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Transport Infrastructure Ireland

TII Publications

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Pavement Asset Management Guide

AM-PAV-06060
February 2023

AM Asset Management & Maintenance

Technical

About TII

Transport Infrastructure Ireland (TII) is responsible for managing and improving the country's national road and light rail networks.

About TII Publications

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Each document within TII Publications has a range of attributes associated with it, which allows for efficient access and retrieval of the document from the website. These attributes are also contained on the inside cover of each current document, for reference.

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TII Publications

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Contents

1. Introduction 1

2. Network Definition and Inventory 6

3. Pavement Condition & Skid Resistance Surveys 15

4. Data Management 26

5. Pavement Asset Management Software 29

6. Programme Planning & Scheme Development 43

7. Network Level Reporting & KPIs 49

8. References 53

Appendix A: 54

Relevant TII Publications 54

Appendix B: 59

PAMS Data Dictionaries 59

Contents Table

1. Introduction 1
1.1 Background 1
1.2 TII Asset Management Overview 1
1.3 Functions of TII Network Management 3
1.4 Pavement Protection and Renewal - Scheme Identification 4
1.5 Relevant TII Publications 4

2. Network Definition and Inventory 6
2.1 National Road Network 6
2.2 Subnetworks 7
2.3 Managing Organisations 8
2.4 Linear Referencing and GIS 11
2.5 Network Model and PAMS 13
2.6 Asset Inventory (Roads) 14

3. Pavement Condition & Skid Resistance Surveys 15
3.1 Introduction 15
3.2 Survey Types 15
3.3 Survey Requirements 15
3.4 Referencing Data to the Network 16
3.5 Pavement Condition Parameters 17
3.6 Skid Resistance 19
3.7 Structural Condition and Surface Defects 21
3.8 Pavement Structure & Structural Capacity 23
3.9 Surveys for Other Road Information 25

4. Data Management 26
4.1 Data Validation 26
4.2 Data Storage 26
4.3 Data Processing 26
4.4 Data Security 27
4.5 Data Confidentiality 27
4.6 Data Structure and Formats 27
4.7 Video Image Formats 28
4.8 Programme for Data Delivery 28

5. Pavement Asset Management Software 29
5.1 Introduction 29

5.2 Data Storage and Management 30
5.3 Strategic Analysis 35
5.4 Reporting 41

6. Programme Planning & Scheme Development 43
6.1 Overview 43
6.2 Pavement Asset Repair and Renewal (PARR) Schemes 43
6.3 Management of Skid Resistance 45
6.4 Routine Maintenance Inspections by Local Authorities 47

7. Network Level Reporting & KPIs 49
7.1 General 49
7.2 Levels of Service 50
7.3 Strategic Level 50
7.4 Tactical Level 51
7.5 National Roads Network Indicators 51
7.6 CEDR TEN-T KPIs 52

8. References 53
8.1 Key Documents 53
8.2 European Standards 53
8.3 International Standards 53

Appendix A: 54
Relevant TII Publications 54

Appendix B: 59
PAMS Data Dictionaries 59

Table of Definitions

Heading	Definitions
Characteristic Skid Coefficient (CSC)	The Characteristic Skid Coefficient (CSC) is an estimate of the underlying skid resistance once the effect of seasonal variation has been taken into account.
Design Organisation	Usually an Implementation Authority, National Roads Design Office (or a Consultant acting on their behalf) who is responsible for the design of the Scheme.
Designer	The Designer will be a Chartered Engineer or equivalent and who has at least 5 years' experience in the design and supervision of PARR Schemes. This experience should include a thorough understanding of the interaction between the attributes of drainage, geotechnics, utility issues, land issues, and pavement design
Employer's Representative	As defined in the Public Works Contract.
Implementation Authority	The Implementation Authority shall be the relevant local authority responsible for the PARR scheme or for the purposes of this procedure the MMaRC Contractor.
Investigatory Level (IL)	An Investigatory Level (IL) represents a level above which the skid resistance is considered to be satisfactory and at or below which the road is judged to require a further assessment of the site-specific risks in more detail.
Life Cycle Cost Analysis	(LCCA): Life-cycle cost analysis is the process of calculating whether a particular investment, resultant from a specific design strategy, will generate a positive return on investment over the life of the renewed pavement.
Managing Organisation	The local authority or contracted organisation commissioned to manage part or all of the national road network by TII.
Motorway Maintenance and Renewals Contract (MMaRC)	Contractors appointed to maintain, operate, and renew sections of the motorway network.
National Road Network	The national primary and secondary roads network in Ireland which is operated and maintained by TII, and which comprises motorways and dual carriageways, including their interchanges / junctions, merge and diverge ramps, and circulatory elements of roundabouts; and national primary and national secondary single carriageway roads.
Network Management	Network management is the process of configuring, monitoring, and maintaining a reliable network.
Pavement Asset Management System (PAMS)	The network pavement asset management system which is maintained and managed by TII Network Management.
Pavement Asset Repair and Renewal (PARR)	Activity targeted at extending the life of an existing road pavement and/or improve its load carrying capacity or skid resistance. Examples include overlay and inlay works and edge strengthening of an existing road pavement.
Routine Maintenance	Programmed and reactive maintenance activities required to maintain the serviceability and durability of the road.
Seasonal Variation	The variation in the skid resistance measured during the course of the year due to climatic conditions, traffic, and weathering and polishing cycles.
Site	A collection of averaging lengths at or below IL which are grouped together to form an efficient basis for planning and conducting site inspections.

Heading	Definitions
Skid Resistance	Skid resistance is the characterisation of the friction of a road surface when measured with a specified device in accordance with a standardised method as described in AM-PAV-06045.
Treatment	Remedial works to improve the skid resistance of a road surface.
Tactical Level	Tactical Level KPIs are used for detailed condition monitoring, overall pavement programme development, and also feed into calibration of future pavement performance modelling.
Strategic Level	Strategic level reporting is intended for managers and decision makers at an executive level. They are primarily aimed at Senior Management, Board members and external bodies to allow a summary understanding of the network's condition performance over time.

Table of Abbreviations

Heading	Definition
2G	Second Generation
AADT	Annual Average Daily Traffic
AC	Asphalt Concrete
AGOL	ArcGIS Online
ALRS	Authoritative Linear Reference System
AM	Asset Management
API	Application Program Interface
AWS	Amazon Web Services
CEDR	Conference of European Directors of Roads
CSC	Characteristic Skid Coefficient
DBFOM	Design Build Finance Operate Maintain
DCP	Dynamic Cone Penetrometer
DMI	Distance-Measuring Instrument
dTIMS	Deighton Total Infrastructure Management System
ESRI	Environmental Systems Research Institute
FWD	Falling Weight Deflectometer
GIS	Geographical Information Systems
GLAMP	Group Level Asset Management Plan
GNSS	Global Navigation Satellite System
GPR	Ground Penetrating Radar
GRC	Gross Replacement Costs
HRA	Hot Rolled Asphalt
IA	Implementation Authority
IRI	International Roughness Index

Heading	Definition
ITM	Irish Transverse Mercator
ITS	Intelligent Transport Systems
KPI	Key Performance Indicator
LA	Local Authority
LCA	Life Cycle Assessment
LCCA	Life Cycle Cost Analysis
LCMS	Laser Crack Measuring System
LOS	Levels of Service
LPV	Longitudinal Profile Variance
LRS	Linear Referencing System
MMaRC	Motorway Maintenance and Renewal Contract
MPD	Mean Profile Depth
NM	Network Management
NSAI	National Standards Authority of Ireland
PAMS	Pavement Asset Management System
PARR	Pavement Asset Repair and Renewal
PPP	Public Private Partnership
ROW	Right of Way
SAMP	Strategic Asset Management Plan
SFC	Sideway Force Coefficient
SMA	Stone Mastic Asphalt
TII	Transport Infrastructure Ireland
TMA	Tasked Maintenance Area
TRL	Transport Research Laboratory

1. Introduction

This publication provides guidance to internal and external users on the application of pavement asset management practices to the national road network by TII. The document gives an overview of TII's pavement asset management approach and details the relevant processes and technical information associated with the operation of the TII Pavement Asset Management System (PAMS). The key aspects of pavement asset management to achieve optimal life-cycle performance are also described in the document.

The document is aimed primarily at TII Network Management (NM) personnel but may also be beneficial to implementation authorities, design organisations, and other interested parties to help promote a more consistent and effective pavement asset management approach by all stakeholders.

1.1 Background

Transport Infrastructure Ireland (TII) is responsible for the operation, maintenance, and improvement of the national road network in Ireland. The network consists of national primary and national secondary roads totalling c.5,300 centreline kilometres and is made up of motorways, dual carriageways, and single lane roads. The network varies from multi-lane dual carriageways with annual average daily traffic (AADT) of c. 150,000 vehicles to single carriageways with AADT of c. 1,500 vehicles.

There is very significant variation across the network under a variety of headings, including pavement construction, pavement age, carriageway width, lane width, geometric design, and traffic volumes. Newly constructed road schemes are fully engineered with defined alignment, pavement, and drainage standards. However, a large proportion of the network consists of "legacy" roads that may have evolved from historic routes that lack clear and consistent engineering and are often constrained by physical or environmental conditions. This road network requires a complex management approach to ensure a consistent operational and asset management strategy.

TII is responsible for the maintenance and development of a diverse set of road assets that includes the most fundamental element – the road pavement. Our road pavements are predominately made of layers of flexible and flexible composite materials that are designed to be strong enough to support the loads over their lifespan (c. 20-40 years). Furthermore, the surface course must also provide adequate wet skidding resistance, acceptable ride quality, acceptable noise levels, and resist deterioration from environmental conditions. All pavements deteriorate over time as a result of traffic loading and exposure to environmental and climatic conditions. As they deteriorate, they exhibit a variety of structural and functional distress symptoms.

As part of the TII's pavement management procedures, an annual survey is undertaken of all national road pavements utilising an array of electronic, laser, and digital video equipment mounted on specialised vehicles. Year on year these surveys measure and record a range of network condition parameters including longitudinal profile/roughness, rutting, cracking, and skid resistance. Together with recorded traffic volumes, the rate of deterioration can be projected to enable a prioritisation of maintenance intervention programmes to be established based on best practice asset management principles.

1.2 TII Asset Management Overview

The strategic objectives of TII include the continued operation and maintenance of the existing transport network to ensure public safety and to optimise the use of emerging technologies to extend the life of the existing network while ensuring appropriate and sustainable management of environmental resources.

TII's Statement of Strategy establishes a commitment to protecting the significant investment that has been made in our national transport system. In line with that commitment, TII established the Asset Management Policy that states,

“Assets will be managed in a sustainable manner through the development, implementation, and maintenance of an asset management approach that is risk- based and data-driven, enabling us to make informed decisions throughout the life of our assets.”

Our policy contains six asset management guiding principles:

- Policy-driven
- Performance-based
- Founded on quality information
- Reliant on analysis of options and trade-offs
- Providing accountability and feedback
- Continual improvement

Our Asset Management Strategy builds on the Policy by introducing our role in delivering safe, efficient, and sustainable transport infrastructure and services that contribute to Ireland’s quality of life and economic growth while respecting the environment. The Strategy outlines the range of assets that are managed and their value. It describes the importance of asset management and its link to our strategic objectives and other TII, Department of Transport, and government initiatives. It also introduces the concept of life cycle planning.

The Asset Management Framework builds on the Policy and Strategy by providing the ultimate objectives that will be achieved through asset management. The Strategic Asset Management Plans (SAMPs) will provide more detailed plans on how the objectives will be achieved for light rail, local authority roads, and TII-managed and concession roads.

The SAMPs will be developed collaboratively with input from various stakeholders across all groups within TII and will consist of a review of the current state and maturity of asset management practice, and assess compliance against the overall asset management vision, guiding principles and objectives as set out in the AM Policy, Strategy and Framework. A gap analysis and improvement plan will be carried out in order to achieve the various objectives and performance measures set out in the framework.

Further Group Level Asset Management Plans (GLAMPs) will follow this for the various asset classes within TII NM such as pavement and structures. These will include more detail around asset specific performance measures and KPIs. Figure 1.1 below shows the overall hierarchy and scope of each asset management level noted above.

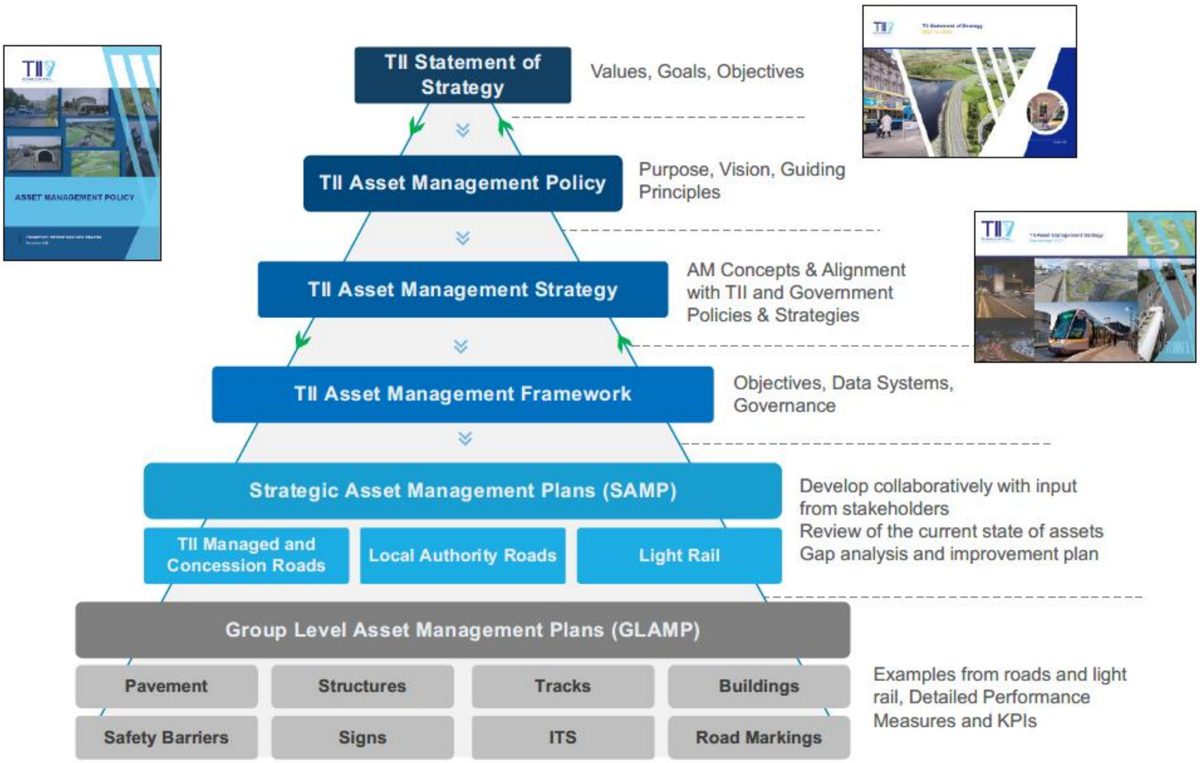


Figure 1.1 TII Asset Management Hierarchy

1.3 Functions of TII Network Management

The management of the national road network is assigned to a number of bodies with the majority share of national primary and national secondary roads being managed by local authorities. Motorways are generally managed under the motorway maintenance and renewal contracts (MMaRC) or by public-private partnership (PPP) concession companies.

The Network Management (NM) division of TII is responsible for the management and operation of the national road network including responsibility for pavement asset management and operation of the TII PAMS.

Among the key functions of TII NM include:

- Operation of the TII PAMS.
- Development and funding of annual maintenance programmes on the national road network.
- Overseeing pavement scheme design and development in accordance with TII standards.
- Undertaking site inspections and development of works programmes based on TII's skid resistance management standards and procedures.
- Liaising with implementation authorities in the delivery of annual maintenance programmes on the national road network.
- Provision of winter service operations including funding of the national winter maintenance fleet and procurement of salt stocks for roads nationally.

1.4 Pavement Protection and Renewal - Scheme Identification

'Protection and renewal' refers to maintaining the physical infrastructure of the transport network in a safe and adequate condition. A robust and continual protection and renewal plan for the existing road network is necessary to ensure that it upholds its function of providing safe and convenient travel to people and goods across the country. The key steps taken by TII NM in identification of pavement protection and renewal schemes on the national road network can be summarised as follows:

- Identify the overall need for pavement intervention
- Determine the level of funding needed
- Select feasible funding options and strategies
- Determine the impact of different options on condition and level of service
- Develop the preferred funding option and strategy
- Identify road lengths for maintenance and renewals under available funding
- Define relative priority of road section lengths in the maintenance programme within available budgets
- Identify suitable treatments

1.5 Relevant TII Publications

TII Standards and Technical Documents within the TII Publications system provide a key resource in understanding current pavement asset management practices within TII. Relevant activities and streams within the TII Publications system are described in Table 1.1.

Appendix A contains a non-exhaustive list and a brief outline of the contents of each of the relevant TII Publications grouped according to their activity and stream. For ease of reference, the list also includes a hyperlink to each of the relevant documents on the TII Publications website.

The order of these documents generally corresponds to the life cycle stages of a road pavement i.e., design, construction, assessment then maintenance. However, it must be emphasised that there is interaction between the components and that they should not generally be dealt with in isolation.

Table 1.1 Relevant TII Publication Activities and Streams

Activity and Stream	Overview
General - Pavement (GE-PAV)	Contains GE-PAV-01006 Use of Volume 7 which provides details regarding implementation of TII Publications (Standards) previously referenced under NRA DMRB Volume 7: Pavement Design & Maintenance
Planning & Evaluation – Strategic Management (PE-SMG)	Contains PE-SMG-02002 Traffic Assessment, which sets out a method for the estimation and calculation of traffic loading for the design of road pavements.
Design - Pavement (DN-PAV)	Standards for the design of road pavements and foundations, requirements and options for surfacing, advice and information on the selection and properties of bituminous mixtures and other products, footway design, requirements, and advice for using products detailed in the Specification for Works and requirements and advice for the approval of specific products not covered by a harmonised technical specification which are detailed in the Specification for Works.
Construction & Commissioning - Specification for Works (CC-SPW)	Sets out the regulations for products incorporated into national roads in Ireland for both harmonised and non-harmonised product standards. A collective group of documents containing a number of parts (previously series) which refer to specific work disciplines.
Construction & Commissioning - Notes for Guidance on the Specification for Works (CC-GSW)	Contains notes for guidance on the Specification for Works, divided into parts corresponding to those in the Specification.
Construction & Commissioning – Pavement (CC-PAV)	Includes a suite of 'Checks & Key Points' guides to provide Employer's Representatives and other interested parties with information on key aspects for the installation of bituminous mixtures, and key aspects on the delivery of schemes in relation to site documentation, traceability, sampling, storage and retention of bituminous mixtures. Other documents within this stream include a test methodology for close range photogrammetry to characterise texture in a pavement surfacing material, guidance on the methods of construction of rolling crowns and requirements for the reinstatement of openings in national roads.
Asset Management & Maintenance – Pavement (AM-PAV)	Covers pavement asset repair and renewal (PARR) scheme approval and assessment procedures, the assessment and management of skid resistance, and interim technical advice on crack sealing and joint repair systems.
Asset Management & Maintenance – General (AM-GEN)	Contains a number of technical documents in the asset management and maintenance area, including summary reports on the development of a comprehensive Asset Inventory and related Asset Valuation for the TII network.

2. Network Definition and Inventory

2.1 National Road Network

The national road network is made up of c. 5300 centreline kilometres of pavement. In total there are 66 national routes broken out into 34 national primary routes (N01-N50) and 32 national secondary routes (N51-N87), totalling c. 2650km in each designation. National primary roads form the major routes between the major urban centres. Just under 50% of national primaries are motorway or dual carriageway. National secondary roads form an important part of the national road network but are secondary to the main arterial routes. National secondaries are largely single carriageway with varying medium to low traffic volumes.

Figure 2.1 shows a map of the national primary and national secondary road network.

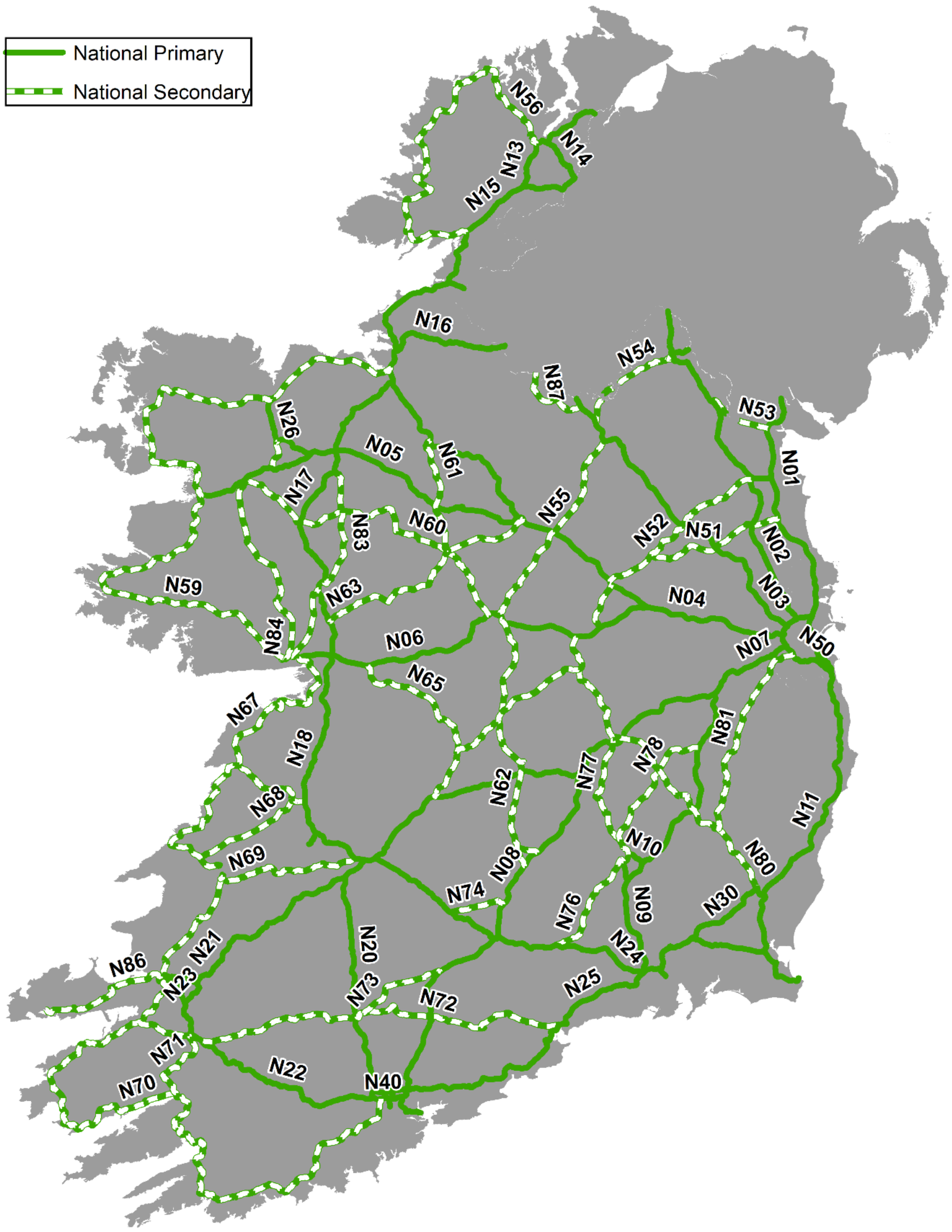


Figure 2.1 National Primary and National Secondary Road Network

Table 2.1 provides a summary of mainline routes, roundabouts, interchange elements, and link roads that make up the national road network. For further details in relation to individual route/element lengths and locations, refer to TII NM for the latest GIS Network Model.

Table 2.1 Breakdown of National Road Network by Route/Element Type

Route/Element Type	Total	
	Count (No.)	Indicative Length (km)
Mainline Routes	66	5300
Mainline Roundabouts	246	39
Interchange Elements	1368	569
Link Roads	68	31

2.2 Subnetworks

There is a very significant variation across the national road network under a range of headings, including pavement construction, pavement age, carriageway width, lane width, geometric design and traffic volumes carried. In order to effectively manage this diverse network, a series of subnetworks have been defined to considerably reduce the variation in pavement condition, traffic, and construction type within each subnetwork (subnet). Figure 2.2 shows details for each of the five subnets. Figure 2.3 shows the geographical spread of each subnet throughout the network.

Figure 2.2 Subnet Descriptions and Lengths

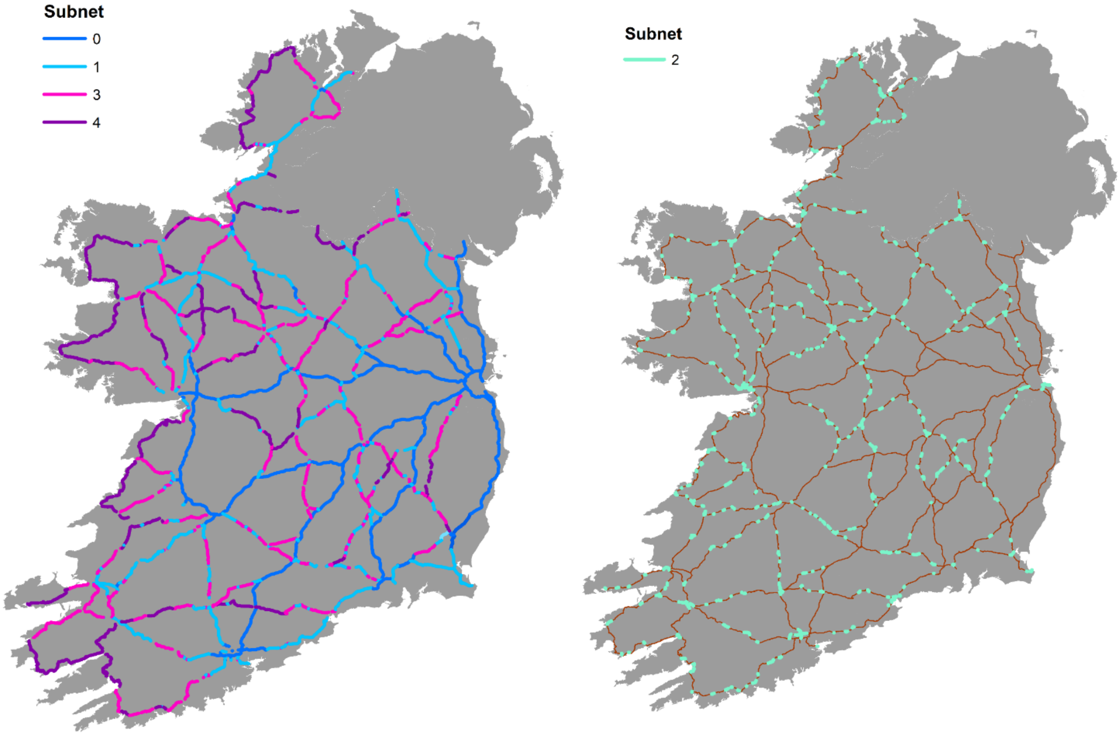


Figure 2.3 Subnets 0, 1, 2, 3 and 4

2.3 Managing Organisations

As noted above, the national road network is made up of c. 5300 centreline-km of pavement. Of this c. 4000 km is managed and maintained by 31 local authorities, c. 800 km is operated and maintained by contractors appointed by TII via the MMaRC contracts, and c.400km is operated and maintained by PPP concessionaires. Figure 2.4 shows a map of the national road network by managing organisation type.

2.3.1 Motorway Maintenance and Renewals Contract (MMaRC) Networks

In 2011, TII initiated a process under which maintenance and operation of the motorway network would be undertaken through a number of multi-annual tendered regional contracts. These contracts would encompass all activities related to the maintenance and operation of the motorways in question, including routine maintenance, winter maintenance, incident support, and renewal and improvement works. The first generation MMaRC contracts commenced in 2013. The MMaRC contracts were geographically split into three Networks (A, B and C) as described in Table 2.2.

The second generation (2G) contracts commenced in 2019. The principal change was the addition of ten Tasked Maintenance Areas (TMAs) across the network. The total route length included in the MMaRC 2G contracts is 831 kilometres. Figure 2.5 below shows the locations and extents of the three MMaRC Networks.

Table 2.2 MMaRC Network Breakdown

MMaRC Network	Core Network Length (km)	Tasked Maintenance Areas (km)	Region
Network A	173	28	Greater Dublin Area
Network B	257	34	Midlands/West
Network C	330	9	South/Southeast

2.3.2 Public Private Partnership (PPP) Schemes

TII has entered into fifteen PPP contracts which consist of eight Toll Concession Schemes, five Design Build Finance Operate Maintain ("DBFOM") Schemes, and two Motorway Service Area PPPs. Toll Concession Schemes are partly or fully financed by the private sector and remunerated by user charges (tolls) and TII payments. DBFOM Schemes are financed by the private sector and remunerated by payments from TII (termed availability payments or unitary payments). Table 2.3 below provides a description of the various PPP schemes on the network. Figure 2.5 shows the locations of the various PPP schemes on the network.

Table 2.3 National Road PPP Schemes

PPP Scheme	Description	Operations Commenced	Contract Award/ Expiry	PPP Type
M4/M6 Kilcock/Kinnegad	40km motorway	2005	2003/2033	Toll Concession
M1 Dundalk Western Bypass	11km motorway & O&M 42km existing motorway with 361m cable stay bridge	2004	2004/2034	Toll Concession
M8 Rathcormac/ Fermoy	18km new motorway with 450m viaduct	2006	2004/2034	Toll Concession Toll Concession
N25 Waterford City Bypass	23km dual carriageway with 475m cable stay bridge	2010	2006/2036	Toll Concession
N18 Limerick Tunnel	10km dual carriageway with 900m immersed tube tunnel	2010	2006/2041	Toll Concession
M3 Clonee/Kells	50km Motorway & 10 km dual carriageway	2010	2007/2052	Toll Concession
M6 Galway/Ballinasloe	56km motorway	2010	2007/2037	Toll Concession Toll Concession
M7/M8 Portlaoise/Cullahill	40km motorway	2010	2007/2037	Toll Concession Toll Concession
M50 Upgrade	Upgrade of 25km of 2+2 motorway to 3+3, Junction Upgrades and provision of auxiliary lanes / & O&M existing 10km	2007	2007/2042	DBFOM
N7/N11 Arklow/Rathnew (incl Newlands Cross)	16km new build motorway / Newlands cross junction Upgrade & O&M 30 km of existing N/M11	2013	2013 / 2040	DBFOM
N17/N18 Gort to Tuam	57km motorway	2017	2014 / 2042	DBFOM
M11 Gorey-Enniscorthy	27km motorway	2019	2015 / 2044	DBFOM
N25 New Ross Bypass	14.6km of dual carriageway with 900m bridge	2020	2016 / 2045	DBFOM

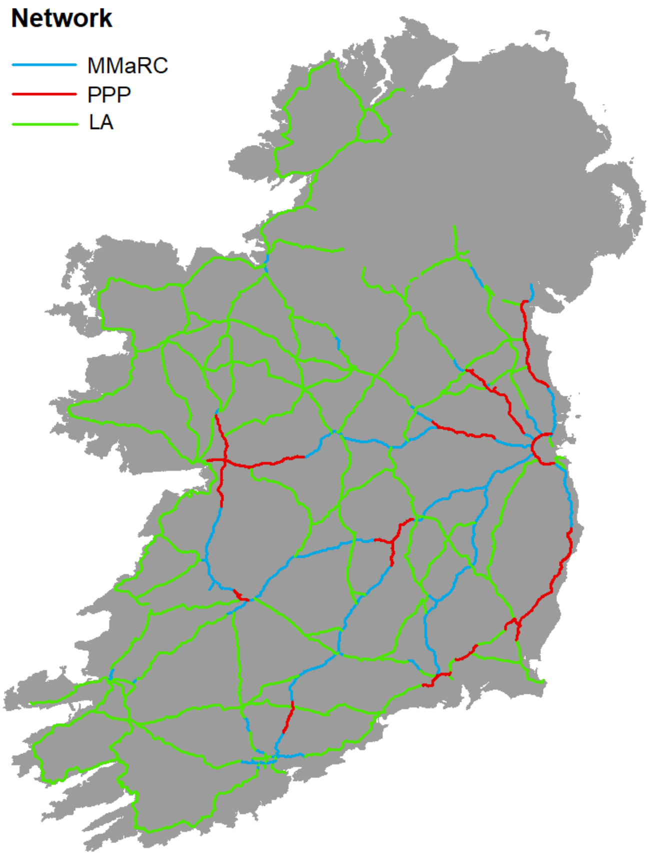


Figure 2.4 National Road Network by Managing Organisation

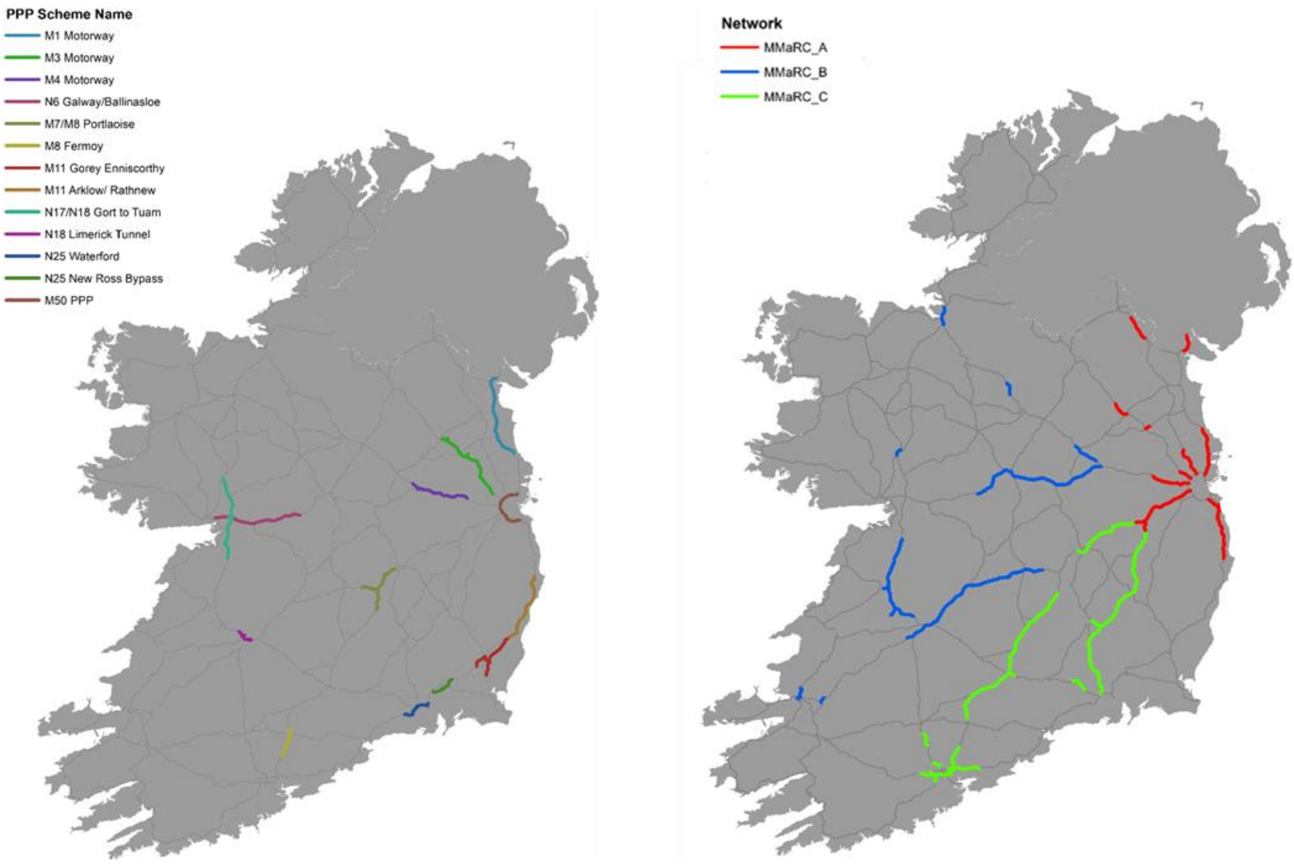


Figure 2.5 PPP Schemes & MMaRC Networks

2.4 Linear Referencing and GIS

This section outlines a Linear Referencing System (LRS) and associated GIS Network Model developed by TII to assist in the management of the national road network and associated assets. The ability to identify locations along the national road network and being able to accurately communicate this information to third parties is an essential aspect of efficiently managing the national road network.

2.4.1 Authoritative LRS and GIS Network Model

There is a need for a robust and accurate LRS in facilitating the efficient management of road network asset data. This is particularly true when management of the network is spread out over several systems. In such cases, having a single Authoritative LRS (ALRS) is a critical component in maintaining direct cross-system interoperability. TII has defined its ALRS through the GIS Network Model. The original GIS Network Model was developed in 2012 and has undergone various stages of evolution and refinement to reach its current state. TII routinely leverage the geo-spatial positional data collected as part of the annual network surveys to update the location, extents, and geometry of realignments not recorded anywhere else in TII or local authority systems.

The GIS Network Model includes all elements of the national road network including mainline carriageways, roundabouts, ramps, free flow lanes, and all associated link roads within the national road network.

2.4.2 Rule Base for Network Model

The development of a sophisticated rule base has been critical in order to split the national road network into manageable sections for the various pavement management applications. The modelling of each element type, such as mainline carriageway, roundabouts, free flow lanes etc., as well as the direction of travel has been retained through this development of a general rule base in which each element type on the network model has its own unique labelling methodology.

2.4.3 Mainline

The mainline can be defined as the ‘through route’. For national roads, it is the route along which traffic travels from route origin to route destination.

- All mainlines are modelled in each direction of travel with the geometry digitised to represent the leftmost running lane of travel and the suffix ‘ML’ is incorporated into section name.
- The direction of travel of each mainline section is indicated by the directional code ‘D1’ or ‘D2’ which is also incorporated into the section name.
- Chainage is measured in kilometres along each route and increases in the ‘D1’ direction.
- All ramps, link roads, free flow lanes, and roundabouts are modelled separately to mainline.

2.4.4 Centreline

The centreline is defined as an abstraction of the geometry representing the mainline carriageway. A centreline element has also been put in place which splits the ‘D1’ and ‘D2’ mainline elements.

- Centreline elements inherit section names from the mainline model with the suffix ‘CM’ incorporated into the section name.
- Routes which have 1-way systems in place may have a second centreline defined so that each direction of the 1-way portion has a ‘CM’ representation.

- Where a centreline representation encounters a roundabout, it joins the roundabout at the point where the zero chainage on the roundabout is.
- The primary reason for developing a centreline model of the network is to provide consistent chainage referencing for each direction of travel when deploying marker plates in the field.

2.4.5 Roundabouts

A roundabout is defined as a junction consisting of a circular one-way roadway. All roundabouts with a circumference of greater than 20 metres are modelled separately from the mainline.

- Roundabout geometry reflects the outermost lane (i.e., describing the lane with the largest circumference).
- Direction on a roundabout is always D1.
- Chainage ‘zero’ at a roundabout commences from a point perpendicular to the centre of the splitter island from the D1 approach and increases in a clockwise direction.
- The start/end of a roundabout section is the same point.

2.4.6 Ramps

A ramp is defined as any section of road that provides a link between grade separated sections of the network and where traffic movements are restricted usually at the top of the ramp by traffic controlling mechanisms (traffic lights/stop signs etc.).

- Ramps are modelled separately from the mainline.
- Ramps are recorded as single segments with ‘E’ incorporated into the section name.
- Geometry reflects the left hand/slow lane of the ramp.
- Ramps are connected to adjacent mainline geometry.

2.4.7 Free Flow Lanes

A free flow is defined as a section of road that facilitates the movement of traffic between two or more grade separated routes without requiring traffic to stop enter the new traffic stream.

- Free flow sections are modelled separately from the mainline.
- Free flows generally modelled as single segments unless they split to facilitate movements to more than one road.
- All free flows that are part of a grade separated junction incorporate ‘F’ into the section name.

2.4.8 Link Roads

A link road is defined as a short section of road used to join one road to another. Link roads usually have a ‘parent’ route which it serves and will inherit its number from the parent route.

- Link roads are modelled separately from the mainline.
- Link roads are generally modelled as single segments, unless they split to facilitate movements to more than one road, in which case both sections emanating from the split are modelled.
- All link roads incorporate ‘L’ into the section name.

A schematic representation of the TII ALRS is shown in Figure 2.6. As can be seen from the schematic diagram, each element name starts with a three-digit alphanumeric code indicating the route number, followed by the D1 or D2 directional code. Following this, all mainline elements end with the 'ML' or 'CM' suffix, while the remaining elements are assigned a two-digit code to distinguish the element type (E1, E2, L1, L2, R1, R2) as mentioned above. The final three-digits numeric code (e.g. 041, 045 etc.) relate to the overall interchange number.

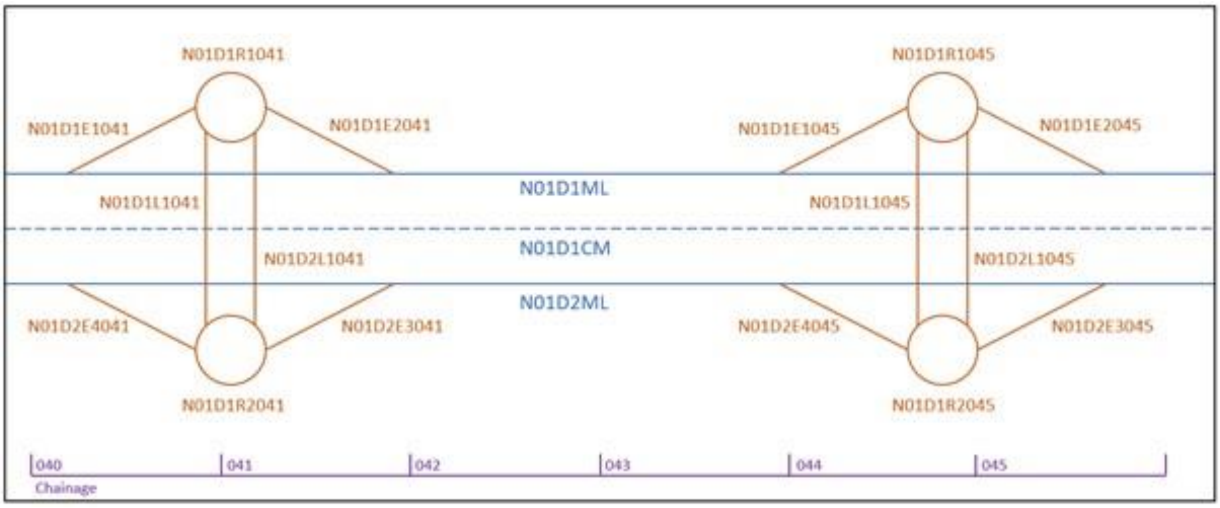


Figure 2.6 TII ALRS Schematic

2.5 Network Model and PAMS

In 2012, TII implemented a pavement asset management software system, dTIMS (Deighton Total Infrastructure Management System), and calibrated, and customised its functions for the unique requirements of the national road network. The dTIMS software system is closely related to the GIS Network Model. Included in the initial GIS-PAMS integration was the development of an Application Program Interface (API) to enable automatic transfer of data between the GIS Network Model and PAMS. For further information on the dTIMS asset management software, refer to Chapter 5 of this document.

It is envisaged that all future updates to the GIS Network Model shall be carried through the ESRI Roads and Highways architecture. ESRI Roads and Highways will preclude the need for the original API by maintaining a dynamic link between the ALRS and the other dependent models. This will facilitate the expansion to include existing or new assets which are (nominally) referenced to the ALRS. Some of the benefits of the ESRI Roads and Highways approach are:

- Single ALRS of record for the organisation
- Seamless consumption of relevant data from GIS by PAMS and other systems
- Reduced time spent on network updates
- Reduced time spent on data import/export operations
- Temporal network definition. Network models can be rolled back to review historic geometry and pavement asset status.
- This results in a modernised LRS which streamlines data management workflows, reporting functions, and provides an organisation-wide framework for data sharing and integration.

2.6 Asset Inventory (Roads)

TII Publication AM-GEN-00001 Asset Inventory (Roads) – Summary Report details the findings of a comprehensive asset inventory carried out from 2019-2020 on all national road network assets, including pavement, earthworks, structures, intelligent transport systems (ITS), signs, road markings, land area, light columns, safety barriers etc. The objectives of this project were to develop a central register of assets and valuation mechanism to assign gross replacement costs (GRC) as detailed in TII Publication AM-GEN-00002 Asset Valuation (Roads) – Summary Report.

All assets were geolocated to the TII ALRS (GIS Routes Model) and stored in an ESRI geodatabase which enabled cross asset reporting. Customised asset inventory and valuation reporting dashboards were developed using Tableau interactive data visualization software and ESRI ArcGIS Online. Table 2.4 below summarises the main pavement inventory items collated as part of this project.

Table 2.4 National Road Network Asset Inventory Pavement Data

Parameter	Data Source
Mainline Paved Width (m)	Machine based surveys and geospatial datasets
Mainline Paved Area (sqm)	Machine based surveys and geospatial datasets
Mainline Pavement Depth (mm)	GPR data
Mainline Volume of Bound Material (cubic m)	Paved Width and GPR data
Mainline Volume of Granular Material (cubic m)	Paved Width and GPR data
Interchange Pavement Area (sq. m)	OSI Prime 2 Model
Interchange Pavement & Granular Volume (cubic m)	OSI Prime 2 Model + Assumed Depths
Pavement Value (Gross Replacement Cost)	All above

3. Pavement Condition & Skid Resistance Surveys

3.1 Introduction

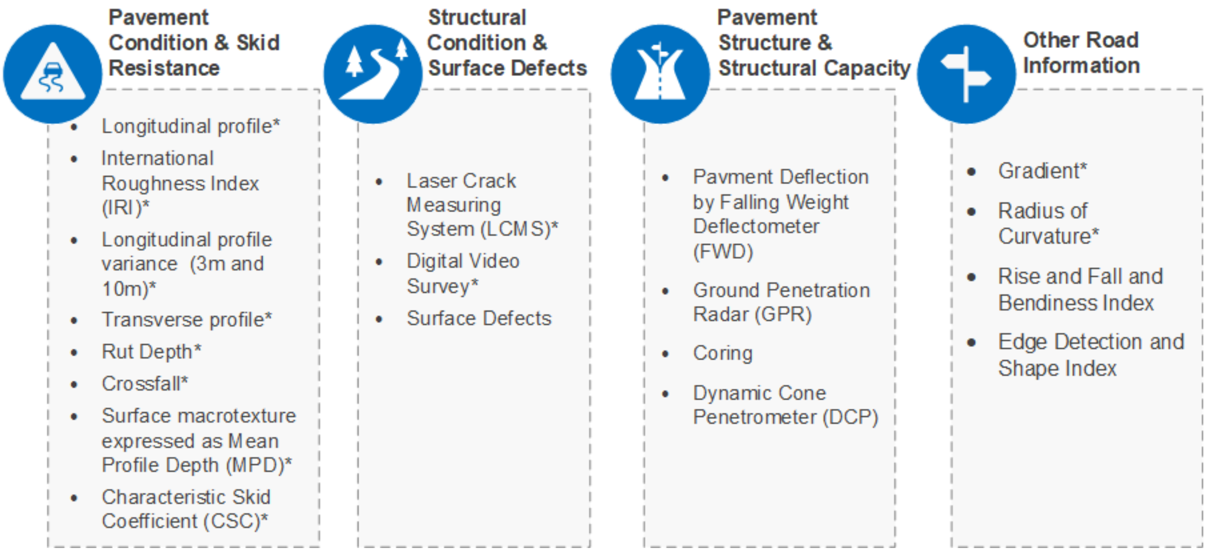
TII NM commission annual surveys for the collection of pavement condition data, digital imagery and other appropriate information and data on all sections of the national road network, inclusive of all motorways, dual carriageways, and single carriageway roads. These surveys include interchanges / junctions, merge and diverge ramps, circulatory elements of roundabouts and all associated link roads within the national road network. The purpose of these surveys is to enable TII to record, monitor, and understand the shape and condition of the pavement asset.

In addition to the annual surveys noted above, TII may also commission surveys including Falling Weight Deflectometer (FWD), Pavement Coring, Dynamic Cone Penetrometer (DCP) and Ground Penetrating Radar (GPR) to be carried out on whole lengths or sample lengths of the road network in accordance with AM-PAV-06050.

These surveys enable TII to plan and undertake maintenance programmes on the national road network using the TII Pavement Asset Management System (PAMS). Further details and examples of the available survey data within the TII PAMS are provided in Annex A of AM-PAV-06050.

3.2 Survey Types

Figure 3.1 lists the various surveys for the collection of all the pavement data required by TII NM. These surveys are further described in Section 3.3.



*Survey parameters denoted with an asterisks * are typically collected and reported on the full network annually.*

Figure 3.1 Pavement Survey Data

3.3 Survey Requirements

All surveys and associated testing operations to collect the data associated with the annual programme of investigation for national roads are generally undertaken on requisite sections of the national road network annually during the testing season (1st May to 30th September).

Single carriageway roads are generally surveyed in the left-hand lanes in one direction each year and in the opposite direction on alternate years.

Dual carriageways and motorways are surveyed in the left-hand lane in both directions every year. Roundabouts on the national road network are surveyed annually in the outermost lane where safe to do so.

Interchanges, including roundabouts within the interchange, junctions, and associated link roads within the national road network are surveyed every two years in all directions. The survey lane for interchanges is the left-hand lane only. Additional road sections may be included in the annual programme of investigation (e.g. MMaRC task maintenance areas), as required by TII NM.

Survey machines that include laser measurement systems may be affected by the amount of water present on the road surface. When the road is damp or wet, this can adversely affect the accuracy of the data or the quality of the survey images. Surveys that include laser measurements are only performed when the road is dry, i.e., road surface is neither damp nor wet, and not in the direction of a low sun. Measurements made with these systems may generally be considered unreliable when the road is damp or wet.

All traffic-speed surveys are performed at the prevailing traffic speed and should not influence traffic flow. The national road network has a range of route lengths. A route may be surveyed continuously. If a route is surveyed in sections, the surveys should be overlapped, and all relevant information to enable the data from the overlaps to be edited efficiently should be recorded.

The surveys are carried out in the direction of normal traffic flow and any deviations from the survey route should be recorded. Survey data collected during deviations from the survey route is considered invalid.

Where features placed in or on the road surface for the purposes of traffic control (e.g. speed humps and traffic "chicanes") are present, their location in the survey data should be recorded. Any of the parameters of the survey data that are affected by these features (for example longitudinal profile) will be marked as invalid.

The coverage achieved in the surveys should be monitored. Invalid measurements will result in reduced survey coverage, where coverage is defined as the total length within any predetermined length over which valid measurements are provided.

Any pavement condition data derived from any new measuring system is required to be satisfactorily correlated and compatible with the existing survey data to ensure continuity of condition criteria and performance monitoring of the national road network, subject to the approval of TII NM. For further information in relation to the pavement condition survey requirements refer to the latest TII network survey contract.

3.4 Referencing Data to the Network

Each measurement collected during a survey is accurately referenced to the road network using a combination of 3-dimensional spatial coordinates using the Irish Transverse Mercator (ITM) Grid Coordinate system, and elapsed distance using an accurate distance-measuring instrument (DMI).

3.4.1 3-D Spatial Coordinates

The survey vehicles are equipped with a global navigation satellite system (GNSS) so that all recorded data is referenced to 3-dimensional spatial coordinates. The GNSS equipment is typically integrated with an inertial measurement system in order that ITM co-ordinates can be derived from the GNSS data irrespective of the quality of the satellite coverage.

The GNSS equipment must have the capability to compensate for signal loss (e.g., encountered in urban and forested areas) such that the coordinates are provided under all survey conditions to the required level of accuracy.

Measurements shall include the 3-D spatial coordinates of the equipment position during the survey at points separated by no more than 5m of longitudinal distance travelled. The coordinates must be reported in meters.

Reports shall include the 3-dimensional spatial coordinates using the Irish Transverse Mercator (ITM) Grid Coordinate system and the altitude of the surface of the road being surveyed.

3.4.2 Elapsed Distance

All survey vehicles are to be equipped with an accurate distance-measuring instrument (DMI) which is calibrated and maintained throughout the testing season so that all measured data is referenced to a longitudinal position on the road to an accuracy of 0.1% or better from the start location of that survey. This accuracy must not be affected by the survey vehicle speed, or the road geometry.

All data measured shall be referenced to its longitudinal position or distance on the network in relation to the survey and the network section, in units of metres, to a resolution of 1mm.

3.5 Pavement Condition Parameters

Table 3.1 provides details and references to further information on the various pavement condition parameters currently collected on the network using the Road Surface Profilometer (RSP). For ease of reference, the Document column includes a hyperlink to the document on the TII Publications website. Note: It is the user's responsibility to ensure that the latest version of the document is referred to. The specific reference should also be considered in the context of the entire TII Publication.

Table 3.1 Pavement Condition Data Parameters

Pavement Condition Parameter	Document	Document Section	Specification Requirements
International Roughness Index - IRI	AM-PAV-06050	Appendix A.4.1	EN 13036-6 EN 13036-5
Longitudinal Profile Variance - LPV (3m and 10m)	AM-PAV-06050	Appendix A.4.1	EN 13036-6 EN 13036-5
Rut Depth	AM-PAV-06050	Appendix A.4.2	EN 13036-6 EN 13036-8
Crossfall	AM-PAV-06050	Appendix A.4.2	EN 13036-6 EN 13036-8.
Surface Macrotexture - Mean Profile Depth (MPD)	AM-PAV-06050	Appendix A.4.3	ISO 13473-1

3.5.1 Longitudinal Profile

The profilometer must meet the requirements of ASTM E950 Class 1 requirement for measurement of longitudinal profile and meet its associated classification in accordance with EN 13036-6. The survey should be performed at or slightly below the prevailing traffic speed of the road and within the range of the equipment manufacturer's specifications. The accuracy of the measured longitudinal profile must be unaffected by the profile of the pavement over the full range of profiles that can reasonably be expected to be encountered on the road network. The wavelength range of the longitudinal evenness parameters below shall be limited to 0.5m to 50m in accordance with EN 13036-5.

3.5.2 International Roughness Index (IRI)

Road roughness has been defined as the changes 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' 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.

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 a significant correlation between IRI and the maximum speed at which a road user is comfortable while driving on the road in question. There are also well-established relationships between IRI and road user costs.

The IRI is calculated from the longitudinal profile following the procedure described in EN13036-5 for left and right wheel paths. The IRI for each wheel path is delivered and reported at 10m intervals together with its average IRI at 10m intervals. The 100m average IRI is also reported.

3.5.3 Longitudinal Profile Variance (LPV)

In addition to IRI, the RSP longitudinal profile output is used to calculate the 3 metre and 10 metre longitudinal profile variance. Essentially, the LPV is used to identify locations with distress that causes short wavelength ride problems for the driver. Examples would be bumps and sags, potholes, and poor utility trench reinstatements. This parameter, in conjunction with the IRI parameter which examines vehicle response over a wider range of wavelengths, is used to measure the ride quality of the pavement from the user's perspective.

The 3m LPV and 10m LPV parameters are calculated from the longitudinal profile using wave band analysis as described in and in accordance with EN 13036-5 for left and right wheel paths. The 3m LPV and 10m LPV for each wheel path are reported at 10m intervals together with its average. The 100m average of the 3m LPV and the 10m LPV are also reported.

3.5.4 Transverse Profile

The transverse profiling measurements are carried out simultaneously using the same profilometer used in the longitudinal profiling measurement. The profilometer must also comply with the requirements in EN 13036-6 for transverse profiling. The measurement of transverse profile should be continuous using a non-contact laser system. The survey should be performed at or slightly below the prevailing traffic speed of the road and within the speed range in the equipment manufacturer's specifications.

3.5.5 Rut Depth

Rutting in the wheel path is a structural distress induced by heavy vehicle traffic. Rutting is identified as a permanent longitudinal deformation of the pavement, creating channels in the wheel paths. It is caused by the consolidation or lateral movement of material under repeated traffic loading, inadequate compaction of the pavement layers during construction or inadequate thickness of pavement layers.

The rut depth is calculated in accordance with EN 13036-8 for left and right wheel paths from the transverse profile. The rut depths for each wheel path are delivered and reported at 10m intervals together with its average rut depth at 10m intervals. Average rut values in millimetres (mm) are also obtained and reported for each 100 metre length. Prior to calculation of rut depth, an additional step is carried out to identify and remove road edge features (e.g., kerbs) that could affect rut depth results.

3.5.6 Crossfall

Crossfall is defined as the angle between the horizontal and the regression straight line through the transverse road profile fixed by at least seven measurement points across that profile. Crossfall is calculated according to EN 13036-8 and reported in [%] and degrees.

3.5.7 Surface Macrotexture

The macrotexture or surface texture of the pavement surface refers to the coarser texture defined by the shape of the individual coarse aggregate particles used in the surface course mix, and by the spaces between the individual aggregate chips. Macrotexture is the major influencing factor on frictional resistance at higher speeds (>50km/hr) and is particularly important in relation to wet conditions. The macrotexture provides the drainage channels for rainwater to escape to allow the vehicle tyre maintain greater contact with the pavement surface, in particular at high speeds.

Macrotexture is determined as Mean Profile Depth (MPD) calculated in accordance with ISO 13473-1 (Characterisation of pavement texture by use of surface profiles – Part 1: Determination of Mean Profile Depth). The MPD is expressed in millimetres at every 1-metre interval as measured continuously in the near side wheel path by a profilometer with a non-contact laser system that meets the requirements of ISO 13473-1. The MPD is typically reported at 10m intervals in MS Access or ASCII-delimited format.

3.6 Skid Resistance

Measurements of the in-service skid resistance of the national road network are made using Sideway-force Coefficient Routine Investigation Machine conforming to requirements of National Standards Authority of Ireland (NSAI) Standard Recommendation S.R. CEN/TS 15901-6. “Road and airfield surface characteristics – Part 6: Procedure for determining the skid resistance of a pavement surface by measurement of the sideway force coefficient (SFCS): Sideway-force Coefficient Routine Investigation Machine” and carried out in accordance with AM-PAV-06045, Skid Resistance Assessment.

Before the in-service skidding resistance surveys are conducted on the national roads each year, a certificate from TRL (Transport Research Laboratory), confirming that the SCRIM machine to be used in the surveys performed within the set limits of the Annual Accreditation Trial for that year must be provided. The Sideway-force Coefficient Routine Investigation Machine identified in the certificate must be used for all surveys in that year.

A control benchmark sites covering a range of Sideway-force Coefficient (SFC) values must be identified. The purpose of the control benchmark site is to ensure consistency of results over the testing period. The selected site must conform to the general requirements in NSAI S.R. CEN/TS 15901-6. The site must be surveyed immediately following the Annual Accreditation Trial to establish baseline data and to evaluate the repeatability of the equipment. The site must be surveyed at the beginning and end of each survey cycle or at least twice weekly in the case of a continuous survey programme. The control site data must be checked to ensure that the machine is measuring SFC accurately and that the DMI and GNSS equipment are performing within specifications.

Prior to the start of the annual survey, test tyres conforming to the specification in NSAI S.R. CEN/TS 15901-6 must be run in on the control benchmark site and only tyres which fall within an agreed range are to be subsequently used in the surveys. This data must be approved by TII NM prior to starting the annual survey.

The SFC data collected is from the near side wheel path of the left-hand lane surveyed in the direction of travel unless otherwise specified. Occasionally, it is required for measurements to be carried out in both wheel paths. The survey equipment, therefore, must be capable of measuring the SFC in both wheel paths. Only machines fitted with Dynamic Vertical Load Measurement system shall be used.

The collected data in terms of Characteristic Skid Coefficient (CSC) are to be provided in accordance with AM-PAV-06045 including adjustment for seasonal variations for each 10-metre length with full location references.

Table 3.2 outlines the process for the assessment of skid resistance on the national road network including references to the relevant document section within AM-PAV-06045 and associated deliverable and responsibility for each stage. For ease of reference, the Document column includes a hyperlink to the document on the TII Publications website. Note: It is the user's responsibility to ensure that the latest version of the document is referred to. The specific reference should also be considered in the context of the entire TII Publication.

Table 3.2 Process for the assessment of skid resistance

Stage	Document	Document Section	Deliverable	Responsibility
Skid Resistance Measuring Equipment				
Measurement Equipment	AM-PAV-06045	Sec 3.1	Evidence of satisfactory performance at Annual Accreditation Trial arranged by TRL	Service Provider
Location Referencing	AM-PAV-06045	Sec 3.2	Confirmation that equipment meets TII Specifications	Service Provider
GPS Recording Equipment	AM-PAV-06045	Sec 3.3	Confirmation that equipment meets TII Specifications	Service Provider
Digital Video	AM-PAV-06045	Sec 3.4	Confirmation that equipment meets TII Specifications	Service Provider
Skid Resistance Measurement and Data Processing				
Background Information	AM-PAV-06045	Annex 1		
Determine the Survey Strategy	AM-PAV-06045	Sec 4.2 & Annex 2	Control benchmark site data and summary report	TII / Service Provider
Plan Surveys	AM-PAV-06045	Sec 4.3		Service Provider
Conduct Surveys	AM-PAV-06045	Sec 4.4		Service Provider
Process Survey Data	AM-PAV-06045	Sec 4.5		Service Provider
Check Survey Coverage	AM-PAV-06045	Sec 4.6	Monthly Report	Service Provider
Apply Seasonal Correction	AM-PAV-06045	Sec 4.7 & Annex 2	Corrected Skid Resistance Data	Service Provider
Site Categories and Investigatory Levels				
Identify Sections for Review	AM-PAV-06045			Service Provider / TII
Assign Site Category and IL	AM-PAV-06045	Annex 3		Service Provider

3.7 Structural Condition and Surface Defects

Table 3.3 provides details and references to further information on various structural condition surveys collected as part of the annual network surveys and surface defect types contained in AM-PAV-06050. For ease of reference, the Document column includes a hyperlink to the document on the TII Publications website. Note: It is the user's responsibility to ensure that the latest version of the document is referred to. The specific reference should also be considered in the context of the entire TII Publication.

Table 3.3 Structural Condition Surveys and Surface Defect Types

Structural Condition Survey/Type	Document	Section
Laser Crack Measurement System (LCMS)	AM-PAV-06050	Appendix A.3.2
Digital Video Survey	AM-PAV-06050	Appendix A.3.3
Cracking	AM-PAV-06050	Appendix A.4.4 & G.3
Ravelling, Bleeding	AM-PAV-06050	Appendix G.1
Pavement Deformation, Rutting, Surface Distortion	AM-PAV-06050	Appendix G.2
Patching	AM-PAV-06050	Appendix G.4
Potholes	AM-PAV-06050	Appendix G.5
Road Disintegration	AM-PAV-06050	Appendix G.6

3.7.1 Laser Crack Measuring System (LCMS)

The LCMS is a high-speed and high-resolution transverse profiling system. The LCMS uses laser line projectors, high speed cameras, and advanced optics to capture high resolution 3D downward-facing images of the road.

The downward-facing images from LCMS should cover a minimum width of 3m and a maximum width of 4m. The width covered by the downward-facing cameras should be chosen according to the predominant lane width of the road network to be surveyed. The evaluation is restricted to the actual lane width of road surveyed to prevent the inclusion of defects located in the adjacent lane(s).

The downward-facing images should cover a minimum length of 3m and a maximum length of 10m in longitudinal direction. The minimum resolution in the vertical direction shall be 0.5 mm or better. The accuracy of the vertical measurement shall be 1 mm or better. The minimum ground resolution per pixel in longitudinal direction is 1 mm or better. The minimum ground resolution per pixel in transverse direction is 1 mm or better.

The resolution, distortion and focus of the images, and evenness of the lighting system should not be affected by ambient light levels expected to occur commonly during survey, nor for the range of appropriate survey speeds.

The analysis of the images is carried out across the full lane width. When reporting, the lane is divided into 5 equal bands, where Bands 1 and 5 represent the left and right outer bands, respectively; Bands 2 and 4 represent the left and right wheel paths, respectively; and Band 3 represent the area between the wheel paths in the direction of travel. The defects are reported in 10m interval images within the band that defects are located. The data is subsequently quantified and analysed into each defect description and in the case of cracking, its crack severity.

3.7.2 Digital Video Survey

A video survey of the national road network is undertaken using a forward-facing video camera. The video survey is primarily focused on centreline of the driving lane but also captures much of the adjacent lanes, shoulders, ditches, barriers, signage etc. The data provider must ensure that good quality imagery is provided at all times.

Imagery is typically captured at 5 metre intervals across the network. Every image is georeferenced. The imagery may be provided as a video or a set of still images. All imagery is uploaded to the TII data lake at the end of the survey cycle.

The imagery is also uploaded to the UBIPix platform (https://tii-pam.ubipix.com/). UBIPix provides an online integrated mapping/media browser display. The user can visualise and interact dynamically with the georeferenced imagery by controlling play-back, tagging, performing spatial queries and sharing with other interested parties. An example of the UBIPix interface is shown below.

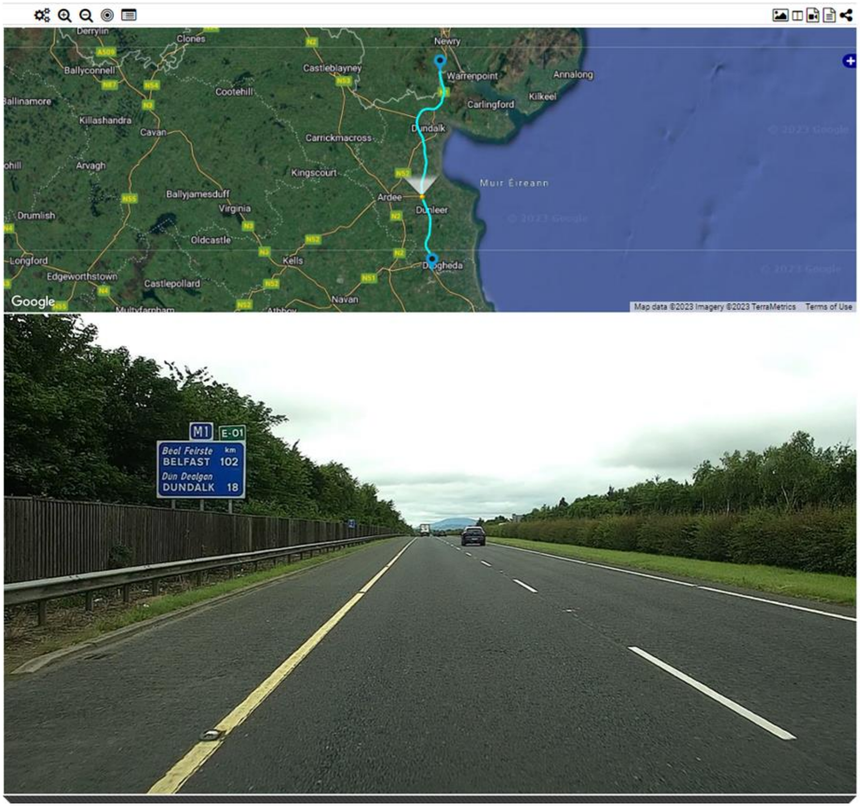


Figure 3.2 Example of the UBIPix interface

3.7.3 Surface Defects

Surface defects can be obtained from analysis of images of the pavement surface using both 3D downward-facing cameras, such as the Laser Crack Measuring System (LCMS) and Digital Video Survey from forward-viewing surface-oriented digital cameras as described in Appendix A of AM-PAV-06050. The data collection to enable surface defect identification is collected at the prevailing traffic speed of the road. The frequency distribution of surface defects is based on data representing individual 10m sections. The pavement features and defects that can be identified and reported are shown in Table 3.4 below.

Table 3.4 Definition of Pavement Feature and Defects

Feature / Defect		Definition
Cracking	Transverse	Cracks that run perpendicular to the pavement centreline, but are not over an underlying joint in a concrete pavement
	Longitudinal	Cracks that run parallel to the pavement centreline, but are not over an underlying joint in a concrete pavement
	Alligator	Interconnected cracks forming small, many-sided, sharp-angled polygons resembling chicken wire or the skin of an alligator. Caused by fatigue failure of the surface due to traffic loading and inadequate base or subgrade support
Delamination/ Ravelling / rutting		Area of pavement surface missing due to the loss of adhesion between the surface course and underlying layer. Ravelling is progressive loss of binder and aggregate chippings from the pavement surface. Rutting is a permanent longitudinal deformation due to the displacement of material in the wheel paths caused by traffic loading creating channels in the wheel paths.
Bleeding / Fatting		The presence of excessive bituminous material on the pavement surface. Fatting is due to embedment (in surface dressings) or loss of texture in the surface with binder filling the voids. Bleeding is often due to low viscosity binder being forced to the surface by the action of water and binder stripping.
Pothole		Bowl shaped hole in the pavement surface which may extend through more than one pavement layer
Edge Erosion		Area at the outer edge of the carriageway that has fallen away or collapsed. Caused by inadequate pavement width, inadequate lateral support to the pavement, moisture penetration, poor drainage, or frost action. Accelerated by repeated traffic loading
Patching		Areas of the pavement that have been removed and replaced with new material to repair the original pavement, or other defects
Trench		Lengths of the pavement that have been removed and replaced due to the addition of utilities below the pavement parallel to the pavement centreline
Sealed Crack		Crack which has been repaired using liquid bitumen to prevent water ingress
Joint	Longitudinal	Joint between two pavement surfaces parallel to the pavement centreline
	Transverse	Joint between two pavement surfaces perpendicular to the pavement centreline

3.8 Pavement Structure & Structural Capacity

Table 3.5 below provides a list and references to further information on pavement structure and structural capacity site investigation methods undertaken on selected parts of the road network identified by TII, in accordance with AM-PAV-06050. For ease of reference, the Document column includes a hyperlink to the document on the TII Publications website. Note: It is the user's responsibility to ensure that the latest version of the document is referred to. The specific reference should also be considered in the context of the entire TII Publication.

Table 3.5 Pavement Structure & Structural Capacity Investigation Methods

Survey/Test Method	Document	Document Section
Falling Weight Deflectometer	AM-PAV-06050	Appendix B
Coring	AM-PAV-06050	Appendix C
Dynamic Cone Penetrometer	AM-PAV-06050	Appendix D
Ground Penetrating Radar (GPR)	AM-PAV-06050	Appendix F

3.8.1 Pavement Deflection by Falling Weight Deflectometer (FWD)

The measurement of pavement deflection by Falling Weight Deflectometer (FWD) is carried out in accordance with Appendix B of AM-PAV-06050. FWD surveys are carried out on whole lengths or sample lengths of the pavement in need of structural investigation. During FWD testing a load is applied by dropping a constant mass with rubber buffers from a height via a loading plate, normally a 300 mm diameter loading plate.

The target load for analysis on National Road sections is normally 40 kN. The resulting vertical deflections of the pavement are recorded by seven geophones which are located on a radial axis from the loading plate at standard spacing of 0, 300, 600. 900, 1200, 1500, 1800 mm from the centre of the load plate. A drop sequence of three drops should be carried out at each test location ranging from 27 N to 40/50 kN to allow analysis to be carried out at the required load. The FWD is static during testing and requires appropriate traffic management during the survey. The FWD survey is typically run at a 25 m interval, or a 50m interval staggered across adjacent lanes.

3.8.2 Ground Penetration Radar

Ground Penetration Radar (GPR) is used to determine the pavement structure and is the only viable technique in determining pavement structure at traffic speed. GPR surveys may be supplemented by intrusive testing by coring. For pavement structural evaluation, the following three key parameters are derived from GPR measurements:

- Location of changes in construction
- Material thickness
- Material type

GPR measurements are collected along the line of the nearside wheel path. Appropriate antennae are used to achieve a minimum layer thickness resolution of 20 mm within the top 500 mm of the pavement. Appropriate antennae are used to achieve penetration of 1500 mm for lower layers. A combination of different frequency antennae may be needed to achieve both minimum layer resolution and minimum penetration requirements.

Raw data collected is saved in digital format on the collection device. Longitudinal cross-sections of the site must be displayed in a report detailing location and depth. Graphs must show all individual layers and colour code them with a legend display. The material type collected from GPR data are reported in terms of the generic classifications of pavement engineering materials (e.g. asphalt, concrete or granular materials) rather than the more detailed descriptions such associated with asphalt mix (e.g. AC, HRA or SMA). However, for core samples, the thickness of each material layer is reported.

3.8.3 Coring

Coring may be required to supplement the information generated by GPR, to verify material thickness, and to determine the material type of each layer. Core samples may also provide information as to the extent of pavement deterioration when taken at locations where such deterioration had occurred.

Cores may also show defects within the bound layer such as poor compaction, delamination between layers and ‘stripping’ of the asphalt binder away from the aggregate. These defects are noted in the core log.

Core locations are targeted based on a review of the GPR survey and other pavement surveys. Core sampling is carried out in accordance with EN 12697-27 (Bituminous mixtures – Test methods for hot mix asphalt – Part 27: Sampling). The number, interval, and target locations of cores to be taken is to be agreed with TII, however care should be taken to:

- Avoid junctions or other locations where it would be difficult to arrange a lane closure.
- Avoid bridge decks and other non-pavement features.
- Target locations from the GPR data which are representative of the section to be interpreted.
- Choose locations where the material boundaries in the GPR data are relatively flat to minimise the effects of errors in the location referencing of the GPR and core data.

The procedure in determining the core sample thickness is to be in accordance with section 4 of EN 12697-36 (Bituminous mixtures – Test methods for hot mix asphalt – Part 36: Determination of the thickness of a bituminous pavement. Core holes are to be reinstated in accordance with the CC-SPW-00900 (Specification for Road Works Series 900 – Road Pavements – Bituminous Materials) cl. 10.1.14. The location of all changes in construction (evident either on or below the surface) are reported where there is a change of material type. The thickness of each material layer is reported for core samples.

3.8.4 Dynamic Cone Penetrometer

Dynamic Cone Penetrometer (DCP) as described in Appendix D of AM-PAV-06050 is the default method for use in the bottom of core holes and trial pits to measure the strength and thickness of the foundation layers including formation and sub-formation.

The DCP uses an 8kg hammer dropping through a height of 575mm and a 60° cone having a maximum diameter of 20mm. The strength of the material is assessed on the rate of penetration per drop or “blow. Normally two or three people are needed to complete the test. One holds the apparatus by the handle while the same or second person lifts the drop weight. The second/third observes the readings and records them on the appropriate form. The strength of the foundation layers is expressed in equivalent California Bearing Ratio (CBR) values. If required, the Subgrade Surface Modulus estimated from the CBR value can also be reported.

3.9 Surveys for Other Road Information

Other road information collected during the longitudinal and transverse profile survey includes:

- Gradient
- Radius of curvature
- Rise and Fall (m/km)
- Bendiness Index (degrees/kilometre)
- Edge detection and shape index parameters.

All calculated parameters are reported at 10 metre intervals and delivered to TII in MS Access or ASCII-delimited format.

4. Data Management

TII NM oversee the control and management of a significant quantity of pavement condition data collected on the national road network annually. TII NM commission a Service Provider to manage the data from annual pavement condition surveys which includes the validation, storage, processing, and security of all raw and processed survey data files.

4.1 Data Validation

As part of the annual network pavement condition surveys, the Service Provider implements procedures for the validation and quality assessment of survey data throughout the survey period. A team of dedicated engineers and technicians review and quality assess the incoming pavement condition data on a weekly basis under the supervision and direction of the project manager. Any issues arising from the data validation process are notified immediately to the project manager so that repeat surveys can be arranged without delay, where required.

4.2 Data Storage

4.2.1 Introduction

The Service Provider implements procedures for the storage of both raw and processed network survey data. This includes the storage of imagery and pavement condition data collected and processed from the SCRIM, RSP, GPR and LCMS survey equipment. On average, c.6 million individual data files totalling over 6TB is collected and stored for the annual network survey each year.

The Service Provider currently implements two methods of securely storing data. One method is where the data is stored on a main server and readily available if needed and the other method is where the data is archived on removable devices which means it is not as accessible but, can be extracted and reviewed on request. Data backup procedures are implemented to protect against the loss of data and facilitate rapid recovery from an emergency. TII NM oversee storage of data in a format that allows it to be readily available for further interrogation and analysis, if required.

4.2.2 TII Data Lake - Cloud Storage

TII is in the process of developing a data management strategy which will aim to accomplish governance and centralisation of all TII owned data. Under this strategy, TII require that all data owned and collected on their behalf shall be uploaded to a centralised TII data lake facility hosted by Amazon Web Services (AWS). The TII data lake will function as the central data repository for each of the existing TII data management systems.

All data collected as part of the annual pavement condition survey will be uploaded by the Service Provider to the TII data lake at the end of each survey year. The data lake is not intended to act as the data management system but rather a central repository of the latest backed up datasets from the various management systems which will enable control and governance of TII owned data into the future.

4.3 Data Processing

The Service Provider manages and processes significant volumes of data annually. All processing of data is typically carried by the Service Provider using fully customisable and proprietary data analysis software which facilitates clear interrogation and interpretation of data.

Data processing is typically carried out in weekly batches to ensure any issues arising from survey data are identified and rectified at an early stage.

All analysis software is fully customisable to meet any future demands of TII. Data processing operations are scalable and designed to maximise efficiency and output directly to the required formats, with automated generation of maps, charts, and data.

4.4 Data Security

TII NM require a data Security Management Plan which is structured in accordance with ISO-27000 series and ISO-17025. The Security Management Plan must be structured to ensure that the confidentiality, availability and integrity of the data is maintained throughout. The Service Provider shall develop this plan in collaboration with TII. TII NM require that any information received, stored, and distributed is:

- Traceable to a verifiable source authorised by TII NM
- Protected from error and unauthorised modification; and
- Available only to persons or organisations authorised by TII NM

TII NM require data servers that are secured in line with best practice to ensure the integrity of all the data and information held within it. Data must be shared appropriately with the correct permissions assigned to the users and is protected from unauthorised access. This not only ensures that the data remains secure and safeguarded from tampering or loss, but it also improves access to the data and overall performance. TII NM require data storage platforms which schedule both replication and backups of virtual machines, providing a reliable basis for backup and recovery and allowing TII to have access to servers in the event of hardware failures.

4.5 Data Confidentiality

To comply with current data protection legislation the Service Provider, as data processors, managing data on behalf of TII (the data controllers), must implement a policy which keeps track of all data stored, requested, and released, under the instruction of TII.

This policy shall be documented and summarised within a flowchart clearly delineating the process and hierarchy upon which data shall be requested, approved, and released under instruction of the data controller. This policy should also clearly set out the level of permission each party is afforded in relation to accessing, modifying, and releasing data from initial data collection to data processing and reporting stage. The Service Providers must also engage with TII NM in a data protection agreement which ensures the confidentiality and security of all data processed by them on behalf of TII.

4.6 Data Structure and Formats

TII NM recognise the importance of an appropriate and consistent data structure and file naming convention, particularly when integrating multiple datasets within the PAMS (dTIMS) system. Accordingly, TII NM have implemented a data dictionary system for managing data collected as part of the annual network survey. The current set of data dictionaries for the various survey types are contained in Appendix B.

The processed datasets for the various survey types are typically supplied in an ASCII-delimited format (CSV) with a standard file naming convention of the form: TII_Survey Type_Year_Element Type_Reporting Interval_Version No.

For example *TII_RSP_2022_ML_100m_v1.0.csv* contains the mainline RSP data for 2022.

The various survey types, element types and reporting intervals are listed in Table 4.1.

Table 4.1 Processed Data Filename Attributes

Filename Attribute	Values	Description
Survey Type	RSP SCRIM LCMS GPR	Road Surface Profiler Sideway-Force Coefficient Routine Investigation Machine Laser Crack Measurement System Ground Penetrating Radar
Element Type	IC ML RB	Interchange Mainline Roundabout
Reporting Interval	10m 100m	10m Reporting Interval 100m Reporting Interval

4.7 Video Image Formats

The Service Provider shall provide video and image survey data of the Network as per requirements in Chapter 3.

4.8 Programme for Data Delivery

Delivery of all processed data relating to the annual network surveys carried out during the testing season is normally required by 1st November of the same year.

5. Pavement Asset Management Software

5.1 Introduction

The pavement asset management software is a critical component of the overall Pavement Asset Management System (PAMS). The PAMS software currently used in TII is dTIMS (Deighton Total Infrastructure Management System). The system has been in use in TII since 2011 and is primarily used to produce multi-annual pavement rehabilitation and maintenance programmes as well as being the data repository for all pavement condition information. This chapter presents an overview of the TII dTIMS software implementation. Figure 5.1 below shows a schematic of the TII dTIMS workflow. For a detailed explanation of specific elements of the software usage refer to the TII dTIMS BA user manual.

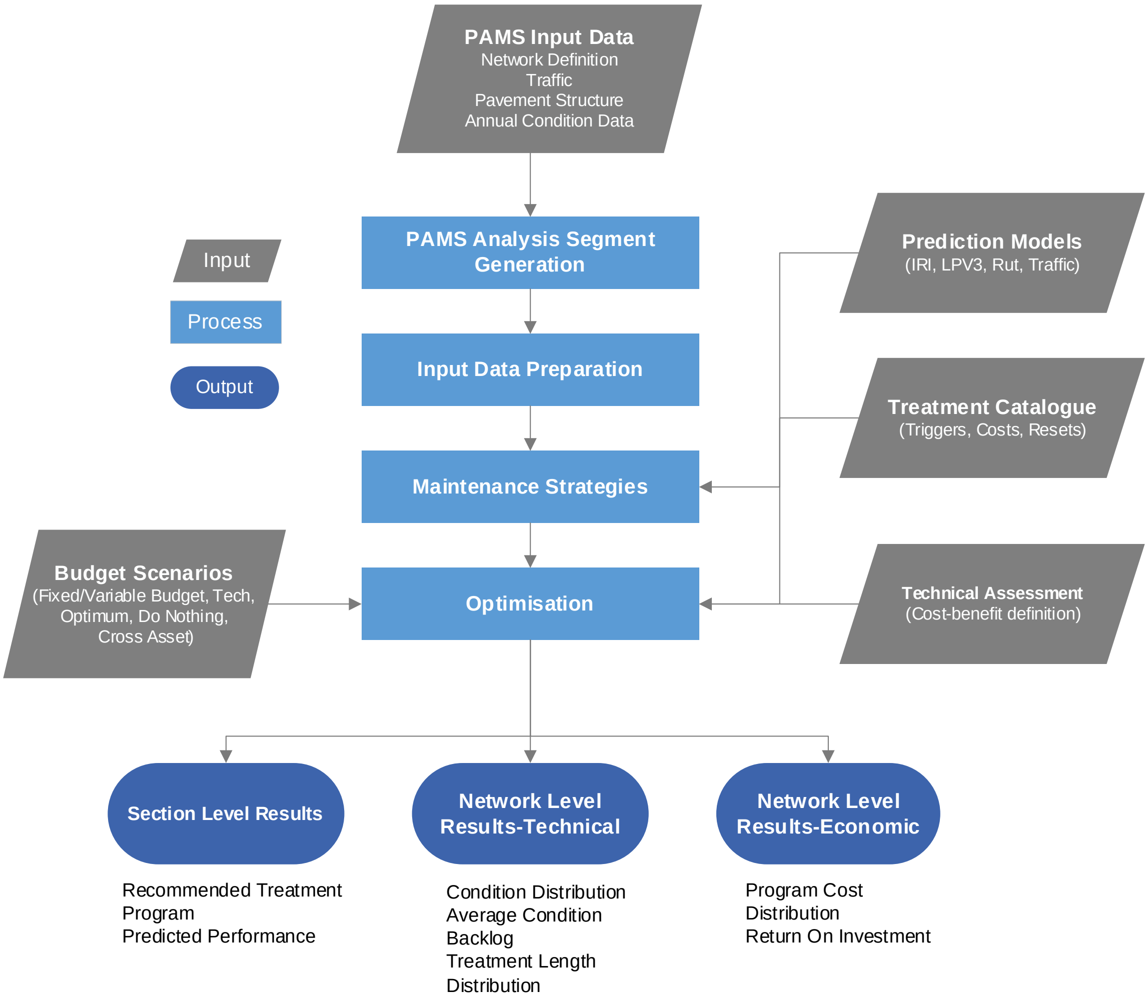


Figure 5.1 Overview of TII dTIMS Workflow

dTIMS was developed to support a wide range of assets, asset types and deployment options. It provides an open, customizable enterprise architecture that serves as the foundation for hundreds of asset management systems around the globe. dTIMS is an Integrated Asset Management System. The system is used by TII to manage the maintenance and rehabilitation programmes for all National Primary and National Secondary roads, including the non-PPP Motorway network. While data from the PPP sections is stored and analysed in dTIMS, responsibility for the maintenance of PPP sections lies with the PPP operators.

The main functional areas of dTIMS can be summarised as follows:

- Data storage and management: definition of data tables and attributes, calculation and data transformation procedures, queries, location referencing, dFrag Auto Sectioning (create homogenous elements), etc.
- Strategic Analysis (life-cycle-assessment / life-cycle-cost-analysis (LCA/LCCA)): Performance prediction, maintenance treatment catalogue, analysis sets and scenarios, optimization, cross asset analysis, etc.
- Reporting: Data reporting (tables, maps, strip maps) and results of strategic analysis (network-level and section/object level)

5.2 Data Storage and Management

The dTIMS data repository is built on collection of tables in a standard SQL relational database. The SQL format facilitates interoperability with other TII systems (e.g. GIS) should this be required. The database stores all the data necessary to perform the various strategic and tactical analyses required by TII.

5.2.1 The Base Element Table

The fundamental analysis unit in dTIMS is the Base Element. In TII, the Base Elements are defined by the GIS Network Model, currently maintained and updated by the TII GIS Section. For a detailed description of the GIS Network Model refer to Chapter 2 of this document.

Each line in the GIS Network Model is used to define a single Base Element in dTIMS. The Base Elements are stored in the Base table. Each Base Element requires a unique name within the database. The GIS Route ID (RID) is used in this case. Base Elements are defined by Name, From Measure (typically Chainage 0), To Measure (typically the length of the line), and Length.

Table 5.1 Base Element Table Extract

Name	From Measure	Representation	To Measure	Created On	Valid On
N83D1CM	0	CM	73.554	25/08/2020	01/01/1901
N83D1ML	0	ML	73.583	25/08/2020	01/01/1901
N83D1RB027	0	RB	0.157	25/08/2020	27/09/2017
N83D2ML	0	ML	73.584	25/08/2020	01/01/1901
N84D1CM	0	CM	73.816	25/08/2020	20/04/2018
N84D1ML	0	ML	73.816	25/08/2020	20/04/2018
N84D2CM	0	CM	0.572	25/08/2020	13/12/2013
N84D2ML	0	ML	73.811	25/08/2020	20/04/2018

The Base Element table underpins all other data tables in dTIMS. All other network information is referenced to the Base Elements using a combination of RID and Measure (Chainage). For point data (e.g. sign locations), a Base Element name and a single measure is required to define its location. For continuous data (e.g. pavement condition), a Base Element name, From Measure and To Measure is required.

5.2.2 Network Data Tables

A wide variety of network data is stored in dTIMS. The data may be stored at fixed intervals (e.g. pavement condition) or varying intervals (e.g. administrative boundaries). Table 5.2 below lists the data tables that are currently configured and populated in dTIMS:

Table 5.2 dTIMS Data Tables

Data Table	Descriptor / Data Parameters	Data Resolution / Reporting Interval
Pavement Surface Condition	IRI, Rut Depth, LPV	100 metre intervals
LCMS Data	Cracking, Ravelling	100 metre intervals
Administrative Boundaries	Local Authority Extents	varying intervals
Subnet Number	0, 1, 2, 3, 4	varying intervals
Carriageway Type	Dual Carriageway, Single Carriageway etc.	varying intervals
Pavement Width		varying intervals
GPR Data	Pavement Layer Thicknesses	100 metre intervals
Traffic Volume	AADT & HGV	varying intervals
AM-PAV-06046 Classification	Bends, Junction Approaches etc.	varying intervals
Skid Resistance Data	CSC	100 metre intervals

New tables can be created, or existing table structures updated, as new types of data become available.

5.2.3 PM_Analysis Table

The PM_Analysis table contains a list of the analysis sections to be used in generating multi-annual programmes and other strategic analyses. Effectively the PM_Analysis table defines the start and end points of possible pavement schemes on the network. dTIMS will use these definitions to produce the pavement programme. Various data manipulation procedures are carried out on the network data to produce the PM_Analysis table and to populate each analysis section with the characteristic values necessary for analysis. Broadly, these manipulations can be classed as:

- Section Creation:
- Smallest Common Denominator Querying (SCD)
- Data Defragmentation
- Population with Characteristic values using Data Transformation. Transformations can be further classified as:
- Formula Transformations
- Table Transformations
- Cross Tab Transformations

5.2.3.1 SCD Queries

The term "smallest common denominator" means:

- Smallest - Least
- Common - Shared by all, a common trait or characteristic
- Denominator - An average level or standard, member of a class or set which is common to things that relate to members of that class

The common denominator is the smallest unit which is divisible by all the denominators. SCD queries in dTIMS are used to compare two or more tables with varying elements lengths and attributes and create a new virtual table, combining the attributes of the input tables. The input tables are segmented such that the new elements contain a single value for each attribute. The procedure is illustrated in Figure 5.2 below for three attributes: Condition, Subnet and Local Authority (LA). Examination of the Figure shows that all adjacent defined sections have unique combinations of the 3 attributes.

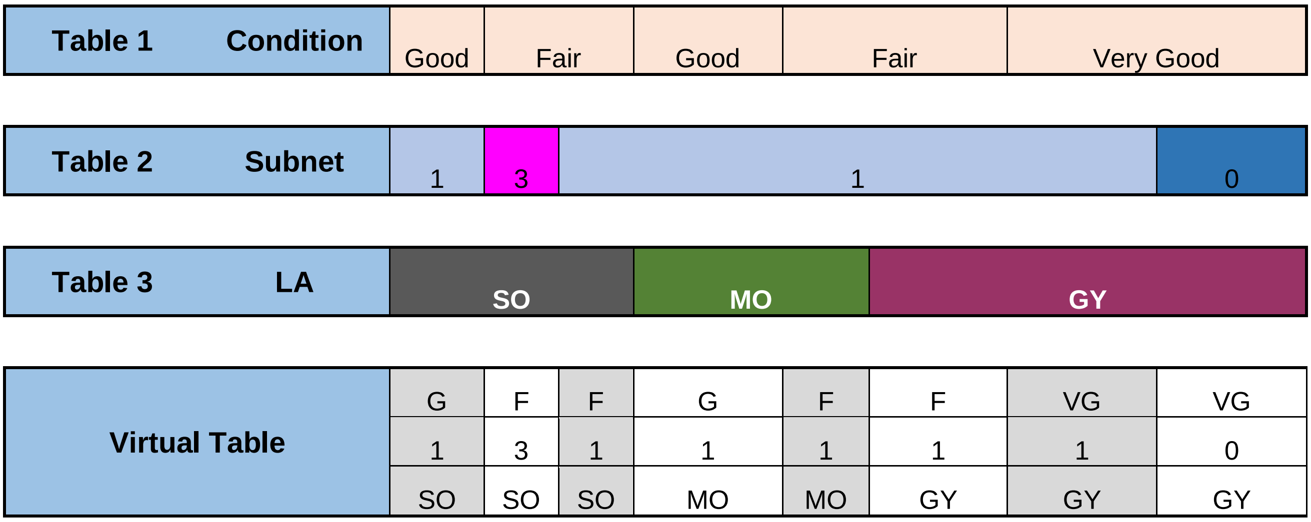


Figure 5.2 SCD Queries

5.2.3.2 Data Defragmentation

The SCD process results in a very large number of short sections where attributes are consistent within a section. This is particularly the case when the number of attributes is large. The defragmentation process takes these short sections and aggregates them up to longer lengths, suitable for pavement schemes. In order to do this, dTIMS examines each SCD section and compares it to the sections immediately before and immediately after it, as defined by the section start and end measures. Sections with similar attributes are merged into longer analysis sections. “Similar” is defined in the business rules implemented in dTIMS. These rules are fully user definable and have been tailored specifically to match TII Processes.

The complete defragmentation procedure is described in detail in the TII dTIMS BA User Guide. A brief overview of the workflow is as follows:

- Individual 100 metre Condition Sample Units are compared to their relevant condition thresholds. Condition thresholds are defined separately for each Subnet (See Table 5.3).
- Sample units exceeding relevant thresholds on two or more parameters are highlighted. The **Poor** threshold is currently used to highlight sample units i.e. Sample Units in **Poor or Very Poor** condition are highlighted.

- Highlighted Sample Units within 300 metres of each other are combined into sections, subject to the following caveat; Sample Units from Subnets 3 and 4 may be combined into a single section. Otherwise, Sample Units from different subnets may not be combined.
- Sections greater than or equal to 400 metres in length are retained and called PAT (Percentage Above Threshold) sections.
- A PAT value is calculated based on how much the measured condition value exceeds the applicable threshold. PAT values range from 0% (at or below the threshold on all parameters to 300% (150% above the threshold on at least two parameters). PAT values are used as a weighting factor in the benefit/cost analysis.
- The remainder of the network is split into sections with a target length of 5 km. The lengths will vary at the end of routes and between PAT sections.

The result of this process is a table of Analysis Sections covering the entire network comprising the PAT sections and the nominal 5 km sections. The various condition thresholds currently used on each subnet are shown in Table 5.3 below.

Table 5.3 Subnet Condition Class Thresholds

Parameter	Category	Subnet 0	Subnet 1	Subnet 2	Subnet 3	Subnet 4
IRI	V. Good	<1.5	<2	<2.7	<2.7	<3
	Good	1.5 to 2	2 to 2.5	2.7 to 3.2	2.7 to 3.2	3 to 4
	Fair	2 to 2.5	2.5 to 3	3.2 to 4	3.2 to 4	4 to 5
	Poor	2.5 to 3	3 to 3.5	4 to 5	4 to 5	5 to 7
	V Poor	>3	>3.5	> 5	> 5	>7
Rut	V. Good	<3	<3	< 4	< 4	< 4
	Good	3 to 5	3 to 5	4 to 6	4 to 6	4 to 6
	Fair	5 to 6	5 to 6	6 to 9	6 to 9	6 to 9
	Poor	6 to 9	6 to 9	9 to 15	9 to 15	9 to15
	V Poor	>9	>9	> 15	> 15	>15
LPV3	V. Good	< 1	< 1	< 2	< 2	< 2
	Good	1 to 2	1 to 2	2 to 3	2 to 3.5	2 to 4
	Fair	2 to 3	2 to 3	3 to 4	3.5 to 5	4 to 7
	Poor	3 to 4	3 to 4	4 to 6	5 to 7	7 to 10
	V Poor	> 4	> 4	> 6	> 7	> 10

5.2.3.3 Data Transformations

Once the Analysis Sections have been created, they are populated with characteristic values for each parameter used in the analysis. This includes pavement condition parameters, initial traffic volumes and growth rates, Subnet number, pavement width etc. The process of populating these attributes is achieved through a variety of transformation classes. Three main transformation classes are used.

5.2.3.4 Formula Transformation

Formula transformations operate on a single table. They take the data in one or more attribute fields, perform a calculation on the data and write the result to a new field in the same table. For example, calculating the average IRI from the left and right IRI values would be carried out using a formula transformation in dTIMS.

PM_Analysis		
LIRI	RIRI	AIRI
1.60	1.80	
1.60	1.90	
1.50	1.80	
2.20	2.60	
2.50	3.00	
3.00	3.00	
3.20	3.10	

Transformation

(LIRI +RIRI)/2

PM_Analysis		
LIRI	RIRI	AIRI
1.60	1.80	1.70
1.60	1.90	1.75
1.50	1.80	1.65
2.20	2.60	2.40
2.50	3.00	2.75
3.00	3.00	3.00
3.20	3.10	3.15

Figure 5.3 Formula Transformations

5.2.3.5 Table Transformations

Table transformations are used to transfer the data from one table in dTIMS to a second target table. If the tables store data at different resolutions the source data is aggregated to the level of the target table using a transformation class. The aggregation method is defined by the user and can include Average, Weighted Average, Most Length, First Occurrence, Min, Max etc. For example, calculating the overall average IRI for an analysis segment would be carried out by transferring the IRI data from the Pavement Condition table to the PM_Analysis table using an Arithmetic Average transformation class.

Pavement Condition - 100 m				
ChFrom	ChTo	LIRI	RIRI	AIRI
0.00	0.10	2.63	2.50	2.57
0.10	0.20	2.83	3.16	3.00
0.20	0.30	2.44	2.54	2.49
0.30	0.40	2.90	2.71	2.81
0.40	0.50	2.56	2.37	2.47
0.50	0.60	2.69	2.24	2.47
0.60	0.70	1.19	1.20	1.20
0.70	0.80	1.12	1.19	1.16
0.80	0.90	1.22	1.11	1.17
0.90	1.00	1.08	1.61	1.35

Transformation

(Arithmetic Average IRI)

PM_Analysis				
ChFrom	ChTo	LIRI	RIRI	AIRI
0.0	0.6	2.68	2.59	2.63
0.6	1.0	1.15	1.28	1.22

Figure 5.4 Table Transformation

5.2.3.6 CrossTab Transformations

CrossTab transformations operate on a single data table and an associated lookup table. The transformation feeds the values of two source attributes into a lookup table and returns a value that is stored in a third attribute. A typical example in the TII implementation is to assign an IRI condition class to a Sample Unit based on the IRI value and the Subnet Number.

Paralysis				
From	**To**	**Subnet**	**IRI**	**IRI Class**
104.5	109.5	1	2.18	
109.5	114.5	1	2.55	
114.5	119.5	1	2.33	
119.5	123.8	1	2.10	
123.8	128.6	1	3.10	

➕

	Subnet 1
IRI	**Class**
0.0 to 2.0	1
2.0 to 2.5	2
2.5 to 3.0	3
3.0 to 3.5	4
>3.5	5

Lookup Table

➡

PM_Analysis				
From	**To**	**Subnet**	**IRI**	**IRI Class**
104.5	109.5	1	2.18	2
109.5	114.5	1	2.55	3
114.5	119.5	1	2.33	2
119.5	123.8	1	2.10	2
123.8	128.6	1	3.10	4

Figure 5.5 Cross Tab Transformation

5.2.4 Other Tables

In addition to the Network Data and PM_Analysis tables dTIMS stores a variety of tables to facilitate the network management effort. These include:

- Look-up tables to define Condition Class bands for IRI, Rut Depth and LPV3 on each subnetwork (Table 5.3)
- Treatment Catalogue comprising treatment trigger values and unit cost
- Treatment Effects and Reset Values

5.3 Strategic Analysis

Strategic planning and analysis aids in making decisions about how to best manage an asset collection. This is the most powerful feature of dTIMS. In the TII implementation of dTIMS, strategic analysis is carried out using IBC (Incremental Benefit Cost) analysis. IBC is an optimization approach using a search strategies method within the total set of treatment strategies to maximize benefits while meeting a cost constraint.

In order to carry out the strategic analysis dTIMS needs three inputs:

- A set of treatment strategies to evaluate.
- A definition of the benefit obtained from each strategy.
- A definition of the cost associated with carrying out each strategy.

5.3.1 Treatment Strategy Creation

Treatment strategies are automatically created in dTIMS by:

- Initiating the analysis with a characteristic value for each analysis parameter on each Analysis Section. Characteristic values are determined using a collection of the transformations described in 5.2.3.3.
- Applying a set of models to the initial values to determine future condition and traffic loading.
- Defining a set of threshold condition values at which a treatment is triggered (Tables 5.3 & 5.4).
- Modelling the application of treatments in terms of costs and expected outcomes (reset values) when condition thresholds are exceeded. See Table 5.4 below for the treatment catalogue currently used in TII's implementation of dTIMS

- Continuing the analysis, restarting the deterioration modelling from the reset values for each treatment.

At least two treatment strategies are created for every analysis section – a defined Do Nothing strategy and at least one maintenance strategy. It is possible for the maintenance strategy to contain no treatments, depending on the initial condition and the rates of deterioration. Generally speaking, however, several treatment strategies will be created for each Analysis Section. There may be more than one appropriate treatment depending on the combination of trigger parameters, or treatments may need to be delayed by one or more years after the initial trigger depending on available budgets.

dTIMS will model all these scenarios to produce a comprehensive list of possible treatment strategies for each Analysis Section. The purpose of the strategic analysis is to determine the best and cheapest set of treatment strategies which maximises the benefit across the entire network

Table 5.4 TII Treatment Catalogue

Name	Treatment	Objective	Trigger Treatments are triggered at the Fair (F), Poor (P) or Very Poor (VP condition classes)
Replace Surface	Surface dressing, microsurfacing, thin surface overlay, plane & replace, thin surface (includes pre-treatments)	Sealing of pavement surface, improve surface characteristics	IRI OR LPV OR RD = F
Overlay	Inlay 50-100mm, overlay up to 100 mm, base/binder patching (includes pre-treatments)	Increase Strength, retard aging, improve or restore surface characteristics, improve, or restore functionality	(IRI OR LPV OR RD = P) **OR** (RD = VP)
Strengthen	Inlay 100-200 mm, overlay up to 200 mm	Increase Strength, retard aging, improve or restore surface characteristics, improve, or restore functionality	(IRI OR LPV OR RD) = VP
Reconstruct	Full depth reconstruction (> 200 mm). Reconstruction of sub-base	Increase capacity and pavement strength to provide a long-life pavement	(IRI OR LPV = VP) **AND** (RD = VP)

5.3.2 Deterioration Modelling

Future condition parameter values are predicted by dTIMS using a set of user-defined models. The models have been configured specifically for the TII implementation. Currently, deterministic modelling is used in TII however research into probabilistic methods using Markov chain modelling is ongoing and will shortly be incorporated as an analysis option.

5.3.2.1 Deterministic Modelling

Deterministic models assume that the progression of the pavement deterioration process is certain. The models are derived from regression analysis of historic condition data. These models depend on an empirical relationship between two or more variables that affect the pavement condition (traffic, age, construction etc). Linear regression models typically do not provide enough accuracy for long-term pavement performance and may underestimate or overestimate the pavement condition at a specific time, unlike the non-linear regression models. The condition deterioration models used in TII are all non-linear.

The parameters currently modelled or tracked deterministically over time are:

- IRI
- 3 metre Longitudinal Profile Variance
- Rut Depth
- Traffic Loading
- Subnet Number
- Pavement Age

The associated deterministic models are given below. The condition models are configured independently for each subnetwork by varying the value of the A and B factors. For a complete list of the A and B factors currently in use refer to the TII dTIMS BA User Guide.

Table 5.5 Deterministic Models

Parameter	Deterministic Model Applied
IRI	$IRI_t = IRI_{t-1} + A + B\ x\ Annual\ Traffic\ x\ 0.41\ x\ 10$
LPV3	$LPV3_t = LPV3_{t-1} + A\ x\ Annual\ Traffic\ x\ 0.41$
Rut Depth	$RD = A\ x\ (0.41\ x\ CumulativeTraffic)^B$
Annual Traffic	$365\ x\ (HCV\ x\ 0.35)\ x\ \frac{0.6}{1000000} + 365\ x\ (HCV * 0.65)\ x\ \frac{3.0}{1000000}$
Cumulative Traffic	$Annual\ Traffic_1 + Annual\ Traffic_2 + \ldots\ldots + Annual\ Traffic_t$
Subnetwork	If a legacy pavement undergoes a strengthening or reconstruction it is modelled as an engineered pavement from that point forward.
Pavement Age	Pavement Age + 1 for each year of analysis

5.3.2.2 Probabilistic Modelling – Markov Chain

Markov chain modelling is a powerful probabilistic method that is used in a variety of transportation infrastructure management systems to develop models that predict asset degradation as a function of time and thereby to study optimal lifecycle maintenance strategies. Markovian models require an initial condition state vector and a transition probability matrix (TPM). The number of TPM's is conditional on the system's homogeneity, i.e. if the degradation of the network is constant throughout time, one TPM suffices for the model, but variability in network degradation requires more than one TPM. Markov Chains are extremely popular in asset management internationally as the future state of the asset(s) depends only on the present (or current) state of the asset(s) and not on the past state(s)

Initial condition state vector

The condition states of a network's assets can range from State 1, which may be assumed to represent the proportion of the assets in near-perfect condition, to State n, which represent the proportion of the assets in the ultimate/worst/very poor condition (the asset is completely damaged/degraded). The present/current condition of the asset(s) can be represented as a vector, presented in Equation (1). It is termed the Initial condition state vector, a0:

$$a_0 = (State\ 1, State\ 2, \ldots, State\ n) \qquad \text{Equation (1)}$$

Transition Probability Matrix

Markov chain modelling uses Transition Probability Matrices (TPM) to predict future asset condition. Developed models describe assets as starting their lives in near-perfect or current condition, then deteriorating as they are subjected to a series of time steps, i.e. as a function of time. The probabilities of transition between states are stored in a matrix (TPM) in which rows correspond to the present state and columns to the future state. The elements of the TPM are referred to with the notation pij, where i indicates the row and j indicates the column of the matrix element. The general form of a 5x5 TPM is presented in Table 5.6.

Table 5.6 General form for Transition Probability Matrix, P.

Moving from State i	To State j				
	State 1	**State 2**	**State 3**	**State 4**	**State 5**
State 1	p11	p12	p13	p14	p15
State 2	0	p22	p23	p24	p25
State 3	0	0	p33	p34	p35
State 4	0	0	0	p44	p45
State 5	0	0	0	0	p55 = 1

The following six rules must be considered when developing transition matrices:

1. The transition probabilities, pii (p11, p22, p33, p44), denote the proportion of the asset remaining in condition i after one time step has passed.
2. Values below the main diagonal are represented with zeros, suggesting that the asset condition cannot improve without treatment (pij = 0 for i>j).
3. Values above the main diagonal indicate the probability of the assets in condition i moving to a lower condition within one duty cycle.
4. The element p55 equals to unity suggest that the asset has reached its worst state of degradation and cannot deteriorate further.
5. All elements of the matrix should be positive.
6. The Total elements in each row should be equal to 1.

The elements of a TPM are calculated using Equation (2):

$$p_{ij} = N_{ij}/N_i \qquad \text{Equation (2)}$$

Where Nij represents the total number of assets moving from state i to state j following one time step, and Ni is the total number of assets in state i at the start of the time step (i.e. based upon date collected by asset condition survey). If the data supplied has been collected over a long period of time (e.g. historical data is available), fluctuations are to be expected; consequently, it is advised that the average value for pij be determined to ensure the model's accuracy.

Condition Prediction

After defining both the initial vector and the transition matrix, Equation 3 can be employed to determine the probability distribution of the condition states at any particular time, t:

$$a_t = a_0 P^t \qquad \text{Equation (3)}$$

Where a0 is the initial condition vector, Pt represents the transition matrix raised to the power of t, t is time in years, and at depicts the distribution of assets condition at time t.

Advantages of Markov Chain in Transportation Infrastructure Management

An example of an asset degradation over a 15-year period, determined using Markov Chain Modelling with associated TPM's is presented in Figure 5.6. It is illustrated that in 2020 approximately 40% of the assets are in VG (very good) condition. By the end of the 15-year period where no intervention (repair works) has taken place, only 5% of the assets are still in VG condition. On the other hand, whereas less than 20% of the assets are in VP (very poor) condition in 2020, 80 % are in VP by the end of 15-year analysis. This condition profile is a function of the maintenance rules/strategies prescribed for intervention on the network.

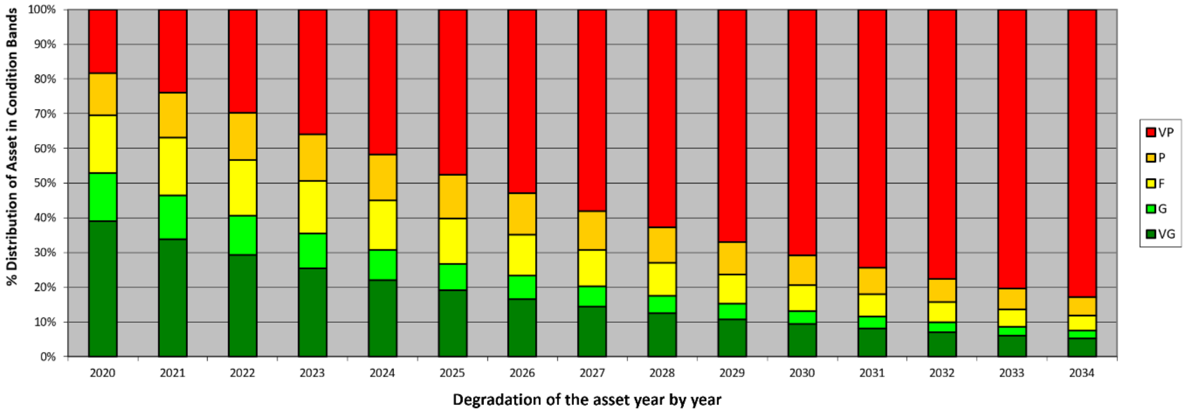


Figure 5.6 Example of an asset class deterioration over time

Markov modelling can be used in this way in evaluating the condition of an asset or a network of assets throughout their lifespan. Estimations obtained using Markov transition probabilities can be used to evaluate, probabilistically, the relative condition of a network and its assets as a function of time. Evolution of individual indicators can be analysed, e.g., IRI, LPV, RUT etc. or combined indicators can be developed. The process makes possible the evaluation of the implication of alternative maintenance scenarios on network condition and to optimise budget spend as a function of time to maximise the condition of the network or to maintain the condition of the network above a prescribed limit, i.e., no more that 25% in Fair condition by Year X. Furthermore, alternative thresholds for condition states can be analysed. Significantly, TPM's may be developed for either homogenous and/or inhomogeneous chains, i.e., TPM's varying as a function of the considered time step.

5.3.3 Benefits

Generally, the benefits of applying a treatment strategy may be considered in two categories:

- Technical Benefit – the improvement in condition gained by applying a treatment strategy. This can be measured in terms of condition parameters, a series of individual indices or one or more composite indices.
- Economic Benefit – the savings in monetary terms, time and environmental effects due to improved pavement condition e.g. shorter journey times, lower vehicle operating costs, fewer accidents, lower CO_2 emissions etc.

TII currently uses the Technical Benefit measure to assess the merits of applying a treatment strategy. Three primary indices are used to calculate the technical benefit:

- IRI Index

- Rut Index
- 3 metre Longitudinal Profile (LPV3) Index

Each index ranges from 1 to 5. These values map directly to the Very Good/Good/Fair/Poor/Very Poor ranges used by TII for each variable. The three individual indices are combined to give a composite Total Condition Index. For a given section of road, the Total Condition Index is the maximum of any of the individual condition indices.

The method used by TII to measure the benefits of a strategy is the Area Under the Curve method. This method compares the condition index produced by a given strategy to the Do Nothing condition index. The benefit is calculated by summing the present value of the difference between the condition index resulting from applying the strategy and the condition index from doing nothing for each year in the analysis period. The Area Under the Curve calculations are carried out for the Total Condition Index.

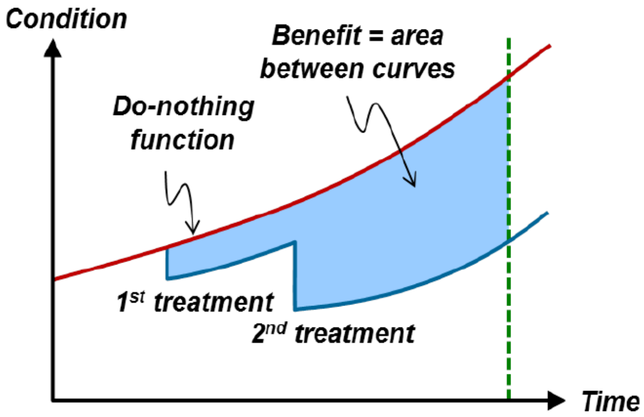


Figure 5.7 Figure 5.7 – Area Under the Curve Calculation

5.3.4 Costs

Two different types of costs are considered in the TII implementation of dTIMS for the pavement network:

- Agency Ownership costs - costs to initially construct, improve, maintain, and operate an asset and;
- User costs – user costs may be further considered as:
  - User Costs due to pavement condition (Time costs, Vehicle operating costs, Accident costs, CO^2 equivalents etc)
  - User Cost due to pavement treatments (delays due to construction, Additional accidents due to construction, CO^2 equivalents due to construction etc.)

TII currently uses the Agency Ownership costs to quantify the costs associated with a treatment strategy (maintenance, preservation, rehabilitation, and replacement costs).

5.3.5 Benefit-Cost Analysis

The TII Benefit-Cost analysis uses the Technical Benefit and the Agency Ownership treatment cost (the total cost of design, materials, labour, traffic management etc.) in determining the optimal pavement maintenance programme within the budgetary constraints. The overall benefit cost for a strategy is calculated using incremental benefit cost analysis.

5.3.6 Incremental Benefit Cost Analysis

Incremental Benefit Cost Analysis is used to compare two or more strategies and determine which is the most beneficial strategy overall. It operates as follows:

- A range of strategies is generated for each analysis section on the network over the analysis period (see Section 5.3.1).
- The costs and benefits for each strategy are determined.
- The benefit-cost ratio is calculated for each strategy.
- Strategies are ranked by cost from lowest, S1, to highest SN where N is the total number of strategies.
- S1 is compared to S2. The IBC is calculated as:

$$\frac{(S2\ Benefits - S1\ Benefits)}{(S2\ Costs - S1\ Costs)}$$

- If the calculated IBC is positive, then the increased spend on S2 is justified. S2 is retained and the calculation is repeated for S2 versus S3.
- If the IBC is not positive, then the increased spend is not justified. S1 is retained and the calculation is repeated for S1 versus S3.
- The procedure continues through the entire collection of strategies across all analysis sections until the set of strategies which maximises the network benefit within the cost constraints is found.

The list of strategies produced using this method can be reviewed prior to sign off as the final programme of works. Individual treatments may be delayed or brought forward for reasons not captured in the dTIMS modelling e.g., overlap with works programmes from other agencies, planned by-passes/realignment making future works redundant etc.

5.4 Reporting

The main reports generated by the PAMS software are derived from the results of the strategic analysis described in 5.2. Two levels of report are produced:

- Section level – reports relating to individual analysis sections
- Strategic/Network – reports based on the aggregated results of all analysis sections over the entire network, or significant portions of it e.g., over a Subnet or a Local Authority.

5.4.1 Section Level Reporting

Section level reports report data at the level of individual analysis sections. There are three primary outputs at the section level in TII:

- The treatment or treatments which will be applied.
- The timing of the treatment or treatments.
- The cost of the treatment or treatments.

Together with the location referencing information for the analysis sections (RID and Chainage), these form the basis for the multi-annual programme of works. This programme is typically integrated with other TII works programmes (AM-PAV-06046 Skid Resistance, Capital Maintenance, PPP & MMARC programmes) and with programmes produced by external agencies (Irish Water, ESB, Eir etc) to produce final 3 and 5 year works programmes.

While the main section level output is the treatment programme, the projected values of each individual analysis variable (e.g. IRI, Rut Depth etc) can be reported for every analysis section for every year of analysis. This level of detail is of limited application at the operational level but is very useful for model calibration and research purposes.

5.4.2 Strategic Level Reporting

Strategic or Network level reporting takes the section level results and aggregates them up to the network level. The aggregated results allow a strategic level view of the current state of the network and facilitates more informed decisions around future network needs. The main set of network level results produced by dTIMS are:

- Annual Average Condition – network average value of the Total Condition Index
- Annual Network Condition Distribution – length weighted
- Annual Network Condition Distribution – traffic weighted
- Annual Length in Backlog – backlog defined as being in Poor or Very Poor condition
- Annual Treatment Costs – costs reported by treatment type (Reconstruction, Overlay etc)
- Annual Program Costs – costs reported by treatment category (Heavy or Routine Maintenance)

dTIMS allows direct comparison of these results for various different scenarios e.g. different funding levels, alternative definitions of cost and/or benefit, different intervention levels for treatments, different treatment types etc. The analysis of these various “what if” scenarios forms a rational basis for the allocation of resources at the strategic level in order to manage the network in alignment with the set of policy goals and objectives that inform all of TII’s asset management decisions.

6. Programme Planning & Scheme Development

6.1 Overview

This chapter describes the planning and development of pavement works programmes on the national road network by TII NM. These include pavement asset repair and renewal (PARR), emergency pavement repair, minor pavement repair, skid resistance, and routine maintenance works programmes.

6.2 Pavement Asset Repair and Renewal (PARR) Schemes

6.2.1 PARR Objectives

PARR is an activity targeted at extending the life of an existing road pavement and/or improving its load carrying capacity or skid resistance. Examples include overlay and inlay works and edge strengthening of an existing road pavement. TII's PARR programme is essential to achieving its core mission of providing a safe and fit for purpose network of national roads.

The overall strategic objective of the PARR procedures is to maintain the overall pavement asset value for the minimum life cycle costs through optimal management of the national road network. Optimal management of the pavement assets requires the combination of local knowledge, intervention and network-wide monitoring, knowledge sharing and co-ordination, especially as new technologies present opportunities to reduce both the economic and environmental costs.

6.2.2 Selection of PARR Schemes

To obtain the maximum value from investment in PARR across the network, determination of the highest-priority pavement repair/renewal projects is undertaken by TII NM. The PAMS software generates an optimised treatment strategy for each individual analysis section resulting in approximately 200 treatment sites per analysis year.

Together with the location referencing information for the analysis sections, these strategies form the basis for the multi-annual programme of works. This programme is typically integrated with other TII works programmes (skid resistance, road safety improvement schemes etc.) to produce final 3 and 5 year works programmes.

6.2.3 Approval and Delivery of PARR Schemes

TII NM will notify the relevant implementation authority (IA) of sections of the national road network for priority development into PARR Schemes, including the potential appropriate high level interventions and treatments.

Procedures for the approval and delivery of PARR schemes on the national road network are set out in AM-PAV-06049. Guidance on the technical aspects of the investigation and design of PARR schemes is set out in AM-PAV-06050. Figure 6.1 describes the main stages, deliverables, and responsibilities for PARR schemes.

6.2.4 Emergency Pavement Repair and Minor Pavement Repair Schemes

Emergency Pavement Repair Schemes are PARR schemes which have to be carried out quickly in response to emergencies to ensure the safety and continued serviceability of the road. For example, these repairs may follow collisions, diesel spillage or unexpected and rapid deterioration of the pavement. Minor Pavement Repair Schemes are typically those with an estimated cost less than €200,000 (excluding Vat), as defined in AM-PAV-06049.

If the PARR Scheme is classified as an emergency pavement repair or minor pavement repair scheme, the IA will be permitted to follow an abridged approval process which is outlined in AM-PAV-06049.

6.2.5 PAMS Database Information Sheet

The collation and inputting of the information required for the PAMS Database Information Sheet in accordance with AM-PAV-06049 is particularly important as this records the details of the completed Works and provides cost information for future updates and treatments.

6.2.6 MapRoad Asset Management System (AMS)

In accordance with TII Circular No. 7/2022, all local authorities / NRDO offices are requested to upload and maintain full records of all TII PARR schemes to MapRoad Asset Management System (AMS). This is to align with the current national requirement to upload pavement interventions to the AMS, including those funded across other grant categories or Government Departments.

This requirement supersedes existing AM-PAV-06049 requirements to submit information via PAMS database information sheets only. While all other requirements contained in AM-PAV-06049 remain in place, the standard will be updated in due course to reflect the switch to using MapRoad for scheme development and reporting.

The AMS is managed by the Road Management Office (RMO) under the shared service model. The RMO will provide any necessary assistance and support in setting up users and training on MapRoad software as well as providing assistance in creating and uploading projects and programmes on MapRoad. The RMO can be contacted at contact@rmo.ie. Once Users start capturing project information on the MapRoad software, TII output reporting frequency and templates will be agreed between TII, LAs and the RMO.

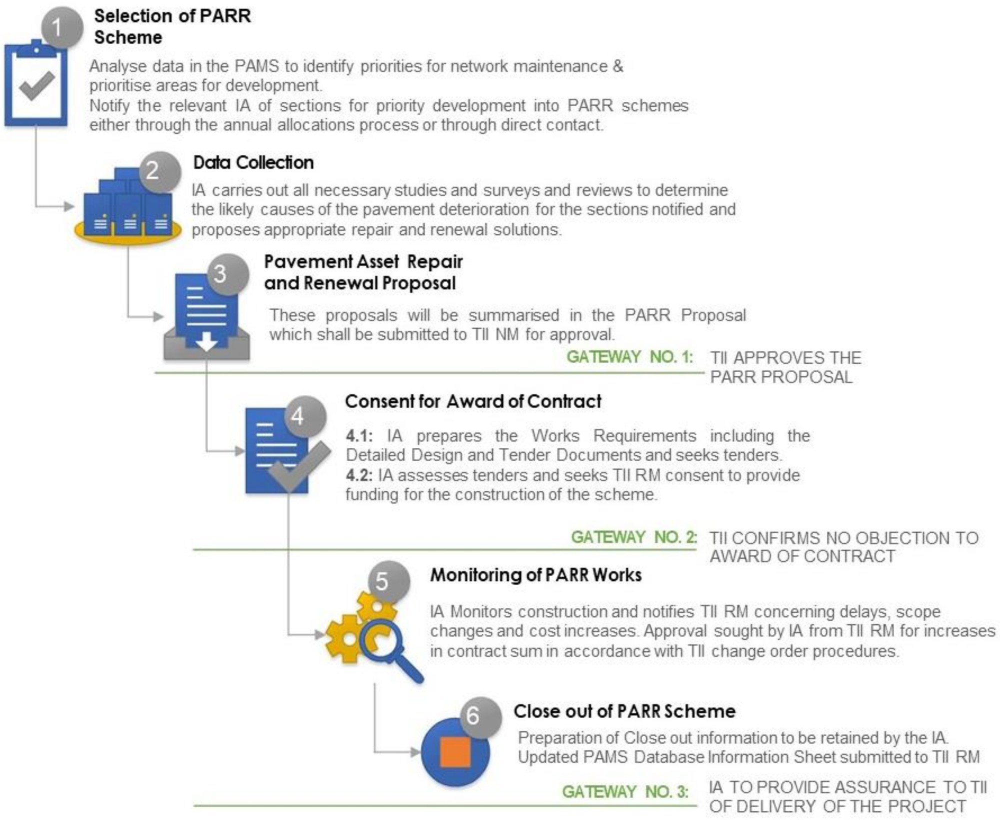


Figure 6.1 Overview of PARR Process

6.3 Management of Skid Resistance

The term "skid resistance" refers to the characterisation of the friction of a road surface when measured using a specified device in accordance with a standardised method as outlined in AM-PAV-06045, Skid Resistance Assessment. The TII policy for managing skid resistance on in-service national roads is set out in AM-PAV-06046, Skid Resistance Management. AM-PAV-06046 provides a methodology to assess the requirement and priority for remedial works based on an engineering assessment of needs taking into consideration local and national constraints.

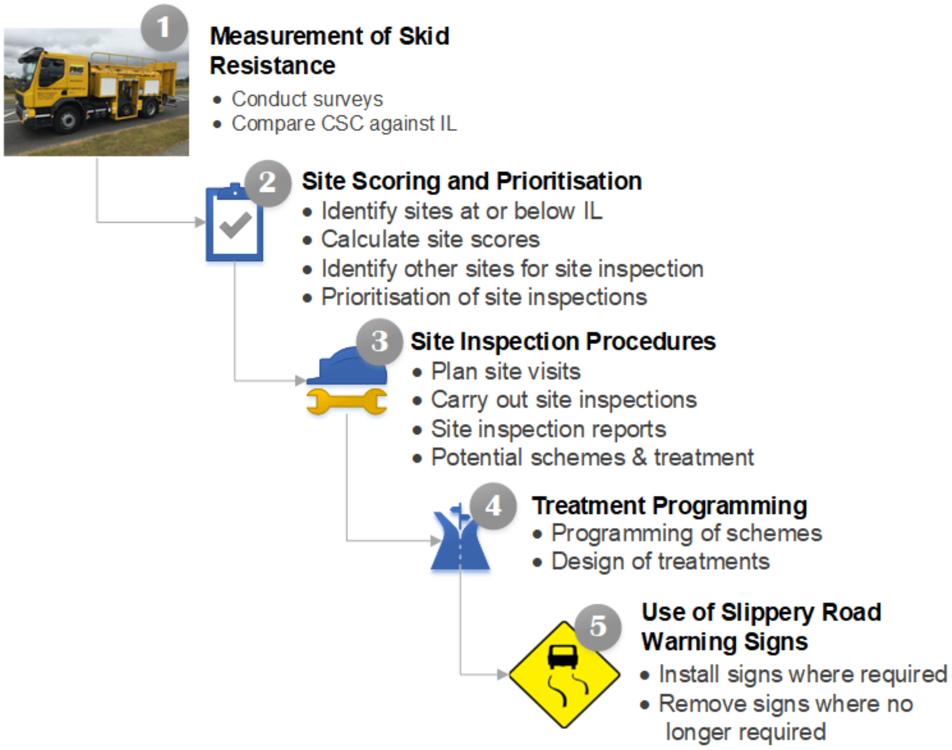


Figure 6.2 Overview of Skid Resistance Management Process

6.3.1 Identification and Prioritisation of Sites for Inspection

Locations requiring a site inspection are identified through a site scoring and prioritisation process as detailed in AM-PAV-06046. The priority is based on the site score derived from the Characteristic Skid Coefficient (CSC), Mean Profile Depth (MPD), collision history and risk rating data.

Where required, a site inspection is carried out to assess the information available for each site in order to reach a decision about the best course of action. The objective of the site inspection is to determine whether treatment to improve the skid resistance is justified to reduce the risk of wet skid collisions, whether some other form of action is required, whether the site should be kept under review, or whether no action is currently required.

The site inspections are carried out by a team of TII Inspectors with experience in road surfacing and materials specification. The objective of the site inspection is to assess the requirement for remedial action based on four main headings:

1. Engineering Pavement Condition Data (CSC, MPD, IRI, rut depth, etc.)
2. Visual Assessment of the pavement surface characteristics (surface type, defects, inadequate drainage, contamination etc.)
3. Road Users & Braking Demand (locations of increased braking demand, road layout, sight lines, evidence of recent collisions, etc.)

4. Routine Maintenance Actions (defects, markings, signage, drainage, vegetation, etc.)

To carry out and record the findings of the desktop study and site inspection, new desktop and mobile software applications based on geospatial, video and pavement condition data have been developed.

6.3.1.1 Desktop Study App

For the Desktop Study, all of the CSC, MPD, Collison and Risk Rating data used to assess averaging lengths, create inspection sites, and assign site scores and priorities are published as a feature service to ESRI's ArcGIS Online (AGOL) platform. The AGOL dashboards enable users to convey information by presenting location-based analytics using interactive data visualisations on a single screen. Other relevant pavement condition information including IRI, Rut Depth and LPV are also published to AGOL. Finally, the most recent georeferenced Right of Way (ROW) video collected as part of the annual network surveys is published to the Ubipix platform and linked to their corresponding sites on AGOL.

The Desktop Study dashboard allows the inspector to view the data in various interactive graphical formats including maps, charts, lists and indicators. In addition, as part of the Desktop Study the inspector can view/stop/rewind etc the ROW video of the site in each direction to carry out a virtual drive through of the site, and to review the pavement surface characteristics (surface type, defects, drainage, contamination) and the road environment characteristics (geometry, signage, markings etc) to assess route consistency and criteria associated with driver workload/braking demand.

The Desktop Study dashboard also allows the inspector to update the feature service with their observations arising from the desktop study. The observations made as part of the Desktop Study are available to the inspectors through the Site Inspection App when the inspector goes on site to conduct the site inspection in the field. An example of a typical dashboard view for the Desktop Study app is shown in Figure 6.3.

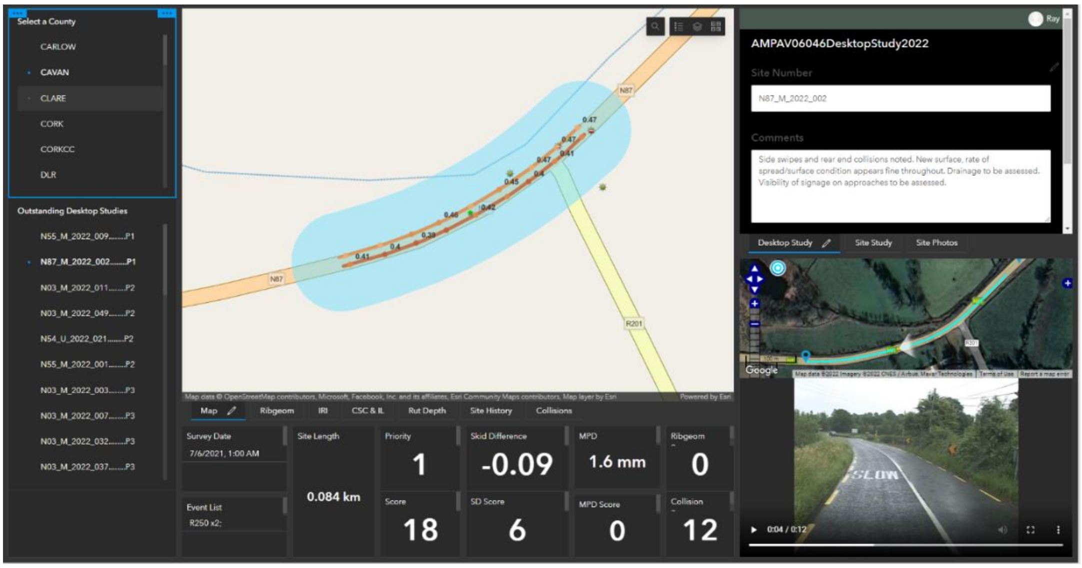


Figure 6.3 Skid Resistance Destop Study App

6.3.1.2 Site Inspection App

The Site Inspection App is built using ESRI's ArcGIS Survey123 form-centric solution for collecting data via mobile devices. The Site Inspection App can be operated in the field using a mobile phone or a tablet. An example of the Site Inspection app interface is shown in Figure 6.4.

Using the Site Inspection App, the inspector is required to record their site observations, to answer a series of questions relating to the four elements of the site inspection outlined above, and to recommend a remedial action for the site from a list of treatment interventions, if required. The site inspection form references the same feature service as the desktop study, ensuring all inspector observations and decision on remedial action are stored in a common database for reporting and subsequent review.

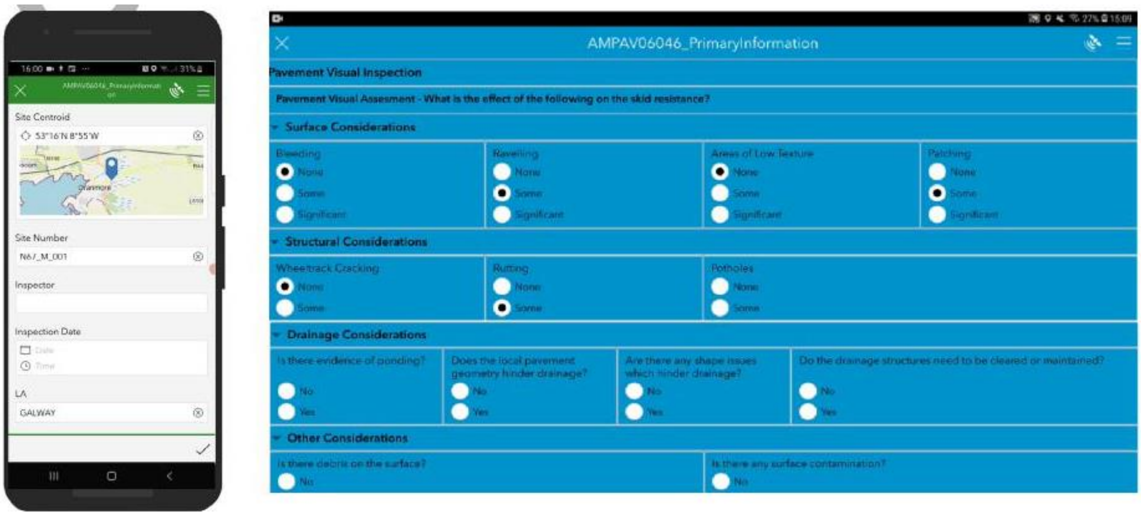


Figure 6.4 Skid Resistance Site Inspection App

6.3.2 Potential Schemes and Treatments

The site investigation process may result in a number of locations being recommended for treatment to improve the skid resistance.

The results of site inspection reports are compiled into a list of potential schemes along with recommended surface treatments, and any other recommended actions including additional routine maintenance, where required. These recommendations are then distributed to the relevant managing organisations to be implemented. The design of treatments is the responsibility of the relevant managing organisation and will be carried out in accordance with current TII standards.

6.4 Routine Maintenance Inspections by Local Authorities

6.4.1 Geo App Data Collection Tool

The Geo App is a data collection tool developed by TII to record and manage routine maintenance inspections across the national road network. It is used to record defects identified on the national road network by local authority engineers. The application can be downloaded by local authority engineers to mobile devices. Figure 6.5 illustrates the overall process for logging defects, managing defects, application for funding, approval and closeout of defects using the Geo App. Figure 6.6 shows an example of the Geo App user interface for identifying and recording defects.

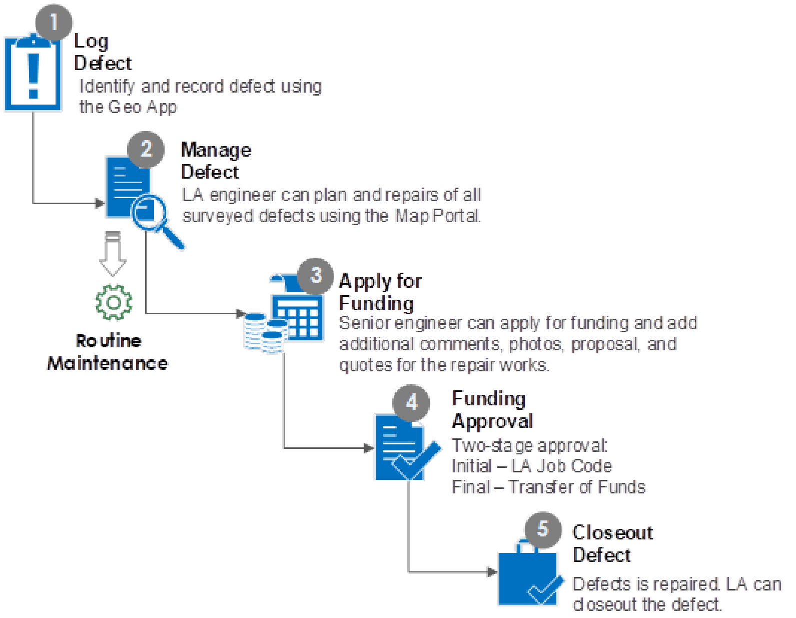


Figure 6.5 Overview of Routine Maintenance Process using the Geo App

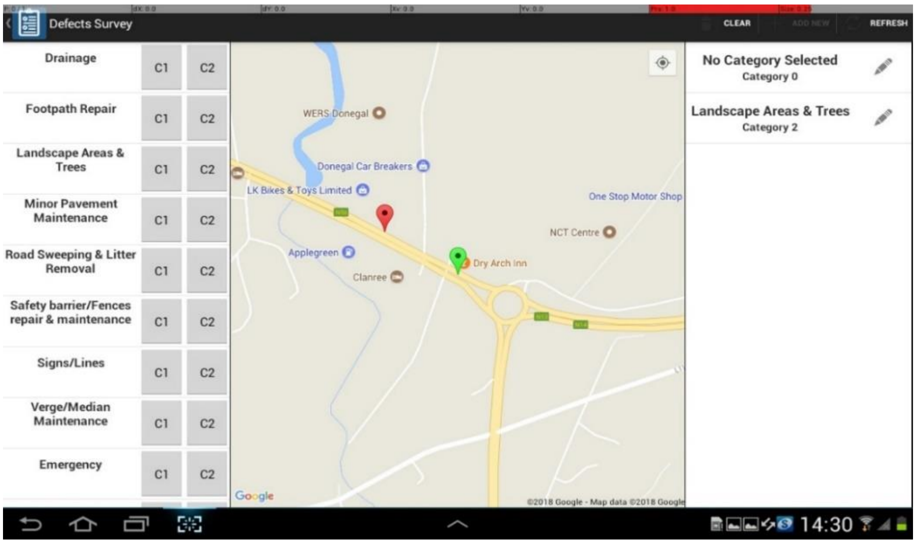


Figure 6.6 Geo App User Interface

6.4.2 Item Defects

Items on the defects survey include: drainage, footpath repair, landscaping, minor pavement repair, road sweep, safety barrier, sign/lines, verge/median, emergency, other, and points of interest.

Special items such as traffic lights and control panels which fall under the 'other' category have different manufacturers and therefore will have different maintenance requirements.

6.4.3 Framework Agreements

There are a number of TII Framework Agreements in place to assist local authorities in maintaining certain national road asset types separately to their main routine maintenance activities, including vehicle restraint systems, invasive species, and signs/lines.

6.4.4 Defects Management System

Defects that are recorded using the Geo App can be viewed and managed via the Defects Management System available through the TII web portal at https://dms.tii.systems/#/login.

7. Network Level Reporting & KPIs

7.1 General

A framework for reporting Key Performance Indicators (KPI) in the pavements area was produced by TII in 2017, "Pavement Performance Management Framework and Key Performance Indicators for the National Network".

The framework allows for reporting performance at both Strategic Level and Tactical Level. The same KPI categories are used at both Levels, but with more comprehensive and detailed breakdown available at Tactical Level.

In the overall framework developed, there are 7 KPIs as shown in Table 7.1 below. The first three KPIs are based on different measures of pavement condition, the fourth monitors actual versus projected required investment level, and the remaining three KPIs target cost efficiency of pavement projects, user satisfaction with the pavement condition and a sustainability (carbon footprint) measure of pavement projects.

Table 7.1 Pavement KPIs

KPI	Name
1	Structural Health
2	Surface Health
3	Surface Safety
4	Investment Level
5	Cost Efficiency
6	User Satisfaction
7	Sustainability

Strategic level reporting is intended for managers and decision makers at an executive level. They are primarily aimed at Senior Management, Board members and external bodies to allow a summary understanding of the network's condition performance over time. Typically KPIs at this level are qualitative rather than quantitative. Strategic level planning involves an analysis of the road system as a whole, typically requiring the preparation of long term estimates of expenditure for road development and preservation under various budgetary and economic scenarios. Predictions may be made of expenditure under selected budget heads, and forecasts of highway conditions in terms of key indicators, under a variety of funding levels.

Tactical Level KPIs are used for detailed condition monitoring, overall pavement programme development and also feed into calibration of future pavement performance modelling.

Tactical level KPIs and other parameters are detailed, yielding information on what impact the investment is achieving in various areas of the road management operation. Close monitoring of trends over time, rates of change in technical and economic parameters, and monitoring of regional or hierarchical differences are common. Tactical level planning involves the preparation, under budget constraints, of multi-year road works and expenditure programmes in which those sections of the network likely to require maintenance, improvement, or new construction are identified. The timeframe at tactical level typically extends for three to five years into the future.

7.2 Levels of Service

Each subnet has defined Levels of Service (LOS) for each pavement condition parameter measured. Typically, there are 5 LOS brackets: Very Good, Good, Fair, Poor, and Very Poor.

7.3 Strategic Level

7.3.1 Strategic Level Overview

At Strategic Level, the Key Performance Indicators (KPI) are reported as Percentage in Fair or Better condition, and the KPIs are compared with a defined target level, following best international practice for fully designed pavement sections, urban areas, and legacy pavement sections with varying standards of geometric and pavement design.

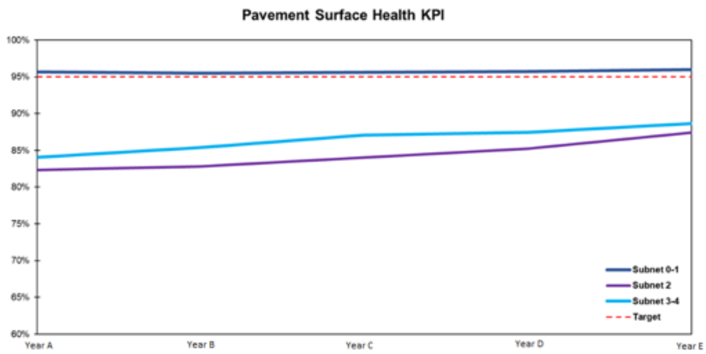
For reporting at Strategic Level, the subnetworks are combined into three groupings.

- Subnetworks 0 and 1 are combined as both are comprised of fully designed pavement sections.
- Subnetwork 2 is reported as is, representing the condition of urban areas.
- Subnetworks 3 and 4 are combined as both are comprised of legacy pavement sections with varying standards of geometric and pavement design.

Three pavement condition KPI are reported at Strategic Level –

- Structural Health,
- Surface Health and
- Surface Safety

A sample Strategic Level KPI for Pavement Surface Health is displayed below in Figure 7.1.



% of Network Fair or Better					
	Year A	Year B	Year C	Year D	Year E
Subnet 0-1	95.7%	95.5%	95.6%	95.7%	96.0%
Subnet 2	82.4%	82.8%	84.0%	85.2%	87.4%
Subnet 3-4	84.0%	85.4%	87.1%	87.4%	88.7%

Years to Target					
	Year A	Year B	Year C	Year D	Year E
Subnet 0-1					
Subnet 2					
Subnet 3-4					

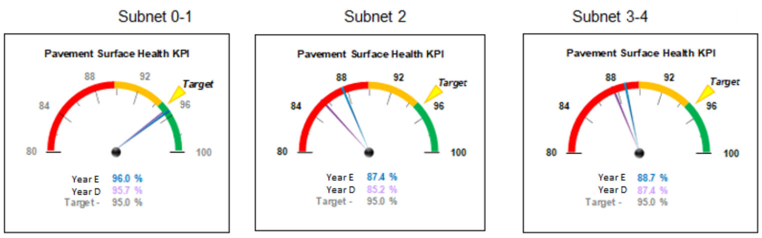


Figure 7.1 Sample Strategic KPI: Pavement Surface Health

7.3.2 Years to Target

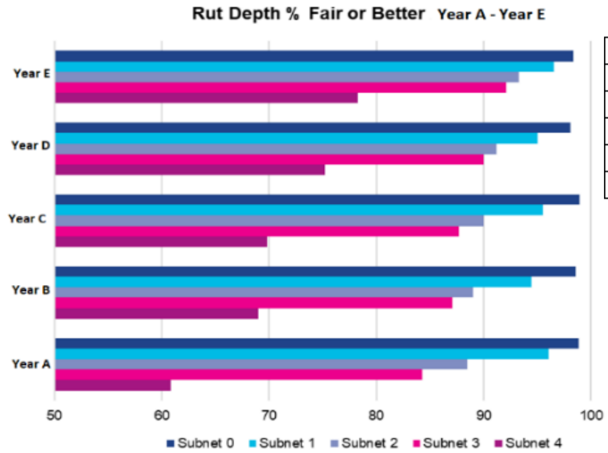
The years to target table shown in Figure 7.1 indicates if current levels of funding will achieve the target level within a defined time period. Each Strategic KPI graph shows the Target Line (dashed red line) and the actual performance lines for the Engineered Pavements, Legacy Pavements and Urban Pavements. KPIs are typically defined for TII as % Fair or Better, in line with international best practice. If the performance line is at or above the target line, the Years to Target box is coloured Green. If the performance line is below the Target Line, the slope of the performance line is extended until it intersects the Target Line, and the Years to Target is calculated. If the Years to Target value is between 1 and 6 years, the Years to Target box is coloured Yellow. If the Years to Target value is 7 years or greater, the Years to Target box is coloured Red.

7.4 Tactical Level

Reporting at Tactical Level is more detailed than at Strategic Level. Each of the five subnetworks is reported separately, and there is a greater range of parameters measured that are grouped under the same three pavement condition KPI framework headings used at Strategic Level.

In the annual KPI report, there are three separate parameters at Tactical level measured and reported under the Structural Health KPI heading, three separate parameters grouped under the Surface Health KPI heading and four parameters grouped under the Surface Safety KPI parameter.

A sample Tactical Level KPI: Rut Depth is displayed below in Figure 7.2.



Subnet	Year A	Year B	Year C	Year D	Year E
Subnet 0	98.9	98.6	98.9	98.1	98.4
Subnet 1	96.0	94.5	95.5	95.0	96.6
Subnet 2	88.4	89.4	90.0	91.2	93.3
Subnet 3	84.3	87.1	87.7	90.0	92.1
Subnet 4	60.8	69.0	69.7	75.2	78.3

Figure 7.2 Sample Tactical KPI: Rut Depth

7.5 National Roads Network Indicators

TII produce an annual National Roads Network Indicators report which documents the key trends and information related to the Road Network, Economics, Road Condition, Safety, Accessibility & Environment and Emissions. A summarised version of the strategic pavement KPIs are typically included as part of this report.

https://www.tii.ie/tii-library/strategic-planning/

7.6 CEDR TEN-T KPIs

TII is also required to submit KPI information to the Conference of European Directors of Roads (CEDR) annually. This information is typically gathered under six main headings

1. Safety
2. Congestion
3. Environment
4. Finance
5. Asset Condition
6. Customer Satisfaction

Pavement information is submitted under the heading Asset Condition. The purpose of the indicator is to allow a benchmark on the condition of the pavement of the road network by road type, see Figure 7.3 below.

Short name	Condition of road pavement				
Code	**PACO_M (NEW, DET; MAINT)** **PACO_P (NEW, DET; MAINT)** **PACO_S (NEW, DET; MAINT)** **PACO_O (NEW, DET; MAINT)**				
Domain	Asset Condition				
Description	The indicator provides an assessment of the quality of road pavements over the last year				
Calculation	The indicator is calculated as a proportion of the network length in each condition band, for each road type. Condition is based on national maintenance standards.				
Segmentation		Motorways	Primary Roads	Secondary Roads	Other Roads
	As New	●	●	●	●
	Starting to Deteriorate	●	●	●	●
	In Need of Maintenance	●	●	●	●
Presentation	Percentage of the network length in each condition band for each road type				
Permitted values	Percent to one decimal place				
Purpose	The purpose of the indicator is to allow a benchmark on the condition of the pavement of the road network by road type.				

Figure 7.3 CEDR Pavement Asset Condition Indicators

8. References

8.1 Key Documents

a) NRA PMS Call-off 2 Strategic Modelling Tool – Mouchel Viagroup

b) National Roads Authority Asset Management Strategy: Network Referencing Methodology

c) National Road Network Pavement Condition Survey and Associated Consultancy Services – Volume A (i) Service Requirements

d) Pavement Performance Management Framework and Key Performance Indicators for the National Network

8.2 European Standards

a) I.S. EN 12697-27, Bituminous mixtures - Test methods - Part 27: Sampling

b) I.S. EN 12697-36, Bituminous mixtures - Test methods for hot mix asphalt - Part 36: Determination of the thickness of a bituminous pavement

c) I.S. EN 13036-5, Road and airfield surface characteristics - Test methods - Part 5: Determination of longitudinal unevenness indices

d) I.S. EN 13036-6, Road and airfield surface characteristics - Test methods - Part 6: Measurement of transverse and longitudinal profiles in the evenness and megatexture wavelength ranges

e) I.S. EN 13036-8, Road and airfield surface characteristics - Test methods - Part 8: Determination of transverse unevenness indices

f) I.S. CEN/TS 15901-6, Road and airfield surface characteristics - Part 6: Procedure for determining the skid resistance of a pavement surface by measurement of the sideway force coefficient (SFCS): SCRIM®

8.3 International Standards

a) ISO 13473-1, Characterization of pavement texture by use of surface profiles - Part 1: Determination of mean profile depth

b) ISO-17025, General requirements for the competence of testing and calibration laboratories

    i) ISO-27000, Information Technology Series

Appendix A:

Relevant TII Publications

Table A.1 gives a non-exhaustive list and a brief outline of the contents of each of the relevant TII Publications grouped according to their activity and stream.

The order of these documents generally corresponds to the life cycle stages of a road pavement i.e., design, construction, assessment then maintenance. However, it must be emphasised that there is interaction between the components and that they should not generally be dealt with in isolation.

Table A.1 Relevant TII Publication Names and Descriptions

TII Publication Name	Description
General - Pavement (GE-PAV)	
Use of Volume 7 GE-PAV-01006	Provides details regarding implementation of Pavement Design and Maintenance Standards previously contained within NRA DMRB Volume 7 and provides an introduction to the whole set of documents
Planning & Evaluation – Strategic Management (PE-SMG)	
Traffic Assessment PE-SMG-02002	Method for the estimation and calculation of traffic loading for the design of road pavements.
Design - Pavement (DN-PAV)	
Analytic Pavement & Foundation Design DN-PAV-03021	Design process for new pavements and the strengthening / overlaying of existing pavements. All pavement designs are to be carried out using the Irish Analytic Pavement Design Method (IAPDM).
Surfacing Materials for New and Maintenance Construction for use in Ireland DN-PAV-03023	Provides a summary of surfacing options available for use on both flexible and rigid pavements and advises on current requirements. Details the requirements for aggregates to ensure that appropriate skid resistance is provided. Includes details of surface texture and how this affects skid resistance and surface noise at the tyre/road interface.
Bituminous Mixtures, Surface Treatments, and Miscellaneous Products and Processes DN-PAV-03024	Advice and information on the selection and properties of bituminous mixtures, surface treatments, and miscellaneous products and processes.
Footway Design DN-PAV-03026	Requirements and advice for new footway construction. Covers footways constructed from common materials that are subjected to a range of pedestrian traffic and some overrun by vehicular traffic.
Design of Bituminous Mixtures, Surface Treatments, and Miscellaneous Products and Processes DN-PAV-03074	Requirements and advice for the design of road pavements using products detailed in the Construction & Commissioning (CC) Activity of TII Publications (Standards).
Approval of Specific Products DN-PAV-03075	Requirements and advice for the approval of specific products not covered by a harmonised technical specification which are detailed in Specification for Works, Series 900 (CC-SPW-0900)
Construction & Commissioning - Specification for Works (CC-SPW)	
Specification for Works Series 000 - Introduction CC-SPW-00010	Introduction to the Specification for Works and general information on compliance with the EU Construction Products Regulations

TII Publication Name	Description
Specification for Road Works Series 700 - Road Pavements - General CC-SPW-00700	General requirements for pavement construction including horizontal alignments, surface levels, surface regularity; excavation, trimming and reinstatement of pavements; breaking up or perforation of redundant pavement, and rolling crown construction methods.
Specification for Road Works Series 800 – Road Pavements – Unbound and Cement Bound Mixtures CC-SPW-00800	Requirements for unbound and cement bound mixtures used in road pavements.
Specification for Road Works Series 900 - Road Pavements - Bituminous Materials CC-SPW-00900	Requirements for bituminous road pavement materials used in road pavements.
Specification for Road Works Series 1000 - Road Pavements - Concrete Materials CC-SPW-01000	Requirements for concrete road pavements.
Specification for Road Works Series 1100 - Kerbs, Footways and Paved Areas CC-SPW-01100	Requirements for Kerbs, footways, and paved areas.
Construction & Commissioning - Notes for Guidance (CC-GSW)	
Notes for Guidance on the Specification for Works NG 000 – Introduction CC-GSW-00010	Guidance on the Specification for Works Series 000 - Introduction to the Specification for Works and general information on compliance with the EU Construction Products Regulations
Notes for Guidance on the Specification for Road Works Series NG 700 - Road Pavements – General CC-GSW-00700	Guidance on the Specification for Works Series 700 - General requirements for pavement construction including horizontal alignments, surface levels, surface regularity; excavation, trimming and reinstatement of pavements; breaking up or perforation of redundant pavement, and rolling crown construction methods.
Notes for Guidance on the Specification for Road Works Series NG 800 - Road Pavements - Unbound and Cement Bound Mixtures CC-GSW-00800	Guidance on the Specification for Works Series 800 - Requirements for unbound and cement bound mixtures used in road pavements.
Notes for Guidance on the Specification for Road Works Series NG 900 – Road Pavements - Bituminous Bound Materials CC-GSW-00900	Guidance on the Specification for Works Series 900 - Requirements for bituminous road pavement materials used in road pavements.
Notes for Guidance on the Specification for Road Works Series NG 1000 - Road Pavements - Concrete Materials CC-GSW-01000	Guidance on the Specification for Works Series 1000 - Requirements for concrete road pavements.
Notes for Guidance on the Specification for Road Works Series NG 1100 - Kerbs, Footways and Paved Areas CC-GSW-01100	Guidance on the Specification for Works Series 1100 - Requirements for Kerbs, footways, and paved areas.

TII Publication Name	Description
Construction & Commissioning – Pavement (CC-PAV)	
Requirements for the Reinstatement of Openings in National Roads CC-PAV-04007	Requirements for excavating and carrying out reinstatement as a part of executing works in national roads. Prescribes materials that may be used, standards of workmanship and performance to be complied with at both interim and permanent reinstatement stages as relevant for the duration of the Guarantee Period
Rolling Crown Construction Methods CC-PAV-04009	Guidance on the methods of construction of rolling crowns, and requirements for designers and contractors in the completion of the proposals.
The Use of Close Range Photogrammetry to Characterise Texture in a Pavement Surfacing Material CC-PAV-04010	Test methodology for close range photogrammetry to characterise texture in a pavement surfacing material. It can be used to determine if a positive surface macrotexture has been achieved in Hot Rolled Asphalt (HRA) where a visual assessment to fails to determine that a positive macrotexture has been achieved.
Hot Rolled Asphalt and Coated Chippings – Checks and Key Points CC-PAV-04011	Provides Employer's Representatives and other interested parties with background information on key attributes for the installation of Hot Rolled Asphalt and Coated Chippings to enhance the understanding of the written requirements of the specifications.
Requirements for Mastic Asphalt CC-PAV-04012	Requirements for the specification of Mastic Asphalt used for the reinstatement and resetting of ironworks in the maintenance and renewal of pavement constructions.
Surface Dressing - Checks and Key Points CC-PAV-04013	Provides Employer's Representatives and other interested parties with background information on key attributes for the installation of Surface Dressing to enhance the understanding of the written requirements of the specifications.
Stone Mastic Asphalt – Checks and Key Points CC-PAV-04014	Provides Employer's Representatives and other interested parties with background information on key attributes for the installation of Stone Mastic Asphalt to enhance the understanding of the written requirements of the specifications.
Asphalt Concrete – Checks and Key Points CC-PAV-04015	Provides Employer's Representatives and other interested parties with background information on key attributes for the installation of Asphalt Concrete to enhance the understanding of the written requirements of the specifications.
Site Documentation & Traceability of Bituminous Mixtures – Checks and Key Points CC-PAV-04016	Provides Employer's Representatives and other interested parties with background information on key attributes for the collation of documentation relating to the installation of bituminous mixtures and traceability of the data.
Sampling, Storage and Retention of Bituminous Mixtures – Checks and Key Points CC-PAV-04017	Provides Employer's Representatives and other interested parties with background information on key attributes for the sampling, storage and retention of Bituminous Mixtures and constituents.
The Technical Delivery of Minor Pavement Schemes CC-PAV-04021	Serves as the starting point for the practitioner for the technical delivery of minor pavement schemes. The document provides the steps to take including references to existing TII Publications necessary to deliver a scheme.

TII Publication Name	Description
Asset Management & Maintenance – Pavement (AM-PAV)	
Skid Resistance Assessment AM-PAV-06045	Describes how measurements of skid resistance are to be made and interpreted. Sets out the procedure to be used for measuring skid resistance and assists the engineer in determining an appropriate Investigatory Level for each site.
Skid Resistance Management AM-PAV-06046	Sets out the TII policy for managing skid resistance on in-service national roads. Provides a methodology to assess the requirement and priority for remedial works.
Pavement Asset Repair and Renewal - Scheme Approval Procedures AM-PAV-06049	Procedures for the approval and delivery of Pavement Asset Repair and Renewal (PARR) schemes on the national road network.
Pavement Assessment, Repair and Renewal Principles AM-PAV-06050	Guidance on the technical aspects of the investigation and design of PARR schemes. Provides information on the review of data from the TII PAMS, visual inspections of pavement and drainage, scheme level surveys, investigations, interpretation of data, treatment options and drainage.
Crack Sealing and Joint Repair Systems AM-PAV-06059	Requirements and guidance for the use and approval of crack sealing and joint repair systems. These systems are intended for use in the repair of cracks and existing joints on National Roads.
Asset Management & Maintenance – General (AM-GEN)	
Asset Inventory (Roads) – Summary Report AM-GEN-00001	Development of a comprehensive Asset Inventory and related Asset Valuation for the TII Networks - Summarises the work carried out to deliver the Asset Inventory scope, presents the key results or findings and makes recommendations on the next steps and way forward.
Asset Valuation (Roads) – Summary Report AM-GEN-00002	Development of a comprehensive Asset Inventory and related Asset Valuation for the TII Networks - Summarises the work carried out to deliver a Gross Replacement Cost for the network, presents the key results or findings and makes recommendations on the next steps and way forward.
Approach to Skid Resistance and Related Research 2011 to 2021 AM-GEN-00003	This document focuses on skidding resistance aspects involved in the management of the national road network and describes the improvements and research that have been undertaken from 2011 to 2021 in the approach to the management of skid resistance and assessment of the performance of surfacing materials on the network.

Appendix B:

PAMS Data Dictionaries

Table B.1 Example Pavement Condition Data Dictionary

Field Name	Description	Units	Type	Decimal Places	Sample Value
RID	Linear Referencing System - Route Identifier	-	text	-	N01D1ML
LRS_Chain	Linear Referencing System - Chainage	km	numeric	3	0.010
LIRI	International Roughness Index – Left Wheel Path	m/km	numeric	1	1.3
RIRI	International Roughness Index – Right Wheel Path	m/km	numeric	1	3.2
AIRI	International Roughness Index – Average	mm	numeric	1	2.2
MPD	Mean Profile Depth	mm	numeric	1	1.3
LRUT	Rut Depth - Left Wheel Path	mm	numeric	1	1.7
RRUT	Rut Depth - Right Wheel Path	mm	numeric	1	6.4
ARUT	Rut Depth - Average	mm	numeric	1	4.0
LLPV3	3 metre Longitudinal Profile Variance – Left Wheel	mm^2	numeric	1	0.4
RLPV3	3 metre Longitudinal Profile Variance – Right Wheel	mm^2	numeric	1	2.3
ALPV3	3 metre Longitudinal Profile Variance – Average	mm^2	numeric	1	1.4
LLPV10	10 metre Longitudinal Profile Variance – Left Wheel	mm^2	numeric	1	0.9
RLPV10	10 metre Longitudinal Profile Variance – Right Wheel	mm^2	numeric	1	4.4
ALPV10	10 metre Longitudinal Profile Variance – Average	mm^2	numeric	1	2.6
Grade	Longitudinal Gradient	%	numeric	2	0.51
Crossfall	Transverse Slope	%	numeric	2	1.17
Grade_Deg	Longitudinal Gradient	Deg.	numeric	2	0.29
Crossfall_Deg	Transverse slope	Deg.	numeric	2	0.67
Radius	Radius of curvature of road	km	numeric	3	-5.964
ITM_E	Irish Transverse Mercator - Easting	m	numeric	1	717619.8
ITM_N	Irish Transverse Mercator - Northing	m	number	1	740927.0
Survey_Date	Date survey was conducted	-	date	-	15/08/2022

Table B.2 Example Skid Resistance Data Dictionary

Field Name	Description	Units	Type	Decimal Places	Sample Value
RID	Linear Referencing System - Route Identifier	-	text	-	N01D1ML
LRS_Chain	Linear Referencing System - Chainage	km	numeric	3	0.010
Survey_Date	Date survey was conducted	-	date	-	07/08/2022
Speed	Speed at which survey was conducted	kph	numeric	0	50
CSC	Characteristic Skid Coefficient	-	numeric	2	0.42
ITM_E	Irish Transverse Mercator - Easting	m	numeric	1	704993.6
ITM_N	Irish Transverse Mercator - Northing	m	numeric	1	754149.8

Table B.3 Example LCMS Data Dictionary

Field Name	Description	Units	Type	Decimal Places	Sample Value
RID	Linear Referencing System - Route Identifier	-	text	-	N01D1ML
LRS_Chain	Linear Referencing System – Chainage	km	numeric	3	0.010
LC_B1	Total Longitudinal cracks in band 1	m	numeric	3	1.234
LC_B2	Total Longitudinal cracks in band 2	m	numeric	3	1.234
LC_B3	Total Longitudinal cracks in band 3	m	numeric	3	1.234
LC_B4	Total Longitudinal cracks in band 4	m	numeric	3	1.234
LC_B5	Total Longitudinal cracks in band 5	m	numeric	3	1.234
TC_B1	Total Transverse cracks in band 1	m	numeric	3	1.234
TC_B2	Total Transverse cracks in band 2	m	numeric	3	1.234
TC_B3	Total Transverse cracks in band 3	m	numeric	3	1.234
TC_B4	Total Transverse cracks in band 4	m	numeric	3	1.234
TC_B5	Total Transverse cracks in band 5	m	numeric	3	1.234
AC_B1	Total Alligator cracking in band 1	m^2	numeric	3	1.234
AC_B2	Total Alligator cracking in band 2	m^2	numeric	3	1.234
AC_B3	Total Alligator cracking in band 3	m^2	numeric	3	1.234
AC_B4	Total Alligator cracking in band 4	m^2	numeric	3	1.234
AC_B5	Total Alligator cracking in band 5	m^2	numeric	3	1.234
RAV_B1	Total Ravelling in band 1	m^2	numeric	4	0.0625
RAV_B2	Total Ravelling in band 2	m^2	numeric	4	0.0625
RAV_B3	Total Ravelling in band 3	m^2	numeric	4	0.0625
RAV_B4	Total Ravelling in band 4	m^2	numeric	4	0.0625
RAV_B5	Total Ravelling in band 5	m^2	numeric	4	0.0625
ITM_E	Irish Transverse Mercator - Easting	m	numeric	1	717685.0
ITM_N	Irish Transverse Mercator - Northing	m	numeric	1	740994.0
Survey_Date	Date survey was conducted	-	date	-	15/08/2022

Table B.4 Example GPR Data Dictionary

Field Name	Description	Units	Type	Decimal Places	Sample Value
RID	Linear Referencing System - Route Identifier	-	text	-	N01D2ML
LRS_Chain	Linear Referencing System – Chainage	km	numeric	3	1.100
Bit_Avg	Average bitumen layer thickness	mm	numeric	0	387
Gran_Avg	Average granular layer thickness	mm	numeric	0	212
ITM_E	Irish Transverse Mercator - Easting	m	numeric	1	717685.0
ITM_N	Irish Transverse Mercator - Northing	m	numeric	1	740994.0
Survey_Date	Date survey was conducted	-	date	0	06/07/2022

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