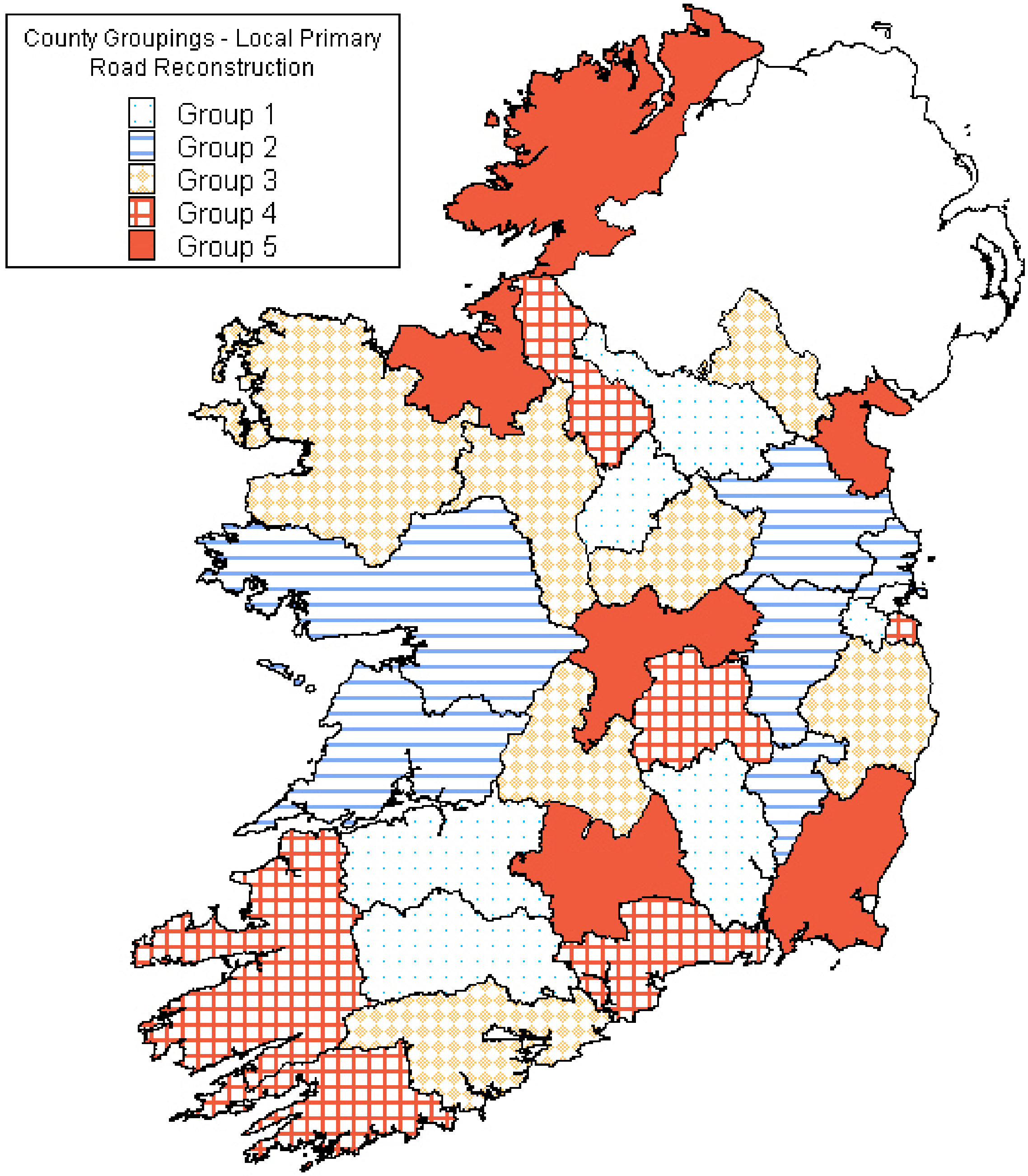


Figure 7: Local Primary – Road Reconstruction

***groups ranked 1 to 5 by increasing % area requiring remedial works**

A REVIEW OF PAVEMENT MANAGEMENT SYSTEMS IN IRELAND

What is a PMS?

A PMS is a tool that can be used to make informed decisions about the maintenance and rehabilitation of a pavement network. The American Public Works Association (APWA) defines a pavement management system (PMS) as, " ….A systematic method for routinely collecting, storing, and retrieving the kind of decision-making information needed (about pavements) to make maximum use of limited maintenance (and construction) dollars." The American Association of Highway Transportation Officials (AASHTO) states that the "…function of a PMS is to improve the efficiency of decision making, expand its scope, provide feedback on the consequences of decisions, facilitate the coordination of activities within the agency, and ensure the consistency of decisions made at different management levels within the organization."

STUDY METHODOLOGY

The methodology used for this review of pavement management systems followed a conventional systems development approach, where user needs and requirements are established before the suitability of available software or systems are evaluated. The steps included:

1. Meetings with client to clarify the requirements and brief, including deliverables and outputs, programmes and timescales, reporting protocols and frequencies.
2. Obtaining contact details of appropriate persons and sections within local authorities and other government institutions and establishing preliminary contacts.
3. Preparation of a study questionnaire to facilitate collection of information and any discussions that took place.
4. Visits to selected authorities and individuals to discuss needs and requirements, as well as their organisational and operating arrangements for carrying out their functions. Where possible, these visits involved groups of people within organizations to elicit balanced responses.
5. Visits to authorities in other countries to discuss their experiences with PMS.
6. Contact with vendors of pavement management system software for product details and information.
7. Compiling a synthesis of user needs and requirements, together with details of existing systems and capabilities.
8. Formulation of recommendations.
9. Compilation and submission of the final reports.

The methodology described above was intended to ensure that account was taken of significant factors that would influence the selection of a Pavement Management System.

USER NEEDS AND REQUIREMENTS

The primary methods used to determine user needs and requirements in relation to Pavement Management Systems included a questionnaire, circulated to road authorities in Ireland, and subsequent visits to selected authorities to develop a good understanding of the environment in which they operate and the way in which they operate. In addition, discussions were held with the Local Government Computer Services Board and a few road authorities in the United Kingdom.
The questionnaire was designed to elicit information about the current status of Pavement Management implementation within road authorities. It covered the following topics:

- Information Technology Environment
- Road Network Information
- Geographic Information Systems
- Existing and proposed Pavement Management Systems
- Personnel involved in Pavement Management
- Pavement Management objectives
- Pavement Management responsibilities
- Time spent on PMS activities
- Data recorded in existing Pavement Management Systems
- Existing and proposed road management systems

A total of twenty-seven responses were received, a response rate of 79%. Selected road authorities were visited between January and the end of May 2004, and discussions held with individuals involved in the management of the road networks. In most cases these discussions included the Senior Roads Engineer, and in some instances the relevant Director of Services attended. A total of eighteen interviews were held. Although focussed on Pavement Management, the discussions inevitably covered other areas of road construction and maintenance, budgets and programmes, all of which all fall within the ambit of management of roads. In addition, three road authorities in the United Kingdom and Northern Ireland were visited to obtain information on their experiences with implementation of pavement management and other road management systems.

THE EXISTING INSTITUTIONAL SITUATION

This section describes the existing institutional and technical factors that are relevant to the selection and implementation of Pavement Management Systems within local authorities in Republic of Ireland. These have been gleaned from the information gathered during interviews with local authority personnel, from the PMS questionnaires, and from published information on local authorities. The factors are relevant, because no computer system exists in isolation.

Business Background

The twenty-six counties in the Republic of Ireland are administered through the County Council structures in each county. These county councils are responsible for provision of services in their areas of jurisdiction, with the services described under the seven general headings of housing and building, road transportation and safety, water supply and sewerage, development incentives and controls, environmental protection, recreation and amenity, and miscellaneous services. The County Councils are elected bodies, each of which has a full time chief executive, the City or County Manager, with supporting administrative staff.

Roads and Local Authority Structures

Local Authorities are responsible for the administration, construction, and maintenance of approximately 87,000 kilometres of Non-National roads. In addition to these, local authorities are responsible, in partnership with the National Roads Authority, for construction and maintenance of the National Road network, comprising approximately 5,400 kilometres of National Primary and National Secondary roads.

Non-national roads account for 94% of this country's road network and carry 54% [NRA 2001] of all road traffic. These roads serve as an indispensable complement to national roads, affording access to the larger urban centres, ports and airports. They are vital to local enterprises, agriculture, forestry and tourism, as well as having a valuable social and community function.

The twenty-nine county local authorities in the Republic vary considerably in size, with their road networks ranging from 600 km in Dun Laoghaire Rathdown County to 11,600 km in County Cork. Most local authorities (20) however have between 1,500 and 4,500 km of road.

Within each local authority, responsibility for roads is assigned to one of the Directors of Services, with a "Roads" component dealing with day to day administration of the network. A Senior Road Engineer usually heads the roads component.

Counties are usually divided into two or more "Engineering Areas" where the Area Engineer is responsible for roads and other engineering functions. The number of permanent technical and engineering staff dedicated to roads within each engineering area is generally relatively small, with the Area Engineer supported by two or three engineers and technicians.

Road maintenance and minor road improvements are generally carried out by direct labour maintenance teams managed by overseers and foremen based in the areas, with some work being contracted out to private contractors. Some local authorities have a road reconstruction unit that moves around the county to handle projects where they occur.

Road Network Provision

Provision of the road network involves planning for new and improved roads, based on identified needs, construction of new roads, and maintenance of the existing network, to ensure that it remains in serviceable condition. Activities involved in the provision of road infrastructure include: Resourcing, Planning, Construction and Maintenance

Effective management requires that good information is available to the individuals and components that have to make decisions in the course of carrying out these activities. Ideally, the information needed should be easily shared amongst the different people, components, and levels of management involved.

Information Technology Environment

The implementation of computerised management systems is affected by the information technology environment that exists or is planned for the authority. This environment includes the physical computer hardware, networks, operating systems and software, as well as the extent to which computer facilities are integrated into the normal work of the organisation.

Networks and Computers - Computer networks have been implemented in virtually all local authorities. These networks typically provide full connectivity for all workstations within the county offices via a Local Area Network (LAN), with robust file servers. The predominant network operating system used is Microsoft NT. Computer workstations are generally Windows XP operating system.
Most local authorities also maintain network connectivity between their head office and their area and other smaller offices via a Wide Area Network (WAN).

Databases - The database systems most extensively used are MS-Access and MS SQL Server. The Local Government Computer Service Board (LGCSB) promotes use of these two databases.

Desktop Software - Most authorities have standardised on Microsoft Office products (MS-Word, MS-Excel, MS-Powerpoint, MS-Project) for normal use. Autocad is the predominant software used for Computer Aided Drafting.

Geographic Information Systems - The great majority of local authorities make use of MAPINFO for Geographic Information System services. A couple of Arcview / Arcinfo installations were encountered, and one authority reported using Autodesk Map.

IT Personnel / Software resources - Most authorities reported having few available in-house personnel to undertake software development, and that they relied on external resources such as LGCSB or contractors for any significant software projects. Most authorities did however have an IT department with personnel for support of their computer networks.

Existing Systems - Authorities reported the existence of various information technology systems related to their road networks within their organisations. (Table 18) Interviews with authorities indicated that several of these systems were supplied by Local Government Computer Services Board (LGCSB) or were prescribed for use on the national road network. Some of the less-well-distributed systems were locally developed databases. It was not clear from the information provided what the status of these systems was or whether these systems were all in regular use.

System	Number	Name
Road Network Information	22	MapRoad
GIS (Geographic Information System)	19	Mapinfo / MapRoad
Traffic Accidents	8	NRA / MapRoad
Bridges / Structures	14	NRA / MapRoad
Traffic Counts / Analysis	13	NRA / MapRoad
Road Maintenance	7	
Road Pavements	7	MapRoad
Road Construction	6	
Plant & Job Costing	5	
Contracts Administration	4	
Road Openings & Encroachments	3	
CPO / Expropriation	3	CPO
Project Prioritisation	3	
Traffic Signs	1	
Traffic Signals	1	
Roadside Development	1	

Table 18: Systems in use

Road Network Information

Each local authority is required to maintain a "Road Schedule" that defines their road network, and this contains basic road descriptors such as road number, road category, road name, section length, width, and descriptions of section start and end points. The majority of authorities have recorded this road schedule within MapRoad GIS which provides tools for maintaining the basic network information, using a link and node referencing system.

Existing Pavement Management Systems

A number of authorities reported an existing pavement management system within their organisations. The majority of these use MapRoad, as supplied by LGCSB. One city council made use of RoSy pavement management system (supplied by Carlbro), and one county makes use of MicroPAVER (supplied by PMS Ltd). The level of utilisation of these systems varies greatly between authorities.

MapRoad is an "integrated, Geographic Information System (GIS) enabled, Roads Management Information System", modular in nature, comprising a core road network module displaying the road network. It is built around the Mapinfo Geographic Information System. The core module displays the road network and the descriptive data associated with each road in an authority. It can produce the "Road Schedule" and various plots of the road network. Additional modules such as "Road Accident", "Road Bridge", "Road Traffic", and "Road Management" run in parallel with the road network module. The Road Management module allows for management of road survey data per road segment including inputting, editing, spatial analysis, reporting and costing of the data.

At present, authorities with MapRoad installed make limited use of the road management modules, especially those elements related to recording and utilisation of survey information. No standard methods have been defined for the collection, processing and utilisation of pavement condition data.

PMS CHARACTERISTICS

Pavement Management Systems (PMS) are tools used by authorities to optimise the maintenance of their road networks. The ultimate goal of these systems is to optimise the allocation and the use of maintenance and rehabilitation. In its broadest sense Pavement Management "…encompasses all the activities involved in the planning, design, construction, maintenance, evaluation and rehabilitation of the pavement portion of a public works program --- a pavement management system provides an organised coordinated way of handling the pavement management process". [AASHTO 1993]

Pavement Management and Road Management

Road Management encompasses both management of the physical assets such as pavements, bridges, as well as human resources, equipment and materials, and other items of value such as finances, CPO, data, computer systems, methods, technologies and partners. [FHWA and AASHTO 1997].

It is desirable that the road authority makes use of management systems, focused on different areas of operation, to assist it to meet its objectives, help personnel to carry out their duties and make the best use of available resources. These management systems typically include a database containing information relevant to the activity concerned, with tools that facilitate gathering of the information, keeping of records, analysis, and reporting of results. Most management systems involve monitoring of relevant factors in order to provide information to the decision maker and his managers. For example, monitoring of traffic flows helps to identify the need for geometric improvements and pavement strengthening, monitoring of speeds could help direct enforcement activities, whilst monitoring of pavement condition will identify where maintenance resources should be directed. Taken together, and functioning in a coordinated fashion, these management systems comprise an integrated road management system.

Examples of systems that could form part of an integrated road management system are:

Traffic Counting	Traffic Analysis
Accidents	Road Safety
Traffic Signals	Public Lighting
Footpaths	Structures and bridges
Road Openings and encroachments	Roadside development / planning
Pavements	Suppliers
Contracts	CPO / Land
Public Transport	Road Maintenance
Plant & Job Costing	Project Prioritisation
Forward Planning	Financial Management

As the various assets and activities associated with a road network are interrelated, it is desirable that individual management systems are effectively linked or integrated in order that data or information in one system may be effectively utilised in another.

Network Level or Project Level

Pavement Management at network level deals primarily with summary information related to the entire network or a significant portion thereof. As such, it involves policy and programming decisions frequently made by upper and middle management. Examples of network-level pavement management is the use of PMS information to:

- Identify and prioritise candidate projects
- Establish rehabilitation programmes
- Estimate overall short- and long-term needs
- Justify budget requests
- Answer “what-if” questions

PMS network-level information may include:

- The current condition of the road network
- Performance trend of the network, with past history
- Projection of future condition and needs
- Estimated impacts of alternative funding plans on future pavement condition.

At the project level, pavement management deals with detailed and technical information related to a specific pavement section. Consequently it involves more specific technical management decisions made by middle or lower management. Examples of project-level pavement management as it relates to specific pavement sections include the following:

- Details of pavement structures and history of pavement maintenance
- Diagnosis of problems with each pavement section
- Analysis of life-cycle costs of alternative strategies being considered for the pavement section
- Estimation of costs of various methods or materials that can be used
- Feedback of performance to provide input into pavement design, construction and maintenance activities
- Details of historical traffic loading

The vast majority of pavement management systems focus on the network level, with some elements of data serving the project level. Integration of project and network level pavement management has not generally become a reality.

PMS SYSTEM REQUIREMENTS

The requirements presented below are based on the findings of the first part of the study, taken together with those dictated by good practice in the implementation of road management systems.

PMS System Requirements		
Institutional	Organisation	System operation by one person, if required. A networked system must allow 5 simultaneous users.
	Simplicity	System must be customisable to suit user requirements Standard and customisable reports must be available
	Quick Implementation	Initial setup not more than 2 days. Tools for import of existing data must be provided.
Information Technology	Windows NT Network / MS-Office Environment	Must operate in Windows NT network environment.
	Networkable	System must be network-enabled
	Databases	System database must be expandable
	Modularity	System must be modular with user-selectable modules
	GIS Compatibility	Be compatible with Mapinfo GIS Must link to Arcinfo / Arcview GIS
Functional	Network Referencing Systems	Utilise a link and node network referencing system Accommodate multiple network referencing systems.
	Network Maintenance Tools	Provide network maintenance tools Maintain network history
	Flexible Inventory and Attributes	Allow users to define their own inventory and attributes
	Condition Monitoring	Definition of condition attributes Definition and use of alternate “rules and parameters”
	Prioritisation Tools	User definition of prioritisation criteria Tools for grouping of condition sections Tools for economic analysis and optimisation
	Work Programming and Budgeting	Generation of treatment options and costs Programming and budgeting tools Multi-year programming
	Reporting and Viewing of data	In-built reporting tools Reports customisable to suit user requirements Can reports be exported
Compatibility	Expandability	Modular upgrading options Additional modules available
	Compatibility - other systems	Can external interfaces be set up
Support and Training		Ongoing software support, including upgrades Initial training On-going training Helpdesk User groups
Cost		Indicative system purchase price Indicative Annual Support costs Indicative training costs Costs for Data conversion Costs for System changes

Table 19: PMS System Requirements

EVALUATION OF COMMERCIAL PAVEMENT MANAGEMENT SYSTEMS

A number of commercially available Pavement Management Systems were identified during the course of the investigation, and detailed information was obtained on most of these. These systems and suppliers are detailed in Table 20 below.

System	Supplier	Country
Micro PAVER	US Army Corps of Engineers Construction Engineering Research Laboratory (CERL)	USA
Confirm Pavement Manager	Southbank Systems plc / TRL	United Kingdom
MARCH PMS	Faber Maunsell Ltd.	United Kingdom
WDM PMS	WDM Limited	United Kingdom
INSIGHT for Pavement Mgment	Symology Ltd.	United Kingdom
Exor Highways	Exor Corporation Ltd.	United Kingdom
dTIMS CT	Deighton Associates Ltd.	Canada
RoSy	Carl Bro Pavement Consultants	Denmark
HIMS	Data Collection Ltd (DCL)	New Zealand
STREETSAVER	Metropolitan Transport Commission	USA

Table 20: PMS Systems and Suppliers

Comparison of Commercial Systems

Each system was evaluated with regard to the requirements identified in Section 4. The overall rating and functional scores for each of the commercial systems are shown in Figures 8.and 9.

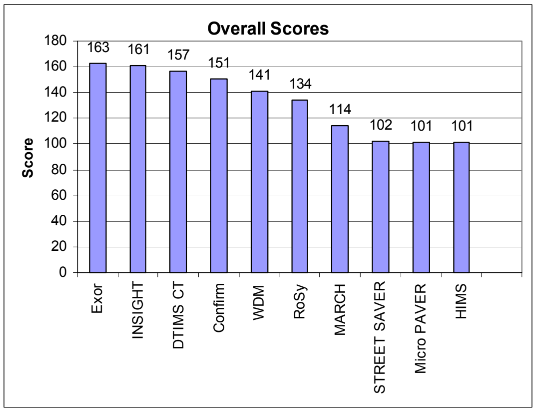
The systems that scored the highest were Exor for Highways (Exor Ltd), and Insight Pavement Manager (Symology Ltd), followed closely by dTIMS CT (Deighton Associates) and Confirm Pavement Manager (Southbank Systems). The scores for other systems were significantly lower.

Systems that generated high scores tended to be those that allowed for significant potential for adaptation and customisation. These are important issues because no definite decisions have yet been taken in Ireland on standards to be adopted for Pavement Management purposes. In addition, no guidelines have been developed to assist authorities on the adoption or implementation of road management systems. If the road network defined for PMS purposes is to form the basis for other road management systems, it is logical that a system that allows for addition of further modules should rate highly.

Systems that generated intermediate scores (such as WDM, RoSy, MARCH) tended to be those that provided good PMS functionality, but with limited flexibility for adaptation or customisation. Some of the lower scoring systems (such as STREETSAVER and MicroPAVER) provide good PMS functionality, but cannot be easily adapted for use outside their design parameters.

Functional ranking is generally similar to the overall scoring, with Exor, Insight and dTIMS gaining the highest ratings. These scores reflect the flexibility and advanced functionality provided. Lower rated systems provided a lesser range of features, and were limited in the ways in which they dealt with aspects such as prioritisation and analysis. Some of these systems (such as MARCH and WDM) were focussed primarily on UKPMS requirements, which limited their suitability outside these parameters.

STREETSAVER and MicroPAVER are designed for use using the PCI method of condition evaluation, which limits their applicability to other situations. HIMS provides very good data management facilities, but lacks any prioritisation and analysis tools.



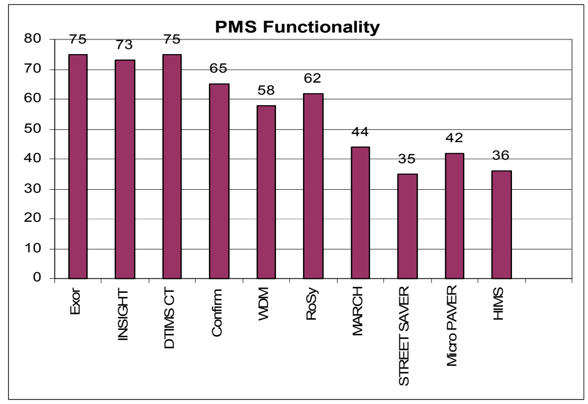


Figure 8

Figure 9

The Top-Scoring Commercial Systems

- At least four systems provide the required functionality. These systems are: Exor Highways, Insight Pavement Manager, dTIMS and Confirm Pavement Manager.
- Each of these four systems is open, in that they offer very good options for users to define their road networks, attributes, and inventory, according to their requirements. They also provide for future growth through addition of modules, and by providing tools that enable users to build additional modules.
- Pavement Condition evaluation is well catered for by each of the four systems. Condition parameters can be user defined, as can the methods of processing the data to produce condition indices. Further tools are provided for deciding on appropriate treatments based on condition values and / or indices, and for estimating the costs of these treatments.
- Each of the four systems provide modules for the projection of current condition into the future, taking into account historic data, and the results of this projection can be used in optimisation models that assist in determining the optimum strategies and treatments to be used.
- Each of the four systems has a good track record of successful implementation, which gives one a sense of the quality of the products, and their ability to be adapted for various situations. Exor and dTIMS in particular have been implemented in numerous countries around the world, with around 200 installations reported for each. Insight has fewer installations (80+), mainly in the UK, whilst Confirm has 25+ installations reported, also mainly in the UK. On this basis, therefore, Exor and dTIMS stand out ahead of Insight and Confirm.
- Confirm is also rated slightly lower than the other systems in terms of its functionality, primarily because of its need for supplier intervention in changing condition evaluation parameters.
- dTIMS falls down slightly in relation to its GIS functionality, compared to the other systems, which results in a marginally lower rating score.
- When reviewing expected costs, there is little to choose between the top-rated systems on the basis of initial cost, as all have similar costs of around €45,000 (2004). Ongoing support costs for each system range between € 4,300 and € 8,660 per annum so are of the same order of magnitude.
- When it comes to expandability, it can be seen that Exor and Insight offer very similar packages of additional modules. The modules offered by Confirm are more limited in scope. dTIMS takes a slightly different approach by providing all the tools needed to build additional modules, with complete flexibility provided to the user. This approach may or may not prove attractive, depending upon the degree of expertise available to the authority.
- dTIMS main strengths are its well-established tools for economic prioritisation, combined with a very strong user base around the world.
- Having regard to all these factors, it considered that there is very little to choose between the top rated systems as they all provide excellent features and functionality.

EVALUATION OF IN-HOUSE DEVELOPED PAVEMENT MANAGEMENT SYSTEMS

An alternative to purchasing and implementing a commercially available PMS is to develop an in-house system to supply the functionality required by the road authorities. This option may be viable where the envisaged implementation timetable allows sufficient time for system development to be undertaken, and where suitable resources are available to undertake the development work.

In Section 4 above the existence of MapRoad, an existing GIS-based road management information system was noted. This system was developed by the Local Government Computer Services Board and has been installed in many local authorities in Ireland. It is currently being used to provide basic pavement management functionality by some of these authorities. It is also being used to facilitate databases of other road-related data such as that for Accidents, Traffic and Bridges. In view of its special position this system is discussed separately from the commercial systems. The discussion will address the current performance of MapRoad in relation to the PMS system requirements, and the feasibility of enhancing it, if required, to conform to these requirements.

Existing Maproad Functionality

MapRoad is an "integrated, Geographic Information System (GIS) enabled, Roads Management Information System", modular in nature, comprising a core road network module displaying the road network. Additional modules such as "Road Accident" and "Road Management" run in parallel with the road network module. The Road Management module allows for management of road survey data per road segment including inputting, editing, spatial analysis, reporting and costing of the data. The current overall functionality of MapRoad was assessed against the same PMS requirements as the commercially available systems, with the outcome summarised in Table 21.

	RATING SCORE
Institutional Requirements	26
Information Technology Requirements	29
Functional Requirements	32
Future Expansion	5
Support and Training	19
Total	**111**

Table 21: MapRoad Evaluation Results

MapRoad's overall current performance is significantly poorer than the top-rated commercial systems, as it scored 111 points compared to around 160 points for the top-rated commercial systems. This lower rating is primarily as a result of its low evaluation scores under the "Functional" requirements, where MapRoad scored 32 points, compared to around 70 points for the commercial systems. This existing lack reflects the fact that this aspect of MapRoad has not been developed due to local authorities not yet requesting this PMS functionality.

Maproad Upgrading

Can MapRoad be enhanced to become a system that closely matches the needs of the road authorities?

This question was addressed through discussions held with the Local Government Computer Services Board (LGCSB) on this issue to ensure they had a good understanding of the system requirements as detailed above, and the "gaps" in MapRoad functionality that would need to be addressed in order to comply with the requirements.

The main conclusions drawn by the study team are:

1. The current version of MapRoad has significant deficiencies that limit its usefulness as a fully-fledged pavement management system, and that these deficiencies must be addressed and rectified if the system can be considered for adoption by road authorities.
2. MapRoad, as previously stated, is supported by LGCSB, a well-resourced Information Technology organisation whose primary purpose is to provide IT and software development services to local government bodies. An existing team within LGCSB is dedicated to maintaining and enhancing MapRoad to meet the identified needs of authorities. This team can be expanded as necessary to provide particular services demanded by authorities, albeit at additional cost. The availability of dedicated resources to carry out system enhancements is a big plus factor for any system.
3. The recent upgrading of the MapRoad database from MS-Access to MS-SQL Server satisfies a number of the IT and multi-user requirements, as this database is robust and can cater for future system expansion. It allows for multi-user access, and can accommodate remote user access.
4. Network history (Item 16), an item of importance to Local Authorities, can be maintained within the MS-SQL Server database, and can be implemented through enhancing MapRoad.

5. Enhancement of MapRoad to meet the defined needs and requirements of road authorities in Ireland would mean that it effectively becomes a “bespoke” or tailor-made system, which would satisfy the above requirements, and in this respect be on a par with other commercial systems.
6. The availability of effective tools for economic analysis and optimisation (Item 22 above) is a valuable system attribute. This capability is of a lower priority than many other PMS requirements, but should be planned for during the implementation stage. Use of an external software product (such as HDM-4) for this purpose is supported as a realistic option.
7. Enhancement of MapRoad will require LGCSB to take on additional resources, and the cost of these resources will have to be carried by someone. Their estimate of the additional cost is probably realistic, based on their estimate of the time involved.
8. It appears that there are no serious architecture or system development obstacles to enhancing MapRoad to meet the defined requirements of the road authorities, provided sufficient time and resources are available to carry out the work involved.

PMS IMPLEMENTATION ISSUES

To ensure successful implementation and operation of a pavement management system in any organisation, it is important that institutional and organisational factors be considered in detail along with the technical components of the system. These factors should be addressed by the authorities prior to the implementation of the system, even before some of the technical issues are addressed. The environment within which a PMS operates is dynamic. Therefore the implementation of a PMS should be a dynamic and interactive process that will address these facets methodically to ensure adaptation to the changing needs of the authority, bearing in mind that full implementation can take a number of years.

Implementation Process

The successful implementation of a PMS depends on management’s commitment to implementation at all levels. Consequently all levels of staff that will be end-users should be involved in the development of the system from an early stage, and the system should comply with the needs of the end-users in order to promote its ultimate usage.

Implementation Factors

Factors that must be considered during implementation include:

- Funding and sources of funding.
- Compatibility of pavement management systems
- Communication – within and without the road authority
- Properly define the position and function of the PMS section within the organisational structure.
- A separate section dedicated to PMS functions is desirable.
- The Information Technology department should be advisory and supportive, but not controlling.
- Pavement management needs should be defined during the implementation phase, and these needs must be classified into short- or long-term needs.
- Phased Implementation
- Cost implications

Does one aim for a quick implementation, or go for an incremental approach?

It seems attractive to obtain a new system, ready to go, that can be up and running almost immediately, however it is certain that if the data, organisational and procedural issues are not dealt with, the system will not become functional for some time. Whatever system is adopted, time will have to be spent by authorities in defining their exact data requirements, taking into account both current and future needs, in order to ensure successful system implementation. They will also have to decide on data collection and processing standards that will ensure reliable and consistent information. Then data collection must take place, both inventory and condition data, before any processing can take place. Typically, it can take one to three years, depending on the size of road network, amount of existing information, availability of resources, training of personnel, etc. to get a PMS up and running.

PMS awareness

An early step in the PMS implementation process is to raise the profile and awareness of PMS and pavement management principles within road authorities, especially amongst personnel that may be involved in PMS operations, or that will make use of PMS information.

Succession Planning

It is common amongst agencies involved in pavement management to fail to properly address the issue of succession planning. The approach is almost invariably ad hoc response to crisis, which occurs when people resign or retire, or the data is inadequate, or the new people don't know how to apply the technology, or the "corporate memory" has disappeared. Key ingredients in succession planning include: developing a well structured personnel plan which involves timing of replacements, training and overlap, contingencies, and contains mentoring responsibilities, making the necessary investments, keeping the plan dynamic, documenting the plan and procedures.

CONCLUSIONS

1. Most road authorities have existing Road Management Software installed, in the form of MapRoad, but at present less than 40% make use of the pavement management modules. The level of implementation of the PMS modules is generally low, and there is generally a fairly low level of knowledge amongst staff on PMS issues. No standard methods have been defined for the collection, processing and utilisation of pavement condition data, which is a stumbling block for those interested in making better use of their systems.

2. Most road authorities indicated that they plan to implement PMS in the future. PMS is not always the highest priority.

3. The priorities of PMS objectives, as reported by road authorities, indicate that the short-term focus should be on having accurate road network and attribute information, on describing current condition of the road network, and on identifying and prioritising current projects and budget needs. Longer-term objectives should focus on network performance and forecasting of future needs.

4. These short- and long-term objectives are reflected in the high priority set by authorities on collecting good data describing their networks and on recording pavement construction and surface details.

5. Road authorities generally have good information technology infrastructure, including local and wide area networks serving their offices. These are supported by IT components within the authorities. This means that there should be few IT-related problems in installing new systems.

6. GIS is installed in most road authorities, with Mapinfo being the dominant GIS software. MapRoad is built as a Mapinfo add-on and requires it in order to function.

7. System requirements, based on the findings of the first part of the study, taken together with requirements dictated by good practice in the implementation of road management systems fell into five areas: Institutional, Information Technology, Functional, Future Expansion, Support and Training.

8. Ten commercially available pavement management systems were evaluated against these requirements, using a numeric rating system, which yielded rating scores as shown in Figure 7.1 and 7.2 above.

9. Each of the four top rated systems (Exor, Insight, dTIMS and Confirm) provide excellent features and functionality, with the required degree of openness to allow for customisation to suit Irish conditions.

10. Systems that generated high scores tended to be those that allowed for significant adaptation and customisation. Systems that generated intermediate scores provided good PMS functionality, but with limited flexibility for adaptation or customisation. The lower scoring systems provided reasonable PMS functionality, but cannot be easily adapted for use outside their design parameters.

11. The indicative costs for the various systems vary substantially, however the four top-rated systems have costs that are comparable, around €45,000 initial cost (2004) for a typical installation.

12. A possible alternative to purchasing a commercial PMS is to develop an in-house system that is designed to provide the functionality required by road authorities in Ireland. This alternative was explored through evaluation of MapRoad, an existing GIS-enabled Road Management Information System.

13. An evaluation of the possible enhancement of MapRoad to produce a tailor-made pavement management system indicated that no significant obstacles exist to doing this. The present system can be relatively easily modified and improved within a year to provide the majority of the PMS functionality that is required. Further enhancements can be undertaken over time. This will require the commitment by LGCSB of additional resources to undertake this work.

14. Implementation of a PMS should follow a structured, stepwise process that will ensure proper definition of data, data processing, and system requirements before full implementation can take place. This structured process could take more than a year to bear fruit, but is essential to the success of implementation.

15. If an in-house system development process is adopted, authorities must have confidence that their software developers will produce the required system modules when they are needed, and that the developed system will in fact meet their long term needs.

16. Road network definition rules should be revisited as part of the system and data definition process to ensure that all desired features of the road network can be properly referenced in the network database. The data structures for the network should ideally be set up using GIS-T database design principles.

17. The profile and awareness of PMS and pavement management principles must be raised within road authorities as an early step in the PMS implementation process.

RECOMMENDATIONS

PMS System Adoption

Commercial Systems - The commercial systems that provide the best range of features and functionality with the required degree of openness to allow for customisation to suit Irish conditions are Exor Highways (Exor Corporation Ltd.); Insight Pavement Manager (Symology Ltd.); dTIMS (Deighton Associates) and Confirm (Southbank Systems plc). Any one of these systems would be suitable for adoption, and all four are therefore recommended.

In-house Development - A feasible alternative to the selection of a new PMS is to significantly enhance MapRoad to produce a tailor-made PMS for Irish conditions.

- It is recommended that the second alternative, the enhancement of MapRoad, be adopted.

This alternative is recommended taking cognisance of the following factors:

- The need for an incremental, structured approach towards implementation
- The timescale required to implement PMS in Ireland
- The need to properly define data and processing requirements before system implementation
- The availability of a strong, dedicated, system development team to enhance MapRoad
- The anticipated reasonable cost of MapRoad system development compared to commercial systems

This alternative, if implemented correctly, will ensure that road authorities remain involved in the definition of requirements and the system development process, and will be able to ensure that the ultimate system will meet both their short- and long-term needs.

Implementation Process

It is recommended that implementation of the PMS follow a carefully structured process, taking into account, *inter alia*, the implementation factors identified above, to ensure the initiative is a success.

- It is recommended that external expert assistance should be brought in to help guide the implementation process.

- It is recommended that a steering group be instituted to oversee and coordinate the implementation process, with working groups as needed to focus on specific data and processing issues.

- The implementation process should include a review of network definition rules and should ensure that the network definition system can accommodate all the anticipated data needs of the road authorities.

- The implementation process should also allow for raising the profile and awareness of PMS within local authorities, as this will pay dividends in obtaining participation in the process and in ultimately using the system.