AECOM

T0049 Collaborative research with industry partners

Executive Summary for all Work Packages

Highways England, Mineral Products Association (MPA) and Eurobitume UK

Project reference: T0049 Collaborative research with industry partners
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2021 - 2022

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T0049 Collaborative research with industry partners (2021-22)

Executive Summary

Highways projects are increasingly required to evaluate project sustainability impacts and benefits throughout the whole lifecycle. Project-wide assessment systems are usually used to do so. However, these do not always match up with the sustainability performance at a product level. Moreover, stakeholders such as designers, infrastructure owners, contractors and suppliers often do not have a single metric for assessing individual products or whole pavement systems in terms of their sustainability.

AECOM was commissioned in [month] 2021, by Highways England (HE, now National Highways), the Minerals Products Association (MPA) and Eurobitume UK to undertake research into the evaluation of sustainability measures and benefits that can be used in the development of a generic UK approach to pavement sustainability.

The project aimed to progress this area of thinking and align it more closely with sustainability labelling systems available for other manufactured products. The project presented a rationalised approach to assess sustainability that can be applied to a wide range of products, from different locations and manufacturers and is applicable at both project and programme levels. The output of this project will provide National Highways and the pavement supply chain with a flexible framework to assess and compare the sustainability impact of a range of different products and lifecycle stages.

The project comprised four work packages:

1. Work Package 1 (WP1) – Environmental Sustainability Indicators – requirements versus existing and gap analysis.
2. Work Package 2 (WP2) – Next Generation Sustainability Measurement.
3. Work Package 3 (WP3) – Material Design for Sustainability.
4. Work Package 4 (WP4) – Dissemination, Benefits & Knowledge Transfer Form.

WP1 - Environmental Sustainability Indicators – requirements versus existing and gap analysis

WP1 comprised a desktop study to identify the most suitable sustainability indicators to be taken forward to the following work packages. The desktop study reviewed the available literature and captured the knowledge of the industry partners through questionnaires, collaborative planning sessions and progress meetings. WP1 bridged the gap between existing whole-life sustainability indicators and assessment tools and potential requirements. The findings from WP1 were presented in a report “Work Package 1: Sustainability Indicators – requirements versus existing and gap analysis – Final Report” submitted in October 2021.

WP2 - Next Generation Sustainability Measurement

WP2 focused on the development of an Excel-based Framework to assist National Highways and other stakeholders in the pavement supply chain to evaluate the environmental impacts of a pavement's construction throughout its lifecycle. The Framework improves the understanding of the calculation of the environmental impact of pavements. A methodology for aggregating different products into pavement design options was also provided to enable a comparison of the sustainability impacts of different options within a pavement system. The Framework was designed in line with the Major Projects Lifecycle as set out in National Highways, Project Control Framework (PCF) handbook. The findings from WP1 were presented in a report "Work Package 2: Next Generation Sustainability Measurement – Final Report" submitted in April 2022. WP2 was delivered in three stages.

- Stage 1 assessed the means to improve the understanding of how to collect the right data, from the right people in the supply chain in a consistent format across the four stages of the asset lifecycle (product, construction, use and end-of-life). Findings indicated that information is more readily available for the product stage, with much more limited information available for the construction, use and end-of-life stages. In addition, data was especially limited for UK-based examples, with more readily available information for Europe and the USA.
- In Stage 2, multiple product data were tested using three calculation tools: AsPECT, OneClick LCA and SimaPro. This aimed to confirm whether the data being requested as part of the Framework developed in Stage 3 aligns with the data requested by the three calculation tools, across all lifecycle stages. Moreover, it enabled a comparison of the outputs across all BS EN 15804:2012+A2:2019 indicators. Product data testing showed that each calculation tool has its advantages and disadvantages. Without prejudice to any tool, it was felt that OneClick LCA was the most accessible in terms of reporting against different sustainability indicators. SimaPro was able to calculate the impacts across multiple sustainability indicators and provided a more granular split of lifecycle stages. However, it was less intuitive and harder for new users, compared to OneClick LCA. AsPECT fell short of the requirement to report against all sustainability indicators. However, it generated more accurate carbon emissions (GWP) results than OneClick LCA. This was attributed to the limited modelling capabilities and the use of generic emissions factors in OneClick LCA.
- Stage 3 aimed to enable National Highways and other stakeholders in the supply chain to compare the impact of different pavement products by translating sustainability data and calculations into scores (metrics). Due to data availability, the scoring methodology was developed for the production stage only and used four sustainability indicators. However, the scoring methodology can be applied to score the remaining stages and indicators in relation to data availability. High, Medium, and Low regimes were defined based on a comparative percentile basis of previous Environmental Product Declarations (EPD)s. This ensures that the resulting scores were based on the relative distribution of data points, rather than an absolute criterion. The scoring methodology was tested on 18 surface course products using currently available EPD data. A scoring framework was developed for the type of products that could not be tested (such as binder and base course products) due to data unavailability.

The recommendations from this stage include the need to:

1. Encourage product manufacturers (with support from the wider supply chain including contractors) to develop EN15804+A2:2019 aligned EPDs, using the data collection framework developed in this project as a guide to the data that is needed.

2. Develop consistency across the sector when calculating sustainability impacts.
3. Develop and provide training, particularly for product manufacturers and contractors, to correctly input the data into the EPD development process.
4. Further test the Framework on a real-life project and as more data becomes available.
5. Develop the scoring methodology (Stage 3) into a user-friendly online-hosted Framework.

WP3 - Material Design for Sustainability

In WP3 a guideline document towards a unified asphalt mixture design method for use in the production of asphalt materials in England was developed. The findings from WP3 were presented in a report "Work Package 3: Material Design for Sustainability" submitted in April 2022.

This work package included a comparative analysis between the asphalt mixture design approach used in England and international methodologies. England was found to be largely dependent on empirical specifications while most international approaches relied on performance specifications. The performance-based approach was found to accelerate design and approval processes for innovative pavement materials and could facilitate the future evolution of asphalt materials in England. Therefore, a move towards a more fundamental approach such as the volumetric and performance-related/based mixture design was recommended. The review identified the need to enhance laboratory assessments in the new protocol to optimise asphalt mixtures' performance and promote sustainability. It also identified the need to consider traffic loading and environmental conditions as inputs to inform the selection of material, the level of compaction, and the type and criteria of performance testing.

The output of the work package was a recommended hierarchy approach associated with the level of traffic and the risk of damage for the prescriptive, empirical, performance-related, and performance-based asphalt mixture procedures. Some outputs from these mixture designs can feed into the Excel-based Framework developed under WP2. In combination with the outputs of WP2, early data gathering, and sustainability impact assessment/scoring might be carried out in parallel with the mixture design process. This can be achieved by assigning indicative impact values depending on selected sources of components to embed the need for relevant data. Inputs gathered at the design stage can be collated and verified for/from full-scale trial and production prior to the validation of the full Life Cycle Impact Assessment (LCIA) at a scheme level. The proposed mixture design protocol potentially offers greater flexibility to include recycled and waste-derived materials with the risk to be managed by selecting the appropriate mixture design approach. These methods consider the use of Warm Mix Asphalts (WMA) which are key to National Highways achieving Net Zero by 2040 by reducing the carbon footprint associated with road construction and maintenance.

Further work is recommended to validate the outputs and proposals within the individual Work Package Reports, particularly WP2 and WP3, of this overall research package. This should include:

- Further bench-testing of the framework aggregator tool as more data becomes available,
- Develop clarity for all stakeholders on requirements and databases to be used for EPD reporting, and ensure consistency across the sector when calculating sustainability impacts,
- Validation exercises using the recommended design protocol (WP3) to identify potential benefits for physical and mechanical performance and sustainability ranking, as generated by the aggregator tool (WP2).

- Refine the design protocol and aggregator tool, or inputs to commercial tools, as necessary to meet all stakeholder needs,
- Develop the outcome of WP2 and WP3 into a user-friendly tool, hosted online, to automate scoring and mix designs and improve consistency and quality output.

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T0049 Collaborative research with industry partners

Work Package 1: Sustainability Indicators - requirements versus existing and gap analysis
Final Report

Highways England, Mineral Products Association (MPA) and Eurobitume UK

Project reference: T0049 Collaborative research with industry partners
Project number: 60657227

5 October 2021

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Quality information

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Revision History

Revision	Revision date	Details	Authorized	Name	Position
1	10/08/21	First draft of WP1 final report			
2	25/08/21	Final version of WP1 report to be circulated		Daru Widyatmoko	Work Package Manager
3	05/10/21	Final version addressing the project sponsors' comments		Daru Widyatmoko	Work Package Manager

Distribution List

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1. Abbreviations and Acronyms

Table 1-1. List of abbreviations/acronyms used in this report.

Acronym/Abbreviation	Explanation/Definition
AsPECT	Asphalt Pavement Embodied Carbon Tool
BEIS	Department for Business, Energy and Industrial Strategy
BREEAM	Building Research Establishment's Environmental Assessment Method
CEDR	Conference of European Directors of Roads
CEEQUAL	The Civil Engineering Environmental Quality Assessment & Award Scheme
DMRB	Design Manual for Roads and Bridges
EPD	Environmental Product Declaration
FWD	Falling Weight Deflectometer – a testing device used by civil engineers to evaluate the physical properties of pavement.
HE	Highways England
ICE	The Inventory of Carbon and Energy
KPI	Key Performance Indicator
LCA	Life Cycle Assessment
LCI	Life Cycle Inventory
LCM	Life Cycle Management
MPA	Minerals Products Association
PCI	Pavement Condition Index
PCR	Product Category Rule
PIARC	Permanent International Association of Road Congresses; now known as World Road Association.
PMB	Polymer Modified Bitumen
SCRIM	Sideway-force Coefficient Routine Investigation Machine - used to measure wet skidding resistance on road surfaces.
SEVE	Software used to compare two technical solutions based on the partial life cycle analysis of each of them.

2. Introduction

Background to the project

AECOM was commissioned by Highways England (HE, now National Highways), the Minerals Products Association (MPA) and Eurobitume UK to undertake research into the evaluation of sustainability measures and benefits that can be used in the development of a generic UK approach to pavement sustainability.

Recently, there has been a proliferation (of availability) of sustainability accreditation systems and 'eco-labels' across all construction sectors, with actual adoption taking place in the building and vertical development sector, but less so elsewhere. Highways projects are increasingly required to demonstrate whole project sustainability benefits through the whole life cycle using project wide accreditation systems, such as CEEQUAL, and these do not always match up with the sustainability performance at a product level.

Designers, procurers and contractors often do not have a single specification for sustainability comparators when assessing products or whole pavement systems. This research seeks to progress this area of thinking and align it more closely with sustainability labelling systems available for e.g. manufactured products. The research should inform a rationalised approach to assessing sustainability that can still apply to a wide range of products, from different locations and manufacturers and should be applicable at a project or programme level, allowing for flexibility in specification throughout the lifecycle.

The project is split into four work packages, comprising:

- Work package 1 (WP1) – Sustainability Indicators – requirements versus existing and gap analysis
- Work package 2 (WP2) – Next Generation Sustainability Measurement
- Work package 3 (WP3) – Material Design for Sustainability
- Work Package 4 (WP4) – Dissemination, Benefits & Knowledge Transfer Form

Purpose of this report

This report aims to summarise the key outputs associated with WP1 of this research project. The methodology used to conduct initial research on sustainability indicators is presented before discussing the key outputs of the literature review, questionnaire and collaborative planning session. Using these outputs, some high-level suggestions and recommendations have been provided for the next steps in WP2.

Objectives

The main objectives of this research were as follows:

- Undertake research into the evaluation of sustainability measures and benefits which, following successful outcomes of this research, may be added, or used in discussion on to the HE standards forward programme.
- The research will support the development of a generic UK approach to pavement sustainability measurement for pavement construction products and processes e.g. sustainability in design, procurement, specification, application and assessment of pavement materials and design assumptions.
- The research will also seek to collate information on what other sectors and industries are doing and take account of future targets e.g. reduced CO_2e and Net Zero.

Work Package 1

The main steps of WP1 are highlighted in Figure 1 and the scope is listed below:

- A desktop review (also referred to as literature review) of existing whole life sustainability indicators and assessment tools for materials, products and pavement construction.

- An evaluation of the initial literature review to select those indicators that are most relevant to flexible pavements.
- Finalisation of the assessment criteria based on the findings from the collaborative planning session and further research.
- Analysis of all the identified indicators to be taken forward to WP2.

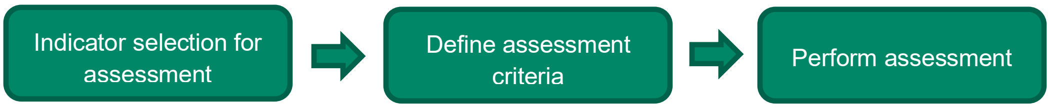

Figure 1 - Flowchart of the main steps associated with WP1.

Work Package 2

As this report discusses some high-level recommendations for WP2, the scope of WP2 is detailed below with the main steps highlighted in Figure 2:

- Determine suitable indicators for flexible pavements, relating to sustainability performance.
- Define and rate each indicator to allow for assessment and scoring.
- Develop a framework to allow for data input and scoring.
- Pilot the framework for 2-3 products.

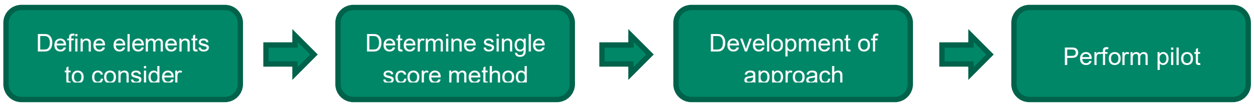

Figure 2 - Flowchart of the main steps associated with WP2.

3. Methodology

A six-step methodology (detailed below) was used to deliver against the objectives of WP1. An iterative process was used in WP1 to ensure that research was coherently undertaken and captured the knowledge of the industry partners.

1. Initial research undertaken by AECOM
    - Initial research into existing sustainability indicators and assessment tools for materials, products and flexible pavement construction was undertaken to help inform the collaborative planning session.
    - Research included project, asset or system level sustainability assessment schemes and standards, as well as tools, software and calculators.
2. Questionnaire developed by AECOM and shared with industry partners
    - In advance of the Collaborative Planning Session, AECOM asked all attendees to complete a questionnaire on their previous experience using various sustainability tools.
    - 78% of those asked completed the survey which focused on participants' general knowledge of tools, challenges experienced, data difficulties in relation to sustainability metrics, lifecycle stages and performance criteria to be considered, and ideas to successfully implement a new tool, if required.
3. Further research undertaken by AECOM
    - Findings from the questionnaire were noted and further research on specific outputs (such as additional tools identified by the industry partners) was subsequently conducted.
4. Collaborative planning session with industry partners
    - The collaborative planning session was held virtually via Microsoft Teams on Monday 28th July 2021 with 26 attendees from AECOM, HE and across the Eurobitume UK and MPA memberships. The main focus of the session was to discuss four key topics: work done to date in the field, need for and scope and boundaries of a new assessment tool, experience of applying existing indicators, and the inclusion of in-life processes.
    - The session helped expand the information gathered as part of AECOM's initial research and provided further information for the AECOM team to research in more detail.
5. Final research undertaken by AECOM
    - Additional tools/initiatives raised during the collaborative planning session were then researched by AECOM in more detail as part of the literature review.
6. Recommendations for WP2
    - An interim report for WP1 (in the form of a PowerPoint Presentation) has been completed and presented to the industry partners. The interim report summarised the key findings in the literature review, questionnaire, and the collaborative planning session.
    - Recommendations for next steps of tool development (part of WP2) have been discussed with industry partners at a progress meeting held on Monday 26th July 2021. Details of the discussion are presented in Section 6 of this report.

4. Literature review

Criteria used in research

AECOM undertook desktop research of project, asset or system level sustainability assessment schemes and standards, as well as tools, software and calculators. For each of the tools researched, a set of criteria, detailed in Table 4-1, was used to enable comparisons to be made.

Table 4-1. Criteria used for assessment.

Broad category of criteria	Detailed criteria
Background Information	Background information including type of tool and managing company (if any)
Sustainability Aspects	Sustainability aspects including: • Scope of assessment (product/material level, or product/asset/system level) • Sustainability topics considered by the tool • Metrics or KPIs used • Boundaries of assessment
Functionality	Functionality aspects including: • Transparency (a score was given between 1 and 5 where 5 = inputs/outputs are clear and easily found, 1 = not clear what is included) • Data required to input into tool • Ease of use and/or application (a score was given between 1 and 5 where 5 = easy, 1 = difficult) • Simplicity of output (a score was given between 1 and 5 where 5 = simple, 1 = complex) • Uptake/popularity (a score was given between 1 and 5 where 5 = widely used/well known, 1 = relatively new or not widely used) • Level of verification provided when using the tool.
Additional Information	Additional information including examples of use, references to key documents and any other comments.

Key findings

A high-level summary of project, asset or system level sustainability assessment schemes and standards, as well as tools, software and calculators that have been reviewed is provided in Table 4-2, with a more detailed version provided in Appendix A.

Out of 23 tools, standards, indicators, and schemes reviewed: 23 (100%) include carbon/energy as an indicator, 15 (65%) include additional environmental indicators such as pollution and waste impacts, and 8 of the 23 (35%) include social indicators such as social fairness and responsible sourcing. Therefore, it can be concluded that carbon is the most widely used sustainability indicator and the majority of existing tools for asphalt, pavement and highways are focused on carbon only.

Most tools include all lifecycle stages, apart from some carbon-specific tools such as SEVE which do not include the end of life stage.

In addition, most tools either use verified databases (e.g. EcoInvent or ICE database) or require external verification of data. There is also some variation in scope and complexity, especially amongst the detailed Product Category Rules (PCR) and tools available for producing Environmental Product Declarations (EPDs).

It was also noted that there are existing and ongoing studies in Europe and internationally to review available tools, for example the PIARC study which reviews 11 carbon footprint tools for pavements. In addition, the Pavement Life Cycle Management (LCM) project is reviewing Sustainability Performance Indicators for pavement materials and pavement activities. It is expected that the Pavement LCM outputs will include tools, guidelines, datasets and roadmaps.

Table 4-2. High-level summary of desktop research.

Type	Name	Overview	References
Project, asset, or system level sustainability assessment schemes and standards	Highways England carbon calculator	Calculator for embodied carbon, carbon emissions from construction site or maintenance area, and emissions from processing of waste, developed by HE. Can be used to assess carbon only at product/material level and also project/asses/system level. Used on all HE schemes. Uses carbon factors from Institute of Civil Engineers.	https://www.gov.uk/government/publications/carbon-tool https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/899360/Highways_England_Carbon_Tool_Guidance_Document_v2.3.pdf
	BREEAM	Ratings/Assessment scheme developed by BRE for buildings, including a range of sustainability related aspects. Includes assessment for roads associated with a building-related project, including the use of BREEAM Wst02 calculator for the sustainability impacts of aggregates. Points awarded under a number of clauses. Performance rating of 'pass', 'good', 'very good', 'excellent' or 'outstanding'.	BREEAM UK New Construction non-domestic buildings (UK) Technical Manual SD5078: BREEAM UK New Construction 2018 2.0
	CEEQUAL	Ratings/Assessment scheme developed by BRE for infrastructure projects, including a range of sustainability related aspects. Points awarded under a number of clauses. Performance rating of 'pass', 'good', 'very good', 'excellent' or 'outstanding'. Used widely in infrastructure projects.	CEEQUAL Version 6 Technical Manual | UK & Ireland Projects SD6051:0.0
	Greenroads	Project/asset/ system level rating system for transport projects. Performance rating of 'bronze', 'silver' or 'gold', based on points scored within a set of 12 sustainability aspects including social and environmental topics. Not widely used within the UK. Required third party review and registration with the Greenroads Foundation.	https://www.greenroads.org/2286/who-we-are.html https://www.greenroads.org/files/12205.pdf
	CEN CWA 17089	European Workshop Agreement for indicators for the sustainability assessment of roads. Sets out recommended Sustainability Performance Indicators (social and environmental) to measure the sustainability of roads, with the aim of supporting National road authorities, private operators, contractors and engineering companies when considering sustainability for roads.	https://shop.bsigroup.com/ProductDetail/?pid=000000000030352879 Indicators for the sustainability assessment of roads, Technical Committee CTN 41/SC 2 Roads the Secretariat of which is held by AEC. Spanish standard UNE-CWA 17089 June 2019
	EN 15643-5 Sustainability of construction works	European standard for Civil Engineering and construction work, providing guidance on the lifecycle modules to assess for each project/asset/system (building on EN 15804) in relation to the functional equivalence (e.g. 1km of road for a specific capacity and period of time).	CEN standard 15643-5, July 2018: Sustainability of construction works. Sustainability assessment of buildings and civil engineering works. Part 5: Framework on specific principles and requirement for civil engineering works
	PAS 2080	BSI standard for carbon management, providing guidance on carbon management across all lifecycle stages. The guidance details very clearly what should and should not be included in carbon calculations depending on the level of detailed data and the lifecycle stages to be included.	https://www.bsigroup.com/en-GB/our-services/product-certification/product-certification-schemes/pas-2080-carbon-management-in-infrastructure-verification/
Tools, software, and calculators to assess product and/or project/asset/system level sustainability	Cradle to Cradle (C2C)	A certification scheme for any type of product in any sector. Widely used in the consumer goods sector. Focused on circular economy but includes other aspects such as water stewardship and social fairness. Levels of certification are: Bronze, Silver, Gold and Platinum.	https://www.c2ccertified.org/get-certified/product-certification
	EN15804 PCR / EPDs	Product Category Rules (PCR) for Environmental Product Declarations (EPDs) for construction products. A range of environmental impacts are included across the whole life cycle of a product.	https://www.bre.co.uk/filelibrary/Materials/BRE_EN_15804_PCR.PN514.pdf
	BES 6001	Framework Standard for responsible sourcing of construction products, developed by BRE. Points awarded for organisational management, supply chain management, and environmental and social requirements. Performance rating of 'pass', 'good', 'very good' or 'excellent'. A range of environmental impacts are included across the whole life cycle of a product.	https://www.bregroup.com/insights/bes-6001-framework-for-responsible-sourcing/ https://www.researchgate.net/publication/273386865_Analysis_of_responsible_sourcing_

		performance_in_BES_6001_certificates
Dutch PCR 0.6	Product Category Rules for EPDs for bituminous materials. Sustainability aspects included are aligned with EN 15804.	https://www.pavementlcm.eu/2020/11/30/second-pavementlcm-workshop-eapa-webinar-sustainability-assessment-of-asphalt-pavements/ 2 webinars that are relevant, Rob Hoffman and Elisabeth Keijzer. https://translate.google.com/translate?hl=en&sl=nl&u=https://docplayer.nl/185507158-Pcr-0-6-bitumineuze-materialen-in-verkeersdragers-en-waterwerken-in-nederland-pcr-asfalt.html&prev=search&pto=aue
DuboCalc	Sustainable Construction Calculator based on LCA methodology, providing a range of environmental metrics and also an Environmental Cost indicator. Covers construction, use, maintenance and End of Life. Created in Dutch, uptake in the UK is unknown.	https://www.dubocalc.nl/en/what-is-dubocalc/
SEVE	Software to assess environmental impacts of maintenance works or building works on roads. Created by LIFE+ SustainEuroRoad project, co-financed by the European Commission, focus on GHG emissions, resource preservation, and transportation.	https://sustainableroads.eu/seve-software/ https://sustainableroads.eu/wp-content/uploads/2017/10/Brochure-SEVE-eng.pdf
AsPECT	Asphalt Pavement Embodied Carbon Tool to calculate lifecycle emissions of asphalt used in highways. A joint initiative of Highways England, Mineral Products Association, and Eurobitume UK. Can be used to calculate lifecycle carbon emissions using BEIS emissions factors or ICE database. Used widely in highways construction in the UK.	https://trl.co.uk/permanent-landing-pages/asphalt-pavement-embodied-carbon-tool-aspect/ https://trl.co.uk/uploads/trl/documents/PPR960---Review-and-update-of-the-asPECT-carbon-footprinting-tool.pdf https://trl.co.uk/Uploads/TRL/Documents/asPECT%20Guidance%20v4.2%20%20-%20%20August%202020%20-%20clean.pdf
ORIS	Digital Material Platform to evaluate road projects, developed by Lafarge Holcim. Considers all lifecycle stages and focused on using local resources and reducing carbon emissions. Limited publicly available information on data requirements and outputs.	https://www.oristic.net/ https://www.lafargeholcim.com/oris-ibm-partnership
ERA-NET Road programme	Sustainability and Energy Efficient Management of Roads was initiated, and funded by the National Road Authorities of Germany, Denmark, Ireland, Netherlands, Norway, Sweden and United Kingdom. Outputs include 4 separate projects: 1. SUNRA (a tool to identify relevant sustainability topics, set targets, and plan implementation for sustainability on road projects); 2. CEREAL (a decision tool for National Road Authorities and contractors for CO2 Emission Reduction in Road Lifecycles); 3. LICCER (A model for assessment of lifecycle energy and GHG emissions of road infrastructure for early design decisions to inform transport planning and procurement e.g. at EIA stage); and 4. MIRAVEC (a tool to Model Infrastructure Influence on Road Vehicle Energy Consumption to reduce energy and emissions).	https://www.cedr.eu/call-2011-energy https://www.cedr.eu/download/other_public_files/research_programme/eranet_road/call_2011/energy/final_report/00_enr-energy_final_report-2014.pdf
EDGAR – Evaluation and Decision	Research programme from Conference of European Directors of Roads, funded by Austria, Germany, Norway, UK, Slovenia and Netherlands. Developed a tool focused on assessing the	https://www.cedr.eu/call-2013-energy-efficiency

	process for Greener Asphalt Roads	sustainability (environmental, social and economic) impacts of asphalt and bituminous materials across the lifecycle. Uses 11 indicators, with calculation methods taken from other sources such as BES6001 for the responsible sourcing indicator.	
	Eurobitume LCI	LCI of an average bitumen produced in any refinery in Europe. The tool includes all LCA indicators and is aligned to EN15804.	https://www.eurobitume.eu/fileadmin/Feature/LCI/EUB2975.001_LCI_Update_2020_01_LR_pages.pdf
	EPD Norge Tool	Product Category Rules for products. It is an EPD generator tool that is web-based and has been developed by LCA. The tool is based on EN15804 and takes account of all environmental impact metrics. The data within the tool is verified and tool itself has also been verified by a third party.	Webinar (Geir Lange and Ole Iversen: https://eapa.org/webinar-sustainability-assessment-of-asphalt-pavements/ PCR: https://www.epd-norge.no/getfile.php/137316-1492770283/PCRer/NPCR%20025%202017%20Part%20B%20for%20Asphalt.pdf
	OneClick LCA	Can calculate carbon and EPDs for products, GHG reporting for corporates and/or conduct building and infrastructure LCAs.	https://www.oneclicklca.com/
Relevant research being conducted	Pavement LCM	Research programme from Conference of European Directors of Roads. Capacity building project introducing Life Cycle Management (LCM) in National Road Authorities with a focus on Sustainability Assessment for both asphalt mixtures and road pavements. Ongoing project, due to finish in Summer 2021.	https://www.pavementlcm.eu/ https://eapa.org/webinar-sustainability-assessment-of-asphalt-pavements/
	LCA of French hot-mix asphalt concrete and asphalt pavement	Study to quantify the environmental impacts of representative French bituminous asphalt and of pavement based on it using the LCA method.	https://www.routesdefrance.com/wp-content/uploads/3-20160113_LCA_-USIRF_Final-report.pdf

5. Findings from planning session

Outcomes of pre-planning session questionnaire

In advance of the Collaborative Planning Session, all attendees were asked to complete a questionnaire on their previous experience using various sustainability tools. 78% of those asked completed the survey which focused on participants' general knowledge of tools, challenges experiences, data difficulties in relation to sustainability metrics, lifecycle stages and performance criteria to be considered in the new tool, and ideas to successfully implement a new tool.

Awareness of existing tools

Participants were asked to select as many of the indicators for product and/or project level sustainability assessments identified by AECOM's initial review that they were familiar with. The majority of respondents were aware of AsPECT and BREEAM, while tools such as SUNRA and LICCER were not as well known. Results from the questionnaire are present in Table 5-1.

Table 5-1. Participants' knowledge of indicators identified in AECOM's initial review.

Indicators identified in initial review	% of responses with knowledge of tool
AsPECT	79%
BREEAM	79%
EN15804 PCR / EPDs	58%
CEEQUAL	47%
BES 6001	47%
Cradle to Cradle (C2C)	37%
CEEQUAL carbon tool	37%
Greenroads	26%
Pavement LCM	26%
EN 15643-5 Sustainability of construction works	26%
ORIS	21%
SEVE	21%
EDGAR – Evaluation and Decision process for Greener Asphalt Roads project	21%
DuboCalc	16%
ERA-NET Road programme 2011 projects (SUNRA, CEREAL, LICCER, and MIRAVEC)	5%
CEN CWA 17089	5%
None of the above	5%

Challenges experienced

Participants raised a number of challenges that they have experienced in relation to product and/or project level sustainability assessments. Any new tool that is developed as part of this research will aim to address challenges currently experienced by participants. The main areas of concern are listed below:

- Lack of consistency when measuring sustainability aspects, such as carbon, as there are too many options available at the moment that differ slightly in their methodology or unit of measurement.
- There is a challenge in estimating durability / lifetime in a whole life cycle assessment.
- Usability of tools often cause challenges for users.

  - It is time consuming to gather data in the correct form from the correct people throughout the duration of a project.
  - There is a lack of simplicity for lay users, particularly with technical sustainability topics.
- Some tools are using outdated datasets.
  - PCRs may not be consistent or comparable between product types.
  - AsPECT was noted as having incorrect constants that could potentially stifle innovation. The default carbon values provided are relatively modest so there is no incentive for users to input their own data and aim for lower carbon results. Industry standard values are also used, which doesn't allow for differentiation.
- There is often a lack of third-party verification.
- There is a lack of flexibility with some tools.
  - The ability to change or improve methods on a project by project basis is difficult and involves wider collaboration with the client.
- There is a lack of buy-in from relevant stakeholders.

In addition to challenges experienced with various product and/or project level sustainability assessments, participants were also asked to provide any information on where there may be difficulties in obtaining sustainability-related data. The following four key concerns were raised in the questionnaire:

- Lack of willingness from suppliers throughout the supply chain to provide data.
  - Gathering the correct data for each part of a lifecycle assessment often involves more than one contractor or supplier. This can make it difficult to distinguish who has responsibility for data associated with specific aspects of the life cycle.
- Gathering data that is sufficiently detailed to undertake the correct assessments.
  - Accurate and up to date data will be necessary in a fast-developing system.
  - True carbon footprint of bitumen and accurate energy usage figures for individual asphalt products.
  - CO_2e data from external sources.
  - Construction method carbon.
  - Project-specific data such as water, fuel, pavement type.
- Gathering data on wider sustainability topics (i.e. not carbon which is commonly captured).
  - Noise and air pollution data for example is difficult to gather on a common basis, let alone more social aspects of sustainability.
- Data validation across sustainability topics might be difficult to obtain consistently.

Views on lifecycle stages

Participants were also asked which of the lifecycle stages would be most appropriate to be included in a new tool and which of those are most relevant to pavements. Table 5-2 provides the participants' view as to which of the lifecycle stages should be included in a sustainability assessment. All participants agreed that the product and construction stage should be included in any sustainability assessment. There was more discrepancy in the inclusion of the remaining lifecycle stages: use stage, end of life stage and benefits of loads beyond the system boundary.

Table 5-2. Summary of the lifecycle stages considered most useful in pavemment sustainability assessments.

Lifecycle stages to be considered	% of responses
Product stage (raw materials, transport, manufacturing)	100%

Lifecycle stages to be considered	% of responses
Construction process (transport to site, construction)	100%
Use stage (application, maintenance, repair, replacement)	79%
End of life stage (transport, waste processing, disposal)	89%
Benefits of loads beyond the system boundary (reuse, recovery, recycling)	84%

Performance criteria

In addition to understanding the sustainability aspects that should be included in a new assessment tool, the questionnaire also asked participants for specific pavement performance criteria that should also be included. The list below illustrates the key suggestions from participants.

- Pavement condition index (PCI) should help determine the current condition of pavements and the extent of maintenance required.
  - Use current surveys e.g. FWD, SCRIM to determine the condition of pavements.
  - Determine the condition and type of existing flexible pavement, such as pen grade binder vs. Polymer Modified Bitumen (PMB), crack resistance, full depth reconstruction vs. inlays.
- Estimated service life should be used to understand the full lifecycle of the pavement into end of life and beyond.
- Environmental conditions and impacts.
  - Impact of prevailing weather on pavement.
  - Resources used and impact on the surrounding environment such as waste to landfill.
- Safety for the user.

Implementation of a new tool

The questionnaire also posed questions on what success would look like in a new assessment tool. Responses have been categorised into five key areas and many address the challenges that participants expressed in earlier parts of the questionnaire.

- Ensure the tool has buy-in.
  - Industry buy-in at all levels, including simple and meaningful cascading of outputs.
  - Buy-in from all stakeholders, including designers, engineers, suppliers, contractors, clients and the public.
  - The tool should be recognised within industry and the wider community and have government backing.
- Request the use of the tool in tender/procurement docs.
  - Make the use of the tool compulsory through contracts to ensure consistency across the sector.
  - For optimal impact the tool could be specified in a DMRB annex (discussions with HE required).
- Pilot the use of the tool.
  - Use the tool on key schemes and gain feedback on usability before amending the tool and publishing.
- Ease of use for all users.
  - The tool needs to be easy to use so all those in the supply chain can be involved. Some inclusion of ongoing support may be required during implementation with some audits to support consistency.
  - Simple, consistent and accessible for the asset holders.

   - Clarity of use and outputs that are universally acceptable.
- Ensure the right tool is developed.
   - Collaboration with all relevant stakeholders.
   - The tool needs to be transparent, drive the right decisions and not be too onerous and costly.
   - Needs to be measurable and comparable.

Outcomes of planning session

The collaborative planning session was held virtually via Microsoft Teams on Monday 28th July with 26 attendees from AECOM, HE, Eurobitume UK and MPA.

The aim of the collaborative planning session was to enable the AECOM team to explore and understand the collaborative partner's experience in this area and take forward learnings where appropriate. The planning session was focused on four main topics as shown in Table 5-3 below.

Table 5-3. Summary of discussion topics in the collaborative planning session.

Discussion Topics	Specific Questions
Work done to date in the field	1. What research work are you aware of that could be relevant to this study? 2. For anyone that has used tools developed by Conference of European Directors of Roads projects or applied/worked on their research, can you share any key learnings / views? (e.g., the SUNRA, CEREAL, LICCER, MIRAVEC, and EDGAR tools and ongoing Pavement LCM).
Scope and boundaries of assessment	1. How far up and down the supply-chain does the indicator need to go (e.g. to consider raw materials and end-of-life)?
Experience of applying existing indicators	1. Have you used existing indicators, and what are their strengths and drawbacks?
Inclusion of in-life processes	1. How can an indicator take account of maintenance and repair issues? 2. What data is most readily available/most appropriate for assessing maintenance, repair, and replacement requirements?

Work done to date

The general consensus amongst participants was that the situation is relatively mature in terms of research, but the practical application of these assessment tools is still an issue.

Discussions focused on the need for all tools to align with EN15804 as this is the baseline standard for industry. For wider sustainability themes, suggestions were provided to look at the DMRB GG103 guidance, which contains 12 goals of sustainable development to be considered during highways design, and SUNRA, which is the Swedish Highways sustainability assessment tool that contains 12 core topic areas for road and bridge design.

Participants also provided suggestions of tools for the AECOM team to research further. This included: PAS 2080, One-Click LCA, Greenbook live, the ICE database and Environmental Product Declarations (EPDs). Participants also recommended the AECOM team look into research being conducted by the Conference of European Directors of Roads (CEDR) and PIARC World Road Association.

Scope and boundaries of assessment

Following on from the findings in the questionnaire, the scope and boundaries that should be included in a sustainability assessment were discussed in more detail at the planning session. The discussions took the form of two main viewpoints:

- The whole lifecycle should be included.
   - Risk of missing re-use/recycling benefits if whole life isn't included.
   - Maintenance should also be included as part of the assessment.

  - Adding whole lifecycle functionality into a tool today will make it more usable for the future.
  - There is more customer demand for whole life assessments, rather than selected parts of a lifecycle assessment.
- The use stage and end of life stage could be excluded in the initial phase of the tool.
  - There are many challenges with the use stage and end of life stage so why include it in our scope if it will be primarily based on assumptions.
  - In the use phase, it's difficult to build in reasonable scenarios as the scheme today may not be the same in the future. To avoid inaccuracy, it is perhaps better to exclude this stage from the assessment tool.

Experience of applying existing indicators

Detailed discussions took place with participants on their experience of specific tools and the lessons that could be learnt for this new assessment tool.

Specifically, discussions focused on the Dutch PCR system, for which the main positives and negatives are listed below:

- Positives of using the Dutch PCR system.
  - Incentive to calculate your own product numbers (high default numbers used if users are unable to calculate their own products).
  - The tool is linked to cost as one of the outputs is a value in Euros for the environmental burden of your product. The main output of the system is an EPD.
  - The tool includes a broad range of sustainability issues, including 18 indicators, of which carbon is one.
  - The system is a rigorous process that results in a fair and equal comparison between all products.
- Negatives of using the Dutch PCR system.
  - The Dutch system is a complex system that draws heavily on commercial databases.
  - The system is auditable, and users must get third party sign off before any of the values can be used by customers – this can be seen as a rigorous process that is very time consuming.
  - The system is expensive: the cost involved in the actual system, annual audits and renewals of data, change data every time the rules change. This will have a bigger impact on smaller organisations compared to those that are more established in the industry.

More generally, participants also raised the following as further considerations when developing a new assessment tool:

- Challenge of normalising data and standards in order to enhance comparability.
- Make the input of data as easy as possible, such as the HE carbon tool. Users only need to input the quantity of materials which assumes no prior technical knowledge and is therefore applicable to a broader audience.
- Challenge of ensuring we have a level playing field within the industry. There was a suggestion for users to submit their data to a verifier who will conduct spot checks. This should encourage users to input the correct information without it becoming overly onerous on users in terms of resource and time.

Other key findings

Some further discussions took place on whether a brand new tool needs to be developed. Participants questioned whether there is potential to use a tool that already exists or create an umbrella tool that can bring in various existing tools. It was discussed that the majority of attendees have had some experience/knowledge of

AsPECT, which makes it a good contender to be upgraded so it is easier to use, produces outputs more easily and calculates broad sustainability impacts rather than carbon only.

The planning session primarily focused on carbon and there was some discussion as to how weighted the new assessment tool should be towards this indicator compared to other sustainability topics. There was a suggestion from participants to start with those sustainability indicators that are regulated by for example HE, Net Zero policies or sustainability strategies. Sustainability topics should be split into must haves and nice to haves when developing the new assessment tool, in the given budget and time constraints.

6. Analysis and next steps

Following the planning session, a progress meeting was held with HE, MPA and Eurobitume UK on Monday 26th July 2021. AECOM presented the key findings in this report as well as options for the project sponsors to consider in WP2. The two options presented at the meeting are detailed below with a summary of the discussions.

Option 1 for further development

A 'calculator' tool that helps pavement supply chain organisations to calculate sustainability impacts of their products and materials. This could take the form of a new tool or it could be an extension/development of an existing tool.

Figure 3 demonstrates how a calculator tool may function in practice.

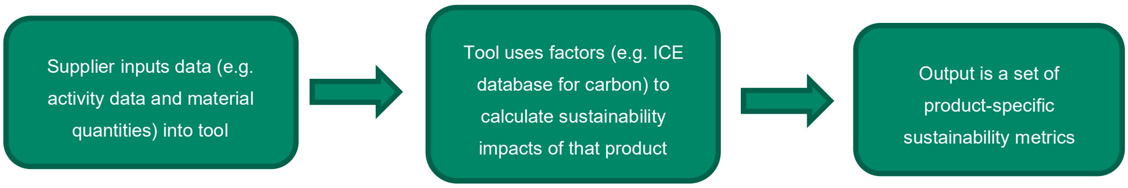

Figure 3 - Example of how a calculator tool would work in practice.

Potential benefits:

- Could help to address the challenges with current tools (e.g. carbon factors in AsPECT limiting innovation).
- Could help to bring more consistency in calculation methods across the supply chain, helping HE and others to be able to compare and contract sustainability impacts of different products more easily.

Considerations:

- There are many existing tools for calculating sustainability and carbon impacts and adding another to the market may add confusion.
- A tool to align with EN 15804 would be complex to build and to use and would require alignment with an LCA database, requiring a licence and regular updates.
- May not help with decision making on a system/pavement design level.
- Assessing other relevant sustainability indicators that are not easily quantifiable may be challenging.

Key discussion points:

- This option would address carbon, which is the main area of current focus for the majority of participants. This option also has the ability to develop further as wider sustainability aspects are expanded.
- Some concerns were raised as to where the ongoing cost and maintenance of a calculator tool would lie.
- Option 1 would add more value to those involved in the asphalt industry.
- If AsPECT was used as the basis for further development, it will be essential that the responsibility for each of the lifecycle stages is identified and reasonably allocated.

Option 2 for further development

An 'aggregator' tool/methodology where product information is inputted from other existing tools and combined to provide scoring and a comparison of sustainability impacts of different pavement systems.

Figure 4 demonstrates how an aggregator tool may function in practice.

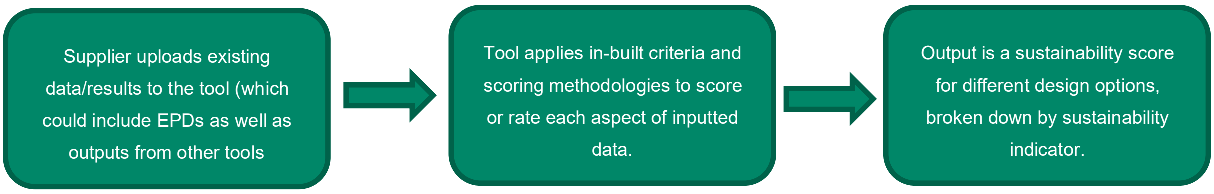

Figure 4 - Example of how an aggregator tool would work in practice.

Potential benefits:

- Could enable the evaluation and comparison of sustainability impacts, benefits, and trade-offs of different pavement designs and products at an asset or system level.
- Could provide an easy to understand scoring output, translating complex data into simple metrics.

Considerations:

- Does not address limitations of existing tools.
- Will require careful consideration of data quality and calculation methodologies to enable comparisons to be made and to compare like with like.
- Where other relevant sustainability indicators are not currently being measured, consideration as to how the tool will capture this information.

Key discussion points:

- Some concerns were raised about data consistency and how data could be gathered in a consistent way and how it would be policed to ensure data integrity.
- Option 2 would acknowledge some of the other sustainability priorities, such as air quality, climate resilience, and biodiversity.

General consensus

Participants in the progress meeting provided a steer on the direction of travel for WP2. A summary of the discussion is provided below, which will now form the basis of WP2.

- Most of the discussion focused on the importance of accurate and consistent measurement of carbon data throughout the supply chain to help manufacturers and HE to understand their baseline and how to reach net zero carbon emissions.
- It was felt that a lifecycle approach is needed, from cradle to grave/cradle to cradle. But this needs to allow for the various players in the supply chain to be allocated responsibility for their relevant data points.
- There was a general consensus that the approach needs to be a combination of Options 1 and 2, but with a focus on measurement to aggregate data across the supply chain, potentially with an aspect of scoring/aggregating to allow for pavement level comparison as well as product level assessment.
- Participants felt that the following indicators were most important to consider:
  - Land, water and air quality
  - Carbon
  - Resource efficiency
  - Responsible sourcing.

- Aligning the new assessment tool to EN 15804 was also suggested, which requires assessment of the following indicators:
  - Air
    - Carbon/Global warming potential (CO_2e)
    - Ozone layer depletion (ODP) (kg CFC-11 eq)
    - Photochemical oxidation (kg C2H4 eq)
  - Resource Use
    - Abiotic depletion (kg Sb eq)
    - Abiotic depletion (fossil fuels) MJ
  - Water
    - Fresh water aquatic ecotoxicity (kg 1,4-DB eq)
    - Marine aquatic ecotoxicity (kg 1,4-DB eq)
    - Acidification (kg SO2 eq)
    - Eutrophication (kg PO4--- eq)
  - Land
    - Terrestrial ecotoxicity (kg 1,4-DB eq)
  - Human
    - Human toxicity (kg 1,4-DB eq)
- Participants questioned whether AsPECT could be further developed to assign clear responsibilities to allow for better aggregation of data across the supply chain, and inclusion of wider sustainability indicators in line with EN 15804.

Next Steps

Following the finalisation of WP1, AECOM has reviewed all the findings from the questionnaire, collaborative planning session and progress meeting to produce an updated scope and high-level methodology for the WP2 deliverables. A briefing note, containing an updated scope and methodology, has been be shared, discussed and confirmed with the project sponsors on 17th August 2021[1].

[1] For more details on the scope and methodology for WP2, please refer to the briefing note circulated by AECOM, titled 'Update to Scope for WP2'.

Appendix A - Extract of Detailed Literature Review

A more detailed version of the literature review findings is presented in Table 6-1.

Table 6-1. Detailed literature review findings.

Name	Overview	Sustainability aspects included	Metrics, indicators and data	Lifecycle stages	Transparency, ease of use, and simplicity of output	Uptake / popularity	Verified data?
Highways England carbon calculator	Carbon tool with emission factors for products/project/ asset/system.	Carbon only. Factors from ICE V3 used.	tCO2e per tonne or m3 depending on product type	Manufacturing construction, end of life	Easy to apply at different scales and in different contexts	Requirement for all HE schemes.	ICE emissions factors are verified
BREEAM	Ratings/Assessment scheme for infrastructure projects	• Material resource efficiency, • Whole life carbon emissions • Presence of LCA and/or EPD • Hazardous materials • Low VOC and/or biodegradable coatings • Application of coatings.	Performance rating of 'pass', 'good', 'very good' 'excellent' or 'outstanding'.	All	Requires detailed data collection across a wide range of aspects. Specific requirements and guidance for points in each category. Not freely available	>550,000 buildings have been BREEAM-certified.	Points for independent third-party certification
CEEQUAL	Ratings/Assessment scheme for buildings	• Social cost of transport for transport of aggregates (including air quality & noise) • Mineral depletion of aggregates • Carbon footprint of aggregates • Points for LCAs, EPD, responsible sourcing, designing for resilience, and material efficiency	As per BREEAM	All	As per BREEAM	Used widely in infrastructure projects. More than 300 projects have CEEQUAL ratings since 2003	Points for independent third-party certification

Name	Overview	Sustainability aspects included	Metrics, indicators and data	Lifecycle stages	Transparency, ease of use, and simplicity of output	Uptake / popularity	Verified data?
Greenroads	Rating system for transport projects	• PR-1 Ecological Impact Analysis • PR-2 Energy & Carbon Footprint • PR-3 Low Impact Development • PR-4 Social Impact Analysis • PR-5 Community Engagement • PR-6 Lifecycle Cost Analysis • PR-7 Quality Control • PR-8 Pollution Prevention • PR-9 Waste Management • PR-10 Noise & Glare Control • PR-11 Utility Conflict Analysis • PR-12 Asset Management	Performance rating of 'bronze', 'silver' or 'gold'.	All	Requires detailed data collection across a wide range of aspects. Specific requirements and guidance for points in each category.	Not widely used in the UK	Yes
CEN CWA 17089	European Committee for Standardization (CEN) workshop agreement	• Primary materials consumption • Secondary materials used • Materials to be reused or recycled, and exported energy • Energy use and GWP • Waste • Formation potential of tropospheric ozone (POCP)	Sustainability Performance Indicators (SPIs), split into sustainability pillars and indicators	All	Provides guidance on each indicator, the methods for calculation, and how to report on each	Unknown from publicly available information	Does not specify

Name	Overview	Sustainability aspects included	Metrics, indicators and data	Lifecycle stages	Transparency, ease of use, and simplicity of output	Uptake / popularity	Verified data?
		• All LCA environmental indicators • Whole life cost • Comfort index • Safety audits and inspections • Adaptation to climate change • Tyre pavement noise • Responsible sourcing • Traffic congestion due to maintenance activities					
EN 15643-5 Sustainability of construction works	European Standard. Sustainability assessment of buildings and civil engineering works	Environmental, social and economic performance as well as the technical and functional performance. References EN 15804 for product related information.	Streets and roads 1 km of road for a specified capacity and period of time).	All	Same as LCA (see EN15804) for all civil engineering works stages (before use, use, end of life, and beyond the system boundary	Unknown from publicly available information	Environmental information at the product level shall be in accordance with EN 15804.
PAS 2080	BSI standard for carbon management	Carbon only	Emission factors in carbon dioxide equivalents (CO2e)	Can be used on all, but does not need to be	The guidance in the PAS 2080 standard is very detailed and sets out what should and shouldn't be included in carbon calcs.	Unknown	Can be
Cradle to Cradle (C2C)	Certification scheme run by The Cradle-to-Cradle Products Innovation Institute	• Material Health • Material Reutilization	Levels of certification are: Bronze, Silver, Gold and Platinum.	All	Ease of use depends on level of certification. E.g.,	Widely used in consumer goods sector. Not freely available	Yes. Re-assessment every 2 years.

Name	Overview	Sustainability aspects included	Metrics, indicators and data	Lifecycle stages	Transparency, ease of use, and simplicity of output	Uptake / popularity	Verified data?
		• Renewable Energy and Carbon Management • Water Stewardship • Social Fairness.			for gold/platinum, an EPD is required. Output is a certificate with level of certification		
EN15804 PCR / EPDs	Product Category Rules for EPDs for construction products	• Environment impact (GWP, ODP, AP, EP, POCP, ADP and ADP fossil fuels. • Resource use • Waste and Output flows	Environmental impacts in relevant functional unit e.g., m2 of pavement	All	Requires detailed data collection across a 24 indicators, requiring commer cial software and expertise in sustainability assessment	Used widely in construction. Freely available	Yes
Dutch PCR 0.6	Product Category Rules for EPDs for bituminous materials	As per EN15804	Sum of the environmental impact of metric ton of product	All	As per EN15804	Freely available. Feedback that is more onerous than EN15804	Yes
BES 6001	BRE Framework Standard for responsible sourcing of construction products.	• Organisational man agement • Supply chain management • Environmental and social requirements	Performance rating of 'pass', 'good', 'very good' or 'excellent'.	All	Ease of use depends on level of certification. E.g., for 'excellent' an EPD is required. Output is a certificate with level of certification	As of 2014, 16 certificates for aggregates, sand, gravel, asphalt, and RMC products. Not freely available	Points for independent third-party certification
LCA of French hot-mix asphalt concret e and asphalt pav ement	Study to quantify the environmental impacts of representative French bituminous asphalt and of pavement based on it using the LCA method.	As per EN15804	1m2 of pavement over 100 years for pavement. For asphalt, declared unit is 1 tonne of representative hot mix asphalt.	All	As per EN15804	Unknown. Specific to France market	Yes
DuboCalc	NL Sustainable Construction Ca lculator	Various, based on methodology of Life Cycle Analysis	Environmental Cost Indicator (MKI). Can	Construction, Use, Maintenance	Without purchasing a software	All user guides online are in Dutch, so for UK market usability is limited	Utilises the National Environmen tal Database

Name	Overview	Sustainability aspects included	Metrics, indicators and data	Lifecycle stages	Transparency, ease of use, and simplicity of output	Uptake / popularity	Verified data?
		(LCA) according to ISO 14040 standard and Environmental Assessment Method Buildings and Construction.	also calculate environmental metrics such as kgCO2eq	or End of Life.	licence it is difficult to understand the properties and abilities of the calculator.		
SEVE	Software to assess impacts of maintenance works or building works on roads	Carbon only	Process energy, GHG emissions, resource preservation, transportation	All	Available through a yearly subscription	Unknown from publicly available information	Verified by BIO (Deloitte)
AsPECT	Asphalt Pavement Embodied Carbon Tool to calculate lifecycle emissions of asphalt used in highways	Carbon only	RIS2 KPIS: CO2e) in tonnes associated with HE activities, and CO2) in tonnes within the supply chain activities	All	Detailed user guide. Some feedback that default factors are too low and usability could be improved.	Widely used in Highways construction: 1,964 downloads of AsPECT version 3.1 from 2013	Default factors for materials and energy use or the user can enter their own: BEIS Emission factors ICE Database Eurobitume
Euro-bitume LCI	LCI of an average bitumen produced in any refinery in Europe.	All LCA indicators (see EN15804)	The declared unit is 1 tonne of paving bitumen, (BS EN 12591)	Cradle to gate	Complex data sources but clear metrics for average bitumen	Unknown from publicly available information	Yes
EPD Norge tool	Product Category Rules for products with a tool, an 'EPD Generator' tool. Web-based tool developed by LCA.no.	All environmental impact metrics. Based on EN15804	Declared unit is 1 tonne of asphalt	All	For an EPD system it is very clear and a user-friendly web-based interface. Output to PDF for reporting	Used by all contractors in Norway	All data verified. The tool itself was verified by a third party. Can send to verifier to check
CEREAL	A decision tool for National Road Authorities and contractors for CO2 Emission Reduction in Road Lifecycles	Carbon	Carbon	Production materials, transport offsite, and use of equipment.	Detailed quantified outputs so more complex to use and interpret.	Unknown	Unknown
SUNRA	A tool to identify relevant sustainability topics, set targets, and	Sustainable development (SD) - 26 different	Ambition level for SD, setting a priority performance target,	All	High level SD target setting and assessment	Unknown	No accreditation required

Name	Overview	Sustainability aspects included	Metrics, indicators and data	Lifecycle stages	Transparency, ease of use, and simplicity of output	Uptake / popularity	Verified data?
	plan implementation for sustainability on road projects	sustainable developme nt topics	and identifying metrics and indicators against 4 levels of achievement		of performance so relatively easy to use and implement.		
LICCER	A model for assessment of lifecycle energy and GHG emissions of road infrastructure for early design decisions	Energy and carbon	Energy use and GHG emissions as a proxy for other env. impacts like acidification and eutrophication	All	Detailed quantified outputs so more complex to use and interpret.	Unknown	Unknown
MIRAVEC	A tool to Model Infrastructure Influence on Road Vehicle Energy Consumption to reduce energy and emissions	Energy and carbon	Energy and GHG emissions	All	Detailed quantified outputs so more complex to use and interpret.	Unknown	Unknown
EDGAR	Research programme from Conference of European Directors of Roads	EN15804 impacts, socio-economic factors of health and safety, economic costs, technical feasibility.	Performance related characteristics of bituminous mixtures rather than lifetime predictions. Global warming potential, depletion of resources, air pollution, noise, leaching potential, recyclability, skid resistance, responsible sourcing, financial cost, traffic congestion, performance (durability).	All (including bene fits and loads beyond end of life)	Detailed user guide, but complex. Involves application of numerous method ologies (e.g BES 6001, AsPECT, MIRAVEC). Recognition that tool needs to be made more user friendly. Tool not easily accessible online	Unknown	Some required, e.g. for BES 6001
OneClick LCA	Can calculate carbon and EPDs for products, GHG reporting for corporates and/or conduct building and infrastructure LCAs.	Carbon and global warming potential	Carbon and global warming potential	All	Reports and dashboards can be generated from the tool which provide clear outputs. Need a subscription to view tool.	Unknown	Unknown

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T0049 Collaborative research with industry partners

Work Package 2: Next Generation Sustainability Measurement
Final Report

National Highways, Mineral Products Association (MPA) and Eurobitume UK

Project reference: T0049 Collaborative research with industry partners
Project number: 60657227

April 2022

Delivering a better world

Quality information

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1	28/01/22	Final draft of WP2 report			
2	16/02/22	Final draft of WP2 report following 'Worked Example' meeting			
3	06/04/2022	Final report following Project Sponsors review	08/04/22	Daru Widyatmoko	Work Package Manager

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Figures

Tables

1. Abbreviations and Acronyms

Table 1 List of abbreviations/acronyms used in this report.

Acronym/Abbreviation	Explanation/Definition
AP	Acidification potential
AsPECT	Asphalt Pavement Embodied Carbon Tool
CFC	Any of several simple gaseous compounds that contain carbon, chlorine, fluorine, and sometimes hydrogen, that are used as refrigerants, cleaning solvents, and aerosol propellants and in the manufacture of plastic foams, and that are believed to be a major cause of stratospheric ozone depletion
EPD	Environmental Product Declaration
GWP	Global warming potential
LCA	Life Cycle Assessment
MJ	Megajoule
MPA	Minerals Products Association
NMVOC	Non-methane volatile organic compounds
P eq	Phosphorus (equivalent) – used in calculating Eutrophication Potential
PCF	Project Control Framework
Sb	Antimony is a chemical element with the symbol Sb. Often used as a measure of material scarcity.
WDP	Water deprivation potential
WP	Work Package

2. Executive Summary

This report outlines the key findings from Work Package 2 (WP2) of 'Next Generation Sustainability Measurement', which are focused on the development of an Excel-based Framework. This Framework aims to assist pavement product manufacturers, National Highways, and others in the pavements value chain to understand and evaluate the environmental sustainability impacts of pavements throughout their lifecycle.

The WP2 framework is split into three different stages. A summary of the different stages and AECOM's recommendations for next steps and further research are provided below.

- Stage 1
  - For manufacturers and contractors: Guidance (with examples provided) on understanding how to collect the right data, from the right people in the supply chain in a consistent format to be able to calculate environmental impacts of pavement products.
  - The outputs from Work Package 3 (WP3) of this collaborative research project will be relevant to this stage of the framework as it will provide more details on mixture composition, production methods and durability of the pavement products. The details will vary with the different level of design approaches as outlined in WP3. Using the outputs from WP3 in conjunction with WP2 will help design more sustainable products.
  - Recommendation: National Highways, Eurobitume, and MPA to encourage product manufacturers (with support from the wider supply chain including contractors) to develop EN15804+A2:2019 aligned EPDs, using the data collection framework developed in this research project as a guide to the data that is needed.
- Stage 2
  - For manufacturers: Summary of the existing calculation tools (primarily based on the research undertaken as part of WP1) that can be used to calculate whole-life environmental sustainability impacts at a product level.
  - Recommendation: Develop consistency across the sector regarding the tools and methods used for calculating sustainability impacts. It is recognised that data from Stage 1 inputted to a wide range of different calculation tools and methodologies by different organisations may affect the comparability of outputs, thus compromising Stage 3 of this Framework.
- Stage 3
  - For National Highways and the pavement supply chain: A methodology for an aggregator tool to assess different products that make up a pavement system (with options for base, binder, and surface layers). This stage will enable decisions to be made based on the whole-life environmental sustainability of a pavement system and can also be used to compare products of the same type (for example, two surface products).
  - Recommendation: Development of Stage 3 into a user-friendly Framework, hosted online, that enables EPD data to be uploaded and automatically fed into the calculations for scoring, continually improving the reliability and quality of the assessment.

3. Introduction

Background to the project

AECOM was commissioned by Highways England (now known as National Highways), the Minerals Products Association (MPA) and Eurobitume UK to undertake research into the evaluation of sustainability measures and benefits that can be used in the development of a generic UK approach to delivering sustainable pavement interventions.

In recent years, there has been a proliferation of sustainability assessment and classification systems and 'eco-labels' across all construction sectors, with actual adoption taking place in the building sector, but less so elsewhere. Highways projects are increasingly required to evaluate project sustainability impacts and benefits throughout the whole lifecycle using project-wide assessment systems, such as CEEQUAL, and these do not always match up with the sustainability performance at a product level.

Designers, infrastructure owners, contractors and suppliers often do not have a single metric for assessing individual products or whole pavement systems in terms of their sustainability. This research seeks to progress this area of thinking and align it more closely with sustainability labelling systems available for e.g. other manufactured products. The research should inform a rationalised approach to assessing sustainability that can be applied to a wide range of products, from different locations and manufacturers, and should be applicable at a project or programme level. This should provide flexibility to National Highways and the pavement supply chain by allowing the sustainability impacts of a range of different products and lifecycle stages to be compared.

The project comprises of four work packages:

1. Work Package 1 (WP1) – Environmental Sustainability Indicators – requirements versus existing and gap analysis.
2. Work Package 2 (WP2) – Next Generation Sustainability Measurement.
3. Work Package 3 (WP3) – Material Design for Sustainability.
4. Work Package 4 (WP4) – Dissemination, Benefits & Knowledge Transfer Form.

Purpose of this report

This report aims to summarise the key outputs associated with WP2 of this research project. WP2 has resulted in the development of an Excel-based Framework, aiming to assist pavement product manufacturers, National Highways, and others in the pavements supply chain to collect the data required to assess the environmental sustainability impacts of pavements throughout the lifecycle. The Framework also enables users to improve their understanding of calculating the environmental sustainability impacts of pavements. A methodology for aggregating different products into pavement design options is also provided to enable comparison of sustainability impacts of different options within a pavement system. As agreed with the project sponsors, the framework is intended to be a methodology only at this stage, with potential to further develop in the future into a fully functioning user-friendly tool.

The Framework has been designed in line with the Major Projects Lifecycle as set out in National Highways, Project Control Framework (PCF) handbook (**Figure 1**).

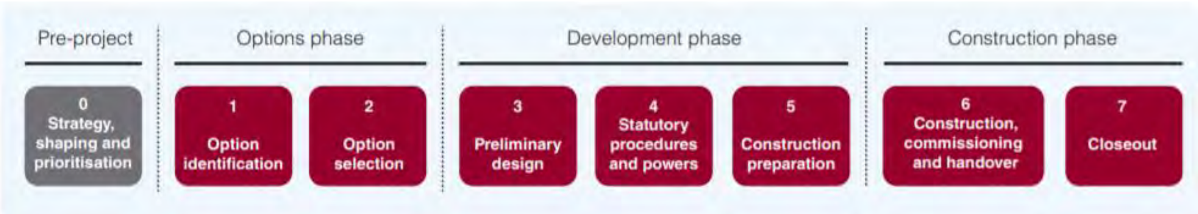

Figure 1 National Highways Major Projects Lifecycle

The earlier the Framework is applied, the more meaningful decisions based on environmental sustainability impact can be made. However, it is recognised that primary data may only be available for certain lifecycle stages if the data collection exercise is being undertaken at the '**Options**' phase.

It is therefore recommended that as much primary data as possible is collected for the 'Product' lifecycle stage[1], with estimates and industry examples being used for the 'Construction', 'Use', 'End of life' and 'Benefits and Loads' stages if needed at the '**Options**' phase.

The Framework can then be used again at the '**Development**' phase with more input from the supply chain (particularly materials suppliers) to replace proxy data with more realistic estimates based on more detailed information on the specific site arrangements and design, to revisit and refine decisions on which products/ materials to use.

This report should be read alongside the following key documents:

- Work Package 2 Framework – Excel; and
- Worked Example – PowerPoint.

Objectives

The main objectives of this research were as follows:

- Evaluation of environmental sustainability measures and benefits, which following successful outcomes of this research, may be added, or used in discussion as part of National Highways' standards forward programme;
- The research will support the development of a generic UK approach to sustainability measurement for pavement construction products and processes e.g. sustainability in design, procurement, specification, application and assessment of pavement materials and design assumptions; and
- The research will also seek to collate information on what other sectors and industries are doing and take account of future targets e.g. reduced CO_2e (carbon dioxide equivalent) and Net Zero.

Work Package 1 Objectives

As this report builds on the findings from WP1, the main steps of WP1 are highlighted in **Figure 2** and the scope is listed below:

- A desktop review (also referred to as literature review) of existing whole life sustainability indicators and assessment tools for materials, products and pavement construction. The scope of WP1 was restricted to flexible (asphalt) pavements;
- An evaluation of the initial literature review to select those indicators that are most relevant to flexible pavements; and
- Finalisation of the assessment criteria based on the findings from the collaborative planning session and further research.
- Analysis of all the identified indicators to be taken forward to WP2.

[1] In line with PAS:2080, the product lifecycle stage covers raw material supply, transportation of materials and their associated manufacturing processes.

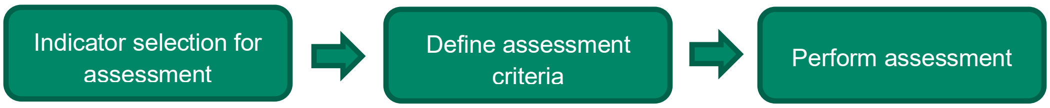

Figure 2 Flowchart of the main steps associated with WP1

The detailed findings can be found in the report "Work Package 1: Sustainability Indicators - requirements versus existing and gap analysis Final Report" (AECOM 2021).

Work Package 2 Objectives

As this report focuses on the outputs of WP2, the scope of WP2 is detailed below with the main steps highlighted in **Figure 3**:

- Determine suitable sustainability and performance indicators for flexible pavements. The scope of WP2 was restricted to flexible pavements;
- Define and rate each indicator to allow for assessment and scoring;
- Develop a Framework to allow for data input and scoring; and
- Pilot the Framework for 2-3 products.

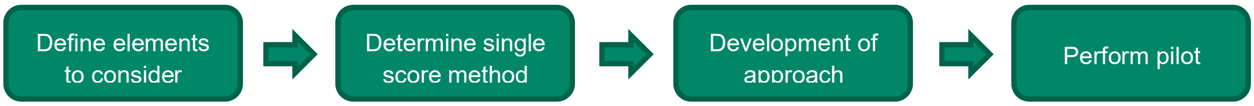

Figure 3 Flowchart of the main steps associated with WP2

In addition, WP2 has been split into three different stages (illustrated in **Figure 4**), as follows:

- Stage 1 – For Manufacturers and Contractors: Guidance (with examples provided) on understanding how to collect the right data, from the right people in the supply chain in a consistent format;
- Stage 2 – For manufacturers: Summary of the existing calculation tools (primarily based on the research undertaken as part of WP1) that can be used to calculate whole-life environmental sustainability impacts at a product level; and
- Stage 3 – For National Highways and the pavement supply chain: Development of a methodology for an aggregator tool to assess different products together as a pavement system. Decisions can therefore be made based on the whole-life environmental sustainability of a pavement system.

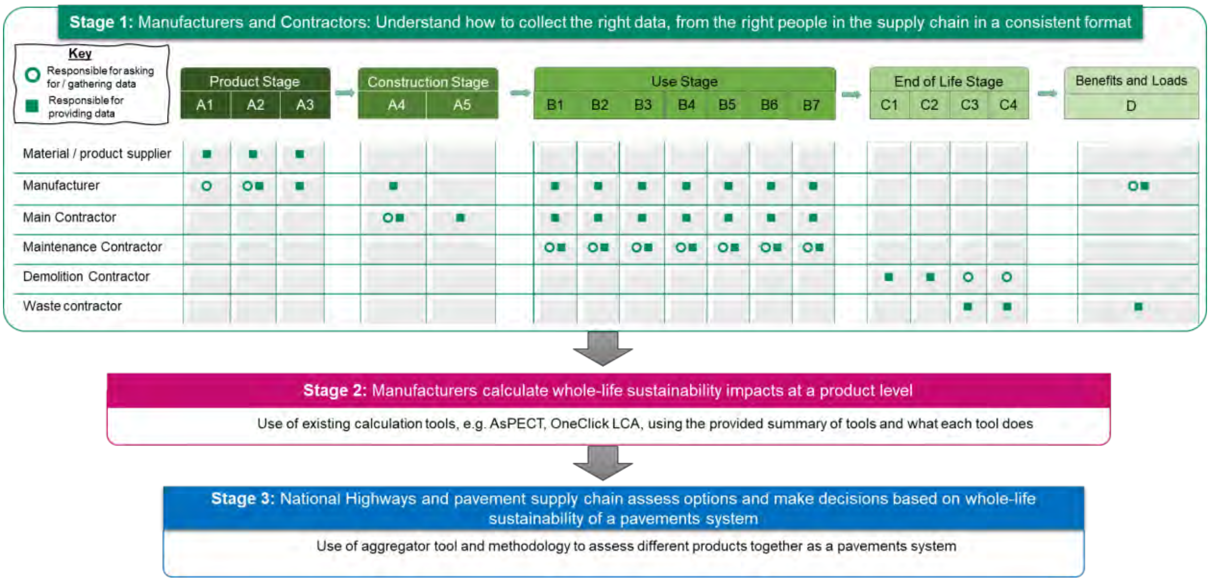

Figure 4 Breakdown of the stages involved in WP2 and presented in this report

As demonstrated in **Figure 4**, this Framework has not scoped out any lifecycle modules in order to enable users to generate Cradle to Grave EPDs. As per the guidance in BS EN 15804:2012+A2:2019, Cradle to Grave EPDs can only be generated with the inclusion of A, B, C and D modules where the declaration is based on a functional or declared unit. It is not expected that all modules will be applicable to pavement products and so where this is the case, the data entered should be declared as 0 in order to enable the manufacturer to apply for a Cradle to Grave[2] EPD rather than being restricted to a Cradle to Gate[3] EPD only. However, EPDs can be generated with the following additional options:

1. Cradle to gate with modules C1–C4 and module D (A1–A3, C and D). These stages are the minimum to be declared for the default type of EPD. They shall be based on a declared unit;
2. Cradle to gate with options, modules C1–C4, and module D (A1–A3, C, D and additional modules. The additional modules may be A4 and/or A5 and/or B1–B7). This type of EPD shall be based on a functional unit or declared unit. If B-modules and use scenarios are not declared the EPD shall be based on a declared unit.

[2] Cradle to Grave is the full life cycle assessment from resource extraction ('cradle') to the use phase and disposal phase ('grave').
[3] Cradle to Gate: is an assessment of a partial product life cycle from resource extraction (cradle) to the factory gate (ie, before it is transported to the consumer).

4. Methodology

Following a progress meeting with National Highways, MPA and Eurobitume UK on Monday 26th July 2021 as part of WP1, the aims of WP2 were identified and agreed with project sponsors.

At this meeting, AECOM presented two options for further development as part of WP2:

- Option 1 - **A 'calculator' tool** that helps pavement supply chain organisations to calculate environmental sustainability impacts of their products and materials. This could take the form of a new tool or it could be an extension/ development of an existing tool.
- Option 2 - **An 'aggregator' tool/ methodology** where product information is inputted from other existing tools and combined to provide scoring and a comparison of environmental sustainability impacts of different pavement systems.

There was a general consensus from participants during discussions that the approach in WP2 should be a combination of Options 1 and 2, but with a focus on measurement to aggregate data across the supply chain, potentially with an aspect of scoring / aggregating to allow for pavement level comparison as well as product level assessment.

Stage 1 Methodology

Stage 1 of WP2 is primarily to support manufacturers and contractors. As part of Stage 1, guidance is provided for each lifecycle stage (with examples provided) to improve understanding of how to collect the right data, from the right people in the supply chain in a consistent format.

Feedback and research gathered though WP1 highlighted the need for a methodology that drives consistency across the pavements supply chain and allows National Highways to compare environmental sustainability data from different organisations.

Stage 1 of the Excel-based Framework includes indicators identified throughout WP1 as the most important to consider and that also align to the indicators, detailed in **Table 2**.

Table 2 List of BS EN 15804:2012+A2:2019[4] Indicators

Classification of Indicator	EN15804+A2 Indicator Descriptions
Climate Change	Global Warming Potential (GWP) total (fossil fuels, biogenic and land use change) (kg CO_2e)
	GWP fossil fuels (GWP-fossil)
	GWP biogenic (GWP-biogenic)
	GWP land use and land use change (GWP-luluc)
Impacts on the ozone layer	Depletion potential of the stratospheric ozone layer (kg CFC-11 eq)
	Formation potential of tropospheric ozone (kg NMVOC eq.)
Depletion of resources	Abiotic depletion potential for non-fossil resources (kg Sb eq.)
	Abiotic depletion for fossil resources potential (MJ)
Impacts on water ecosystems	Acidification potential, Accumulated Exceedance (AP) (mol H' eq)
	Eutrophication potential, fraction of nutrients reaching freshwater end compartment (kg P eq.)

[4] BS EN 15804:2012+A2:2019 Sustainability of construction works – Environmental product declarations – Core rules for the product category of construction products.

Classification of Indicator	EN15804+A2 Indicator Descriptions
	Eutrophication potential, fraction of nutrients reaching marine end compartment (kg P eq.)
	Eutrophication potential, Accumulated Exceedance (AP-Terrestrial) (mol N eq.)
	Acidification potential, Accumulated Exceedance (AP) (mol H' eq)
Water use	Water (user) deprivation potential, deprivation-weighted water consumption (WDP) (m3 world eq. deprived)

The Stage 1 Framework provides guidance and a data input mechanism for manufacturers and those in the pavements supply chain to collect data.

For those that have already generated Environmental Product Declarations (EPDs) or have undertaken Life Cycle Assessments (LCA), this data will already exist and will be held in a similar format, in which case, Stage 1 does not need to be followed.

For those that have not generated EPDs or have not undertaken LCAs, Stage 1 should be led by the product manufacturer, with inputs provided from others in the supply chain where stated. Some generic figures have been incorporated into the guidance to assist where data is not available (for example, generic transport distances for raw materials).

A summary of what is included in the Stage 1 assessment is provided in **Table 3.**

Table 3 BS EN 15804:2012+A2:2019 lifecycle stages included in the Stage 1 assessment

Lifecycle Stage	Aspects included in Stage 1	Types of data required
Product Stage	A1 – Raw material extraction and processing, processing of secondary material input (e.g., recycling processes)	List of raw materials/ ingredients, including % reused or recycled and quantity of materials.
	A2 – Transport to manufacturer	Raw materials/ ingredients as per A1, distance from supplier to manufacturing site and the type of transport expected to be used.
	A3 – Manufacturing: Inputs	Manufacturing input type and amounts, including electricity, gas/fuel, and water usage.
	A3 – Manufacturing: Outputs	Manufacturing output type and amounts, including disposal/ treatment method.
	A3 – Manufacturing: Packaging	Type and amount of packaging required as part of the Manufacturing process. It is expected that this module is declared as '0' for pavement products.
Construction Stage	A4 – Transportation from the production gate to the construction site	Location of manufacturer in relation to construction site, estimate of the distance if the product is purchased directly or through a broker, and the type of transport.
	A5 – Construction: Installation process	Plant type, including engine sizes and hours of usage. Total quantity of water required as part of the installation process. Number of workers, number of days required for installation, distance for workers to travel to site.
	A4-A5 – Waste of products (excluding packaging)	Estimate of the percentage of product that is wasted on site, waste processing type for product waste, estimate of the distance and transport type to waste treatment/ disposal location.
	A4-A5 - Storage of products	Type of storage required. It is expected that this module is declared as '0' for pavement products. If storage is required for pavement

Lifecycle Stage	Aspects included in Stage 1	Types of data required
		products it is likely to be in the form of a builder's yard where no electricity or water supply will be required.
Use Stage	B1 - Use or application of the installed product	No activity data expected as this is in relation to external impacts of the product on the environment, the data for which should be a result of the LCA calculations undertaken in Stage 2. It is expected that this module is declared as '0' for pavement products.
	B2 - Maintenance B3 – Repair B4 - Replacement B5 - Refurbishment	Details of the process required, including frequency and quantity of additional materials. Location of manufacturer in relation to construction site, estimate of the distance if the product is purchased directly or through a broker, and the type of transport. Plant type, including engine sizes and hours of usage. Total quantity of water required as part of the installation process. Number of workers, number of days required for installation, distance for workers to travel to site.
	B6 - Operational energy use	It is expected that this module is declared as '0' for pavement products. Operational energy use will only be captured in relation to maintenance work.
	B7 - Operational water use	It is expected that this module is declared as '0' for pavement products. Operational water use will only be captured in relation to maintenance work.
End of Life Stage	C1 – Deconstruction and demolition	Plant type, including engine sizes and hours of usage. Total quantity of water required as part of the deconstruction/demolition process. Number of workers, number of days required for deconstruction/ demolition, distance for workers to travel to site.
	C2 – Transporting to waste processing site	Distance and type of transport used to waste treatment/ disposal location.
	C3-C4 – Waste processing and waste disposal	Type of waste and quantity, waste processing and disposal type.
Benefits and Loads	D – Reuse, recovery and recycling potential	Quantity of recycled and/or secondary materials used, quantity of reusable product produced and details of the recycling or recovery process.

Although Stage 1 has focused on developing a framework to collect data in a consistent way, example data was also gathered during the process in order to provide default values that users could use should there be limited data available for a specific product. The majority of this data was gathered from existing EPDs, however, where activity data was not fully available, assumptions on transportation of materials (type and distance) and construction plant engine sizes for example, were made. These assumptions were based on previous activity data used in GHG assessments conducted by AECOM for National Highways road schemes, such as the A46. In addition, AECOM pavement specialists were also consulted on the assumptions used to provide example data in Stage 1.

The outputs from WP3 will be relevant to Stage 1 of WP2 by providing more details on mixture composition (% bitumen, % aggregate, % reclaimed asphalt), production methods (hot mix or warm mix technology) and durability (life expectancy). The details will vary with the different level of design approaches as outlined in WP3.

Stage 2 Methodology

Tools for calculating carbon and environmental sustainability impacts already exist, and many are aligned to BS EN 15804:2012+A2:2019[5] and produce EPDs as their output. It is recognised that data from Stage 1 inputted to a wide range of different calculation tools and methodologies by different organisations may affect the comparability of outputs, thus compromising Stage 3 of this Framework. To help tackle this challenge, Stage 2 provides guidance on which methodologies and tools should be used to calculate impacts and details the considerations and limitations of different methods.

The exact format of data required will vary from tool to tool, but the data obtained through the use of Stage 1 should provide users with the majority of the information required, with little additional work to adjust into the specific units or formats that different calculation tools require. It is important that as part of the calculation and presentation of results, the assumptions and estimates used as part of the data collection stage (Stage 1) are clearly documented.

A high-level summary of project-, asset- or system-level environmental sustainability assessment schemes and standards, as well as tools, software and calculators that were reviewed in developing Stage 2 is presented in the WP1 report[6]. In addition, Stage 2 also includes a comment as to whether each of the calculation tools are aligned to BS EN 15804:2012+A2:2019 and whether the tool is freely available to access.

Stage 2 has also used example product data for the product lifecycle stage to test the usability of this framework, using the following three tools:

1. OneClick LCA: is fully aligned to BS EN 15804:2012+A2:2019 and is widely recognised as being one of the most user-friendly LCA tools.

2. SimaPro: uses traditional LCA software and has the capability of calculating multiple environmental impacts.

3. AsPECT: is one of the most widely used sustainability tools for asphalt pavement materials in the UK.

The three tools have been carefully chosen for testing for multiple reasons. AsPECT is currently widely used in the UK asphalt industry while SimaPro is one of the most widely used construction LCA tools on the market. Additionally, OneClick LCA offers an EPD generator option which we understand has been previously used by pavement suppliers in Europe. Lastly all three tools are all freely available to access and/or have a free trial to undertake sufficient testing.

The aim of product testing was to first confirm whether the data being requested as part of this Framework is aligned to the data requests of current calculation tools (this was undertaken across all lifecycle stages). Any identified discrepancies between the data the tools ask for and the data required to be input into the Framework have since been resolved and updated in the Framework. Secondly, product testing during the product lifecycle stage has enabled a comparison of outputs to take place across all BS EN 15804:2012+A2:2019 indicators. Details of this are presented in Section 4.

Stage 3 Methodology

The final stage of the environmental sustainability impact assessment process enables National Highways and others in the supply chain to compare and contrast different products at a pavement level, for example, assessing two pavement design options.

Stage 3 of the framework translates the environmental sustainability data and calculation results into easy-to-understand scores/ metrics. A scoring methodology has been developed for the following four environmental sustainability indicators:

1. Global Warming Potential total (fossil fuels, biogenic and land use change) (kg CO_2e).
2. Abiotic depletion potential for non-fossil resources (kg Sb eq.).
3. Abiotic depletion for fossil resources potential (MJ).
4. Depletion potential of the stratospheric ozone layer (kg CFC-11 eq).

[5] It is expected that those calculation tools not currently compliant with EN 15804:2012+A2:2019, will be updated in the near future.
[6] Work Package 1: Sustainability Indicators - requirements versus existing and gap analysis Final Report, AECOM 2021

A methodology has only been developed for these indicators due to the lack of data available for all other sustainability indicators as the majority of calculation tools have not yet been updated to reflect the full suite of categories in BS EN 15804:2012+A2:2019. The methodology described below can be applied to score the remaining BS EN 15804:2012+A2:2019 indicators when data becomes available.

The scoring methodology has been developed using EPD data for the product stage for 18 surface course products. A scoring methodology has not been developed for base and binder course products, due to the lack of product data. Instead, a scoring framework has been developed for these types of products which can be updated once data is made available.

Figure 5 presents the approach used to develop the scoring methodology that has been implemented and tested for the 18 surface course products.

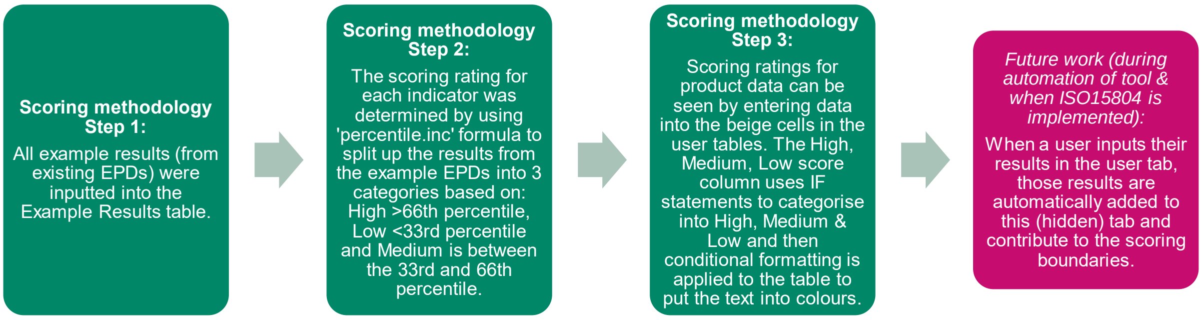

Figure 5 Approach used to develop scoring methodology

Results from previous EPDs have been used to quantitatively define the High, Medium, Low scoring system, where high represents high environmental impact and low minimal environmental impact. Taking all the example EPD data into account, the scoring system has been defined by using the percentiles outlined in **Table 4**. Therefore, the scoring system is based on the relative distribution of data points, rather than being in relation to any absolute criteria. This approach can be applied to other sustainability indicators and pavement products when sufficient data becomes available that enables a large enough range to be established.

Table 4 High, Medium, Low Scoring Key

Scoring System	Percentiles
High	≥ 67th percentile
Medium	34th < x > 66th percentile
Low	≤ 33rd percentile

As well as assessing environmental sustainability scores, Stage 3 includes consideration of the lifetime and maintenance requirements of the products as well as a consideration of data quality to help compare data that has used different calculation methodologies consistently. It is recommended that National Highways reviews the lifespan data provided by the product manufacturers and adjusts if needed based on historical data and knowledge about the specific site and use requirements. **Table 5** presents five data quality measures and the associated issues that the user should consider when applying this scoring system (PAS 2080, 2016). Guidance for this has been provided within the Framework spreadsheet, alongside addition of a data entry column within the Stage 3 Framework to assist in comparing different products. It is recommended that where possible comparisons are made only between product EPDs that have used the same calculation method and/or are compliant with EN15804+A2, as it is recognised that different calculation methods can yield different results.

Table 5 Data quality considerations

Quality Measure	Issues for the practitioner to consider
Age	• Is the data applicable to the time period covered by the quantification? • Was the data created before the infrastructure? • Is the data applicable to future predictions for the infrastructure?
Geography	• Is the data based on assumptions of certain geography?

	• Are there likely to be national or regional variations in the applicability of the data? • Does the data represent the likely location the activity will take place?
Technology	• Is the data specific to the technology applied in infrastructure and its supply chain? • Does it represent a specific or broader category of product or activity?
Methodology	• Does the data follow a defined methodology? • Is this methodology consistent with the scope, boundaries and methodology applied in the quantification? • What are the assumptions and limitations inherent in the data? • What is the uncertainty associated with the data?
Competency	• Is the source of the data reliable? • Is the data widely cited? • Has the data been assured or quality checked (for example, through a certification process)?

5. Key Findings and summary of resources developed

Stage 1 Findings

Although Stage 1 focused on developing a framework to collect data, example data was also gathered during the process to provide default values that users could use should there be limited data available for a specific product or lifecycle stage. In general, information was found to be readily available for the A1-A3 stage, with much more limited information available for the construction, use and end of life stages. In addition, data was especially limited for UK-based examples, with more readily available information for Europe and the USA. This was a significant limitation of the data collection and framework testing exercise.

UK-based EPDs were used where possible, but often activity data examples were not available. To bridge this gap, assumptions on transportation of materials (type and distance) and construction plant engine sizes for example, were made. These assumptions were based on previous activity data used in GHG assessments conducted by AECOM for National Highways road schemes, such as the A46.

Stage 2 Findings

Having tested multiple product data using three calculation tools: AsPECT, OneClick LCA and SimaPro, **Table 6** presents a summary of some pros and cons of each tool in terms of usability and accessibility. All calculation tools have pros and cons, however, in terms of reporting against different sustainability indicators as per BS EN 15804:2012+A2:2019, OneClick LCA (with the full license) appears to be most accessible. While SimaPro is also able to calculate the impacts across multiple sustainability indicators, it is regarded as being less intuitive and harder for new users to use compared to OneClick LCA.

AsPECT falls short on the requirement to report against all sustainability indicators due to its ability to only calculate carbon emissions (GWP). If users were to restrict their calculations to carbon emissions only, AsPECT is deemed to be a more accurate fit compared to the free trial version of OneClick LCA which uses generic emissions factors and limits which aspects can be modelled in the tool.

Table 7 provides the outputs of the testing that has been undertaken using the three calculation tools. Generally, there is a more granular split of lifecycle stages in SimaPro compared to OneClick LCA. In multiple circumstances the results are highest when using the OneClick LCA tool and this is likely due to average emissions factors being used.

It is also worth noting that the current version of SimaPro and OneClick LCA, used to undertake this product testing in December 2021, are both aligned to the previous version of BS EN 15804+A1:2013, as the updated version (BS EN 15804:2012+A2:2019) is not mandatory until July 2022. The main differences between the two standards are as follows:

- The updated standard now accounts for the benefits of end-of-life recycling, with the 'Benefits and Loads' lifecycle stage;
- EPDs are required to include more lifecycle stages in addition to the 'Product' A1-A3 lifecycle stage which was previously the only mandatory stage;
- Additional environmental impact categories are now included in the updated version. Changes include different GWP indicators (including biogenic carbon), water deprivation potential, and additional eutrophication indicators;
- The updated version contains different units for some environmental impact categories, such as aquatic toxicity and acidification; and
- The updated version no longer includes some environmental impact categories, including human toxicity, aquatic toxicity, terrestrial ecotoxicity, and photochemical oxidation.

Therefore, the only indicators that can be tested using the tools that are still aligned with both BS EN15804+A1:2013 and BS EN 15804:2012+A2:2019 are: Abiotic depletion, Abiotic depletion (fossil fuels), Global Warming, and Ozone Layer Depletion.

Table 6 Summary of the pros and cons when using the three calculator tools for testing

Assessment Tool	Pros	Cons
AsPECT	• The tool is free to use and easily accessible. • The tool's lifecycle stages are simplified only concerning stages relevant towards pavement construction.	• Only carbon is assessed. • Tool does not have a suitable place to capture waste produced at the product stage. • Tool is not intuitive and is hard for new users to use.
OneClick LCA	• The tool is intuitive and easier for new users to understand how it works. • If the user has a full license, they can upload their product data directly into OneClick LCA, which makes the data input process more efficient. • Provides a large variety of emission factors to choose from, which should result in more accurate results.	• Tool does not allow users on the free trial to access to the product LCA project function without a full license. This results in generic emissions factors being used which compromises what can be modelled by the tool (i.e. raw energy input data, transportation data and waste data cannot be put into the model). • Users on the free trial can only get results for GWP.
SimaPro	• Results for multiple impacts are available. • All lifecycle stages available	• Likely to require training or use by experienced users.

Table 7 Product testing outcomes for an individual product across the product lifecycle stage across all BS EN 15804:2012+A2:2019 indicators

Lifecycle Stage	Assessment Tool Outputs for a single example product			Commentary
	AsPECT	OneClick LCA	SimaPro	
GWP total (fossil fuels, biogenic and land use change) (kg CO_2e)				
Raw materials	N/A (included in manufacturing)	N/A (included in manufacturing)	0.2	A more granular split of lifecycle stages is possible in SimaPro compared to AsPECT and OneClick LCA.
Transport of raw materials	8.2	N/A (included in manufacturing)	12.8	A more granular split of lifecycle stages is possible in SimaPro compared to AsPECT and OneClick LCA.
Manufacturing	40	56.7	31.1	Results from OneClick LCA show the highest impact compared to AsPECT and SimaPro. This could be due to the fact that average factors are used in OneClick LCA.
TOTAL	**48.2**	**56.7**	**44.2**	Results from OneClick LCA show the highest impact compared to AsPECT and SimaPro. This could be due to the fact that average factors are used in OneClick LCA.

Lifecycle Stage	Assessment Tool Outputs for a single example product			Commentary
	AsPECT	OneClick LCA	SimaPro	
	Depletion potential of the stratospheric ozone layer (kg CFC-11 eq)			
Raw materials	-	N/A (included in manufacturing)	0.000035	A more granular split of lifecycle stages is possible in SimaPro compared to OneClick LCA. AsPECT does not calculate this indicator.
Transport of raw materials	-	N/A (included in manufacturing)	0.000002	A more granular split of lifecycle stages is possible in SimaPro compared to OneClick LCA. AsPECT does not calculate this indicator.
Manufacturing	-	0.000037	0.000012	Results from OneClick LCA show the highest impact compared to SimaPro. This could be due to the fact that average factors are used in OneClick LCA. AsPECT does not calculate this indicator.
TOTAL	**-**	**0.000037**	**0.000014**	Results from OneClick LCA show the highest impact compared to SimaPro. This could be due to the fact that average factors are used in OneClick LCA. AsPECT does not calculate this indicator.
	Abiotic depletion potential for non-fossil resources (kg Sb eq)			
Raw materials	-	N/A (included in manufacturing)	0.000000	A more granular split of lifecycle stages is possible in SimaPro compared to OneClick LCA. AsPECT does not calculate this indicator.
Transport of raw materials	-	N/A (included in manufacturing)	0.000022	A more granular split of lifecycle stages is possible in SimaPro compared to OneClick LCA. AsPECT does not calculate this indicator.
Manufacturing	-	0.000314	0.000010	Results from OneClick LCA show the highest impact compared to SimaPro. This could be due to the fact that average factors are used in OneClick LCA. AsPECT does not calculate this indicator.
TOTAL	**-**	**0.000314**	**0.000032**	Results from OneClick LCA show the highest impact compared to SimaPro. This could be due to the fact that average factors are used in OneClick LCA. AsPECT does not calculate this indicator.

Lifecycle Stage	Assessment Tool Outputs for a single example product			Commentary
	AsPECT	OneClick LCA	SimaPro	
Abiotic depletion for fossil resources potential (MJ)				
Raw materials	-	N/A (included in manufacturing)	27.4	A more granular split of lifecycle stages is possible in SimaPro compared to OneClick LCA. AsPECT does not calculate this indicator.
Transport of raw materials	-	N/A (included in manufacturing)	157.5	A more granular split of lifecycle stages is possible in SimaPro compared to OneClick LCA. AsPECT does not calculate this indicator.
Manufacturing	-	3,430.0	1,030.6	Results from OneClick LCA show the highest impact compared to SimaPro. This could be due to the fact that average factors are used in OneClick LCA. AsPECT does not calculate this indicator.
TOTAL	**-**	**3,430.0**	**1,215.4**	Results from OneClick LCA show the highest impact compared to SimaPro. This could be due to the fact that average factors are used in OneClick LCA. AsPECT does not calculate this indicator.

Stage 3 Findings

Figure 6 presents an example scoring system created to compare surface course products in the product lifecycle stage (A1-A3). The system has been developed to compare up to 20 different products, and when data is available the system will be capable of comparing products across lifecycle stages and within different product categories (such as base and binder course products). Currently, the framework has been set up for the user of Stage 3 (expected to be mainly National Highways but could also be contractors and suppliers) to directly compare up to three products at once (see **Figure 6**). It is recommended that where possible comparisons are made only between product EPDs that have used the same calculation method and/or are compliant with EN15804+A2, as it is recognised that different calculation methods can yield different results.

A tested scoring methodology has only been developed for the product stage, due to the lack of data for the construction, use and end-of life stages. Similar to Stage 1, EPD data was especially limited for UK-based examples, with more readily available information for Europe and the USA. The lack of data is due to the relative immaturity of the EN15803+A2 standard and is expected to increase rapidly throughout 2022 when the standard becomes mandatory for all EPDs.

A tested methodology has only been developed for these indicators only due to the lack of data available for all other sustainability indicators. The formulas have been entered to allow for the user to enter more data as and when more data becomes available, to improve the accuracy and representativeness of the scoring ratings. The final summary of impacts that has been developed to allow the user to compare impacts of up to three different products is shown in Figure 7.

Stage 3 also enables users to select a combination of products (for base, binder and surface) as if creating a pavement system. Here different pavement system combinations can be compared, and hotspots can be identified in terms of where in the system the largest sustainability impact is i.e. base, binder or surface. Users are also able to compare the total sustainability impacts of pavement systems (across all 3 layers of pavement).

		Product stage A1-A3					
		Product 1 Rating		Product 2 Rating		Product 3 Rating	
Environmental Impact Category	LCA indicator (EN15804+A2)	Result	High, Medium, Low Score	Result	High, Medium, Low Score	Result	High, Medium, Low Score
Climate change	Global Warming Potential total (fossil fuels, biogenic and land use change) (kg CO2e)	70	High	45.74	Medium	263.2	High
	Global Warming Potential fossil fuels(GWP-fossil)		No data		No data		No data
	Global Warming Potential biogenic (GWP-biogenic)		No data		No data		No data
	Global Warming Potential land use and land use change (GWP-luluc)		No data		No data		No data
Impacts on the ozone layer	Depletion potential of the stratospheric ozone layer (kg CFC-11 eq)	0.000032300	High	0.000006630	Medium	0.000000019	Medium
	Formation potential of tropospheric ozone (kg NMVOC eq.)		No data		No data		No data
Depletion of resources	Abiotic depletion potential for non-fossil resources (kg Sb eq.)	0.000236000	High	0.000054600	High		No data
	Abiotic depletion for fossil resources potential (MJ)	2740	Medium	2710	Medium		No data
npacts on water ecosystem	Acidification potential, Accumulated Exceedance (AP) (mol H' eq)		No data		No data		No data
	Eutrophication potential, fraction of nutrients reaching freshwater end compartment (kg P eq.)		No data		No data		No data
	Eutrophication potential, fraction of nutrients reaching marine end compartment (kg P eq.)		No data		No data		No data
	Eutrophication potential, Accumulated Exceedance (EP-Terrestrial) (mol N eq.)		No data		No data		No data
Water use	Water (user) deprivation potential, deprivation-weighted water consumption (WDP) (m3 world eq. deprived)		No data		No data		No data

Figure 6 Example scoring system for surface course materials

SUMMARY OF IMPACTS		Product Stage	Construction Stage	Use Stage	End of Life Stage	Benefits & Loads	Comments on data quality (e.g. is the data verified, is it recent, is it compliant with EN15804, have impacts been quantified using a well-known tool such as OneClick LA?)	**Comments on expected lifespan for the specific project conditions** (e.g. does one product offer superior strength/ longevity/ resistance given the specific conditions)
Product 1	Climate change	High						
	Impacts on the ozone layer	High						
	Depletion of resources	High						
	Impacts on water ecosystems							
	Water use							
Product 2	Climate change	Medium						
	Impacts on the ozone layer	Medium						
	Depletion of resources	High						
	Impacts on water ecosystems							
	Water use							
Product 3	Climate change	High						
	Impacts on the ozone layer	Medium						
	Depletion of resources							
	Impacts on water ecosystems							
	Water use							

Figure 7 Example summary of impacts for results from Stage 3 of the framework

6. Recommendations for next steps

This section outlines the recommended next steps for the project sponsors to consider, beyond the limits of this contracted project.

Throughout the development of all three stages of the sustainability rating Framework, the lack of sufficient EPD data being available for pavements products has been a significant limitation to developing a robust and well-tested methodology. This meant that in order to test the functionality and usability of the methodology, data on products manufactured outside of the UK was used where ideally, UK-specific data would have been available so that the proxies within Stage 1 and the scoring ratings in Stage 3 are more representative of the UK market.

It has also meant that data and example results are lacking for many of the indicators and lifecycle stages within the Framework that are required as part of EN15804+A2:2019, and so these cells are currently blank (although are auto-populated so as soon as more data is added the scoring ratings will automatically update accordingly).

In light of these limitations, the first recommendation is:

1. **National Highways, Eurobitume, and MPA to encourage product manufacturers (with support from the wider supply chain including contractors) to develop EN15804+A2:2019 aligned EPDs, using the data collection framework developed in this research project as a guide to the data that is needed.** This will improve the ability of National Highways and the pavements supply chain to improve its ability to compare products on their sustainability credentials.

The second recommendation is:

2. **Develop consistency across the sector when calculating sustainability impacts.** It is recognised that data from Stage 1 inputted to a wide range of different calculation tools and methodologies by different organisations may affect the comparability of outputs, thus compromising Stage 3 of this Framework. Therefore, if everyone uses the same calculation tools and databases to calculate their impacts on sustainability indicators, comparisons between products and solutions can be more accurately achieved as it is recognised that different calculation methods can yield different results. This is likely to ultimately require a client mandate or specification for source data and processing tool to enable benchmarking and ongoing measurement of impacts on a consistent basis. Alternatively, the feasibility of applying ‘National Highways conversion factors’ could be investigated to enable more direct comparability of outputs, while still facilitating producer selection of tools and databases.

To support with the development of EPDs, the third recommendation is:

3. **Develop and provide some training to the pavements industry supply chain, particularly product manufacturers and contractors who are required to input the most data into the EPD development process.** This training would help to raise awareness and understanding of what the new EPD standard is, what the differences are compared to the previous version, and why it is important to understand these sustainability impacts. It should also help to raise the quantity and quality of sustainability impact data within the industry, so the focus moves away from only measuring and reporting on carbon (as is often historically the case).

The fourth recommendation is:

4. **Further testing of the Framework as more data becomes available, and testing using a ‘live’ project.** It is intended that the Framework can be used through early design stages, and then continually updated as more information on the construction stage becomes available throughout the lifecycle of a project. Testing how the Framework works in practice would enable updates and refinements to be made, to make sure it is useful and functional in real-life scenarios with different members of the supply chain inputting into it**.**

The final recommendation is:

5. **Development of Stage 3 (scoring) into a user-friendly Framework, hosted online, that enables EPD data to be uploaded and automatically fed into the calculations for scoring, continually improving the reliability and quality of the scoring.** The Framework is currently hosted on Microsoft Excel, which has limitations including not allowing for easy and streamlined collaboration and data entry between various stakeholders, which is a key component of gathering the lifecycle data required for an EPD. However, it is acknowledged that there are already tools such as OneClick LCA that allow for this collaborative data

collection and input, and also include a calculation functionality to calculate impacts. Therefore, it is recommended that automation is focused on the scoring function in Stage 3. Stage 3 enables EPDs to be 'mined' for information and the data can be used to more accurately calculate the boundaries for the scoring ratings, thus reflecting the UK market over time. The online version of the Framework could also help National Highways more quickly compare many more products (not limited to comparing three at once, like the current Framework), and could have different visualisations of impacts built into a 'dashboard' style report. It is worth noting that should the Framework be hosted online; ongoing maintenance of the online platform (such as software updates) will be essential.

Appendix A – User Guide

A.1 Stage 1 User Guide

Stage 1 consists of 5 green tabs listed below, with each tab representing a different stage of a product's lifecycle:

- S1 Product Stage
- S1 Use Stage
- S1 Construction
- S1 Benefits and Loads
- S1 End of Life

Who this stage should be completed by:

- Manufacturers of pavement products should complete this stage with data on their products, with support from contractors (such as main contractors, demolition contractors, waste contractors) to provide data for relevant lifecycle stages.
- It is expected that manufacturers should be able to provide the majority of the information for the 'Product Stage'. Manufacturers should be able to provide some information for the 'Use', 'Construction', 'Benefits and Loads', and 'End of Life' stages, but it is expected that contractors will need to provide most of the data for these aspects as the information is related to how the product is installed and used on site.
- If product manufacturers already have a compatible EPD or have completed an LCA for their product, then this stage may not need to be completed.

Why this stage should be completed:

This framework is intended to support the pavements supply chain in embedding sustainability into decision making. This first stage is to gather activity data on the product through its life cycle, to enable sustainability impact to be assessed in a later stage.

When this stage should be completed:

- As this framework is intended to support the pavements supply chain in embedding sustainability into decision making, this stage should be completed as early as possible in a project's lifecycle so that early decisions can be made to reduce sustainability impacts of projects.
- It is expected that the amount of data available for the 'Use', 'Construction', 'Benefits and Loads', and 'End of Life' stages will not be available at early project stages when contractors may not have been assigned yet and designs are in early stages. However, there are examples included within each tab that can be used as proxies while primary data has yet to be gathered. Data can be continued to be entered on an ongoing basis throughout the project as and when it becomes available.

How this stage should be completed:

- The green 'S1' tabs provided in this framework are intended to be used by **one product manufacturer** for **one product only**. It is suggested that each product manufacturer that intends to use the framework should copy all of the green 'S1' tabs and complete them.
- Information within the grey cells in each tab provides guidance on what data is required, and also provides example data that can be used as a proxy in absence of primary data. However, primary and proxy data should not be substituted for each other to create a more beneficial outcome, where possible primary data is the preferred approach.
- The user should enter information and data into the yellow cells. If additional rows are needed the user should right click and 'Insert Row'.

A.2 Stage 2 User Guide

Stage 2 consists of the following pink tab:

- S2 Calculation Tools

Who this stage should be completed by:

- Manufacturers of pavement products should complete this stage using the data provided by manufacturers and contractors in Stage 1 across all life cycle stages.
- If product manufacturers already have a compatible EPD or have completed an LCA for their product, then this stage may not need to be completed.
- For those that do not already have an EPD, Stage 2 will provide the option of generating one for a particular product.

Why this stage should be completed:

- This framework is intended to support the pavements supply chain in embedding sustainability into decision making. This second stage is to calculate the impact of the product (and its associated activity data) through its life cycle, on multiple sustainability indicators in accordance with EN 15804.

When this stage should be completed:

- As this framework is intended to support the pavements supply chain in embedding sustainability into decision making, this stage should be completed as early as possible in a project's lifecycle so that early decisions can be made to reduce sustainability impacts of projects. High-level calculations can be useful in understanding the environmental impact of different products and the possible alternatives available.
- Proxies can be used in the Stage 2 calculations for the 'Use', 'Construction', 'Benefits and Loads', and 'End of Life' stages if there is a lack of sufficient data at the early stage of the project. However, it is advised that calculations are undertaken again once more reliable data is provided, especially if the calculation method generates an EPD.

How this stage should be completed:

- The pink 'S2' Tab is designed to provide guidance on the various calculation tools available to calculate the impacts of products on multiple sustainability indicators. The guidance provides a high-level summary of multiple calculation tools as well as a more in-depth look at three tools: OneClick LCA, AsPECT and SimaPro. The in-depth analysis provides some recommendations and example results using the three calculation tools.
- The calculations will not take place on this spreadsheet but directly on the calculation tools' websites and/or using their bespoke software.
- Data from Stage 1 (across all lifecycle stages) is to be inputted directly into the calculation tool chosen. It is anticipated that the format of Stage 1 data collection should align with the majority of calculation tools, but where necessary may require minimal adjustments.

A.3 Stage 3 User Guide

Stage 3 consists of 7 blue tabs listed below:

- S3 Aggregator – BINDER (User)
- S3 Aggregator – BASE (User)
- S3 Aggregator – SURFACE (User)
- Product Selector Dashboard
- S3 BINDER Calculations
- S3 BASE Calculations
- S3 SURFACE Calculations

Who this stage should be completed by:

- National Highways and members of the pavement supply chain should use Stage 3 to assess options and make decisions based on the whole-life sustainability of a pavement system.
- The 'user' tabs should be used by those in the pavement supply chain and National Highways to compare different product options with each other as well as make comparisons between pavement systems and their make-up.
- The 'product selector dashboard' should be used by National Highways when comparing the sustainability of pavement system options.
- It is suggested that the remaining 3 tabs are managed by an independent data/information manager either within National Highways or externally to keep a record of all EPD and LCA data available for different pavement products. This data should be regularly updated to ensure that the scoring classifications are reflective of the latest industry standards and best practice.

Why this stage should be completed:

- This framework is intended to support the pavements supply chain in embedding sustainability into decision making. This third stage enables products to be compared with each other in terms of their sustainability.
- This stage also enables different products to be grouped together to create a pavement system which can then be compared against other pavement systems made-up of alternative products. This comparison stage is vital in aiding National highways and others in the pavement supply chain to make more sustainable decisions.

When this stage should be completed:

- As this framework is intended to support the pavements supply chain in embedding sustainability into decision making, this stage should be completed as early as possible in a project's lifecycle so that early decisions can be made to reduce sustainability impacts of projects.
- The 'user' tabs should be completed once outputs have been calculated from Stage 2. If any proxies were used during the Stage 2 calculations, then Stage 3 may need to be revisited following an update to the calculations used as part of Stage 2.
- The 'product selector dashboard' should be completed when there are different pavement system options to compare.
- The remaining 3 tabs should be updated on a regular basis to keep a record of all EPD and LCA data available for different pavement products. This is particularly important for the 'Use', 'Construction', 'Benefits and Loads', and 'End of Life' stages as there is currently insufficient data available. Data is also limited in relation to binder and base course products and so should be a focus for update as and when the data becomes available.

How this stage should be completed:

- Before the 'user' tabs in Stage 3 can be populated, the 3 'calculations' tabs need to be updated first using the latest EPD and LCA data outputs for different product options that make up the pavement system.

- Data entered into the 'calculations' tab should come directly from published EPDs or LCA outputs and should cover all life cycle stages where possible, although it is recognised that there is currently insufficient data for the 'Use', 'Construction', 'Benefits and Loads', and 'End of Life' stages.
- In the 'calculations' tab a framework is set-up to automatically calculate the boundaries for the scoring ratings. This is based on the following percentiles:

Scoring System	Percentiles
High	> 67%
Medium	Between 33-67%
Low	< 33%

- For the 3 user tabs, data outputs from the Stage 2 calculations should be inputted into the beige cells of the Stage 3 'user' tabs. Data can be added for multiple products, across all life cycle stages and sustainability indicators if available.
- Once data is entered, the scoring rating will auto-populate based on the percentile classifications described above.
- Each user tab contains graphs and a summary table to more easily compare the sustainability of different product options.
- For the 'product selector dashboard', users will need to select a combination of product options (for base, binder course and surface course) from the drop-down list as if creating a pavement system. The main table in this section should then auto-populate, alongside the graphs at the bottom of the tab. Here different pavement system combinations can be compared, and hotspots can be identified in terms of where in the system the largest sustainability impact are i.e., base, binder course or surface course. Users are also able to compare the total sustainability impacts of pavement systems (across all 3 layers of pavement).

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T0049 Collaborative Research with Industry Partners

Work Package 3: Material Design for Sustainability

National Highways, Mineral Products Association (MPA) and Eurobitume UK

Project number: 60657227

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Delivering a better world

Quality information

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Executive Summary

This project aims to develop an asphalt mixture design method/protocol for use in surface course, binder course and base pavement layers in England. The project is a collaborative research venture between AECOM, National Highways (NH), Mineral Products Association (MPA) and Eurobitume UK. This project includes four work packages. This report details the work completed under Work Package 3: Material Design for Sustainability.

The main objective of this work package is to develop a proposal and guideline document towards a unified asphalt mixture design method for use in the production of asphalt materials in England. This report includes a detailed review of the current asphalt mixture design approach used in England, a comparative analysis of formalised mixture design procedures used in the United States (Superpave, Balanced Mix Design), New Zealand, Australia (Austroads), South Africa (SABITA), France (LCPC) and Japan. The report noted that most international specifications rely on performance specifications. The asphalt mixture design approach in England is still largely dependent on empirical specifications. In addition to this, a full-scale trial strip for a Site Installation Performance Trial (SIPT) is adopted for Thin Surface Course Systems to confirm the required properties (e.g., volumetrics, resistance to permanent deformation and stiffness). This is considered good practice for Initial Type Testing, laboratory assessments and optimisation prior to the full-scale trial could further enhance the process and ultimately improve the performance and durability of asphalt mixtures.

The proposed approach in this report embraces a hierarchy associated with traffic level and risk of damage through traffic loading. The different approaches proposed for designing the asphalt mixtures are prescriptive, empirical, performance-related, and performance-based. This report presents the performance-based approach as an aspirational protocol which may also facilitate accelerated design and approval processes for innovative pavement materials and future evolution of asphalt materials in England. For each of the mixture design approaches, the designer should consider the type and level of traffic, type of application, type of asphalt mixture and/or the risk of structural damage.

Some outputs from these mixture designs can feed into the Excel-based Framework which was developed under a parallel Work Package (WP2) of this task (reported separately). In combination with the outputs of WP2, early data gathering, and sustainability impact assessment/scoring might be carried out in parallel with the mixture design process. This can be achieved by assigning indicative impact values depending on selected sources of components to embed the need for relevant data. Inputs gathered at the design stage can be collated and verified for/from full-scale trial and production prior to validation of full Life Cycle Impact Assessment (LCIA) at a scheme level.

The proposed mixture design protocol, therefore, offers greater flexibility to include recycled and waste-derived materials with the risk to be managed by selecting the appropriate mixture design approach. These methods consider the use of Warm Mix Asphalts (WMA) which are key to National Highways achieving Net Zero by 2040 by reducing the carbon footprint associated with road construction and maintenance.

This report recommends further validation of the proposed mix design approach to establish the specification criteria and limitations for use in England. This can be done in three stages:

a) Laboratory assessment to evaluate the performance of asphalt mixtures produced using the new design protocol against mixtures produced using the current specification.

b) Validation of the laboratory results using a full-scale field trial.

c) Conducting a Life Cycle Impact Assessment (LCIA) to assess the impact of the new design.

It is recommended a ‘Questionnaire type survey’ is conducted for asphalt industry specialists and pertinent stakeholders in England to obtain feedback and suggestions about the proposed new asphalt mixture design protocol. This includes assessing the complexity and readiness of the new mixture design methods proposed in this report.

1. Introduction

1.1 Overview

National Highways (NH), Mineral Products Association (MPA) and Eurobitume UK commissioned AECOM to conduct this collaborative research with industry partners. This project comprises four work packages as detailed below:

- Work Package 1 (WP1) – Environmental Sustainability Indicators – requirements versus existing and gap analysis.
- Work Package 2 (WP2) – Next Generation Sustainability Measurement.
- Work Package 3 (WP3) – Material Design for Sustainability.
- Work Package 4 (WP4) – Dissemination, Benefits & Knowledge Transfer Form.

This report presents the work undertaken under WP3. This work package aims to develop a proposal and guideline document towards a unified asphalt mixture design method for use in England. The main drive is the fundamental shift towards considering volumetric and performance-related asphalt mixture designs as a contributor to enhanced durability and sustainability.

1.2 Objectives

To achieve the scope of this work package, the following objectives were identified:

1. Review current asphalt mixture design methods used in England.
2. Review and carry out comparative analysis for asphalt mixture design procedures used in the United States (Superpave, Balanced Mix Design), France (LCPC), South Africa (SABITA), Australia, New Zealand (Austroads) and Japan.
3. Identify interdependencies with pavement design methods as detailed in the Design Manual for Roads and Bridges (DMRB).
4. Identify the gaps and key areas of the current mixture design methods that require improvement. This objective emphasises sustainability by improving the performance and durability of the designed asphalt mixtures in relation to findings from WP1 and WP2.
5. Produce a protocol/guideline document for a proposed new asphalt mixture design for use in England. The new asphalt mixture design procedure should consider specification requirements such as site category, traffic levels, the impact of the inclusion of Reclaimed Asphalt (RA), waste-derived materials and performance modifiers.
6. Enable early-stage indicative measurement of environmental sustainability impact categories as inputs to Scheme level assessment.
7. Provide recommendations for follow-up work to test and validate the proposed mixture design procedure.

2. Current Asphalt Mixture Design Methods in England

2.1 Introduction

The current asphalt mixture designs used in England are generally based on empirical specifications with emphasis on defining and controlling the composition and constituent materials of the asphalt. Each mixture formulation needs a declaration of the performance properties. Performance is demonstrated through a product-type testing procedure. To illustrate, for recipe specified mixtures, aggregate grading and binder content are the main (or only) parameters. In more complex situations, performance-related and performance-based properties such as stiffness, resistance to permanent deformation and fatigue are included.

Table 1 summarises the main reference documents that are associated with the process of asphalt mixture design in England. To illustrate, BS EN 13108 (Parts 1 to 7 and 9) provide the key requirements for asphalt mixtures. BS EN 13108 Part 20 and Part 21 provide the requirements for product type assessment and requirements for conformity. This process is called Assessment and Verification of Constancy of Performance (AVCP). The main output following the AVCP process is to enable the UK Conformity Assessed (UKCA) marking of the product confirming that the material can meet the performance detailed in the declaration of performance.

Table 1: Main Reference Documents for Asphalt Mixture Design in England

Reference Documents	Purpose
BS EN 13108 (Part 1 to 7 and 9)	• Provides options for asphalt mixtures. • Defines requirements for permissible constituent materials. • Permissible target composition of asphalt mixtures. • Classes/categories of properties of the asphalt mixture to be declared. • Means of specimen preparation.
BS EN 13108 – Part 8	• Provides a classification system for Reclaimed Asphalt (RA) as a feedstock material for asphalts.
BS EN 13108-20	• Identifies the Type Testing procedures to be applied to provide assurance that an asphalt mixture formulation complies with the requirements of the product standards (calls up test methods from the BS EN 12697 series of asphalt testing standards).
BS EN 13108-21	• Used by the Producer to ensure product constancy and conformity.
BS EN 12697 series	• Asphalt testing standards.
PD 6691	• Guidance on the use of BS EN 13108. • Includes example specifications.
BS 594987	• Includes the requirements for the laying of asphalts to ensure the durability of the finished work. • Informative protocols/guidelines for mixture development of Hot Rolled Asphalt (HRA), Porous Asphalt (PA) and Béton Bitumineux pour chaussées Aéronautiques (BBA).
MCHW Volume 1, Series 900	• Provides specification requirements for bituminous bound materials.

2.2 Constituent Materials

Table 2 provides a summary of the minimum criteria required for the aggregate and bitumen used in asphalt mixtures. BS EN 13043 defines the properties of aggregates and filler for use in bituminous mixtures. Detailed recommendations for categories of all relevant properties of aggregate are given in PD 6682-2. The required criteria for grading, fines content, flakiness index, resistance to fragmentation and durability of the aggregate are specified based on the intended end-use. The requirements for Polished Stone Value (PSV) and Aggregate Abrasion Value (AAV) for surface courses are specified according to traffic levels in DMRB CD 236 and are based on the road type and geometry in accordance with the requirements and guidance included in DMRB CS 228.

The paving grade bitumen of 40/60 in accordance with BS EN 12591 is the standard grade used in asphalt mixtures for surface course, binder course and base layers in accordance with DMRB CD 226. However, there is an increasing trend to use Polymer Modified Bitumen (PMB). For Enrobés á Module Elevé (EME 2) binder and base courses, 10/20 or 15/25 bitumens are those used in accordance with BS EN 13924 and as detailed in DMRB CD 226.

Table 2: Aggregate and Binder Requirements for Asphalt Mixtures from MCHW Series 900

Aggregate: Comply with BS EN 13043 and the Examples of the Relevant Annexes of PD 6691 in Terms of Grading, Fines Content and Flakiness Index and be CE (UK CA) Marked	
Property	**Criteria**
Resistance to Fragmentation (Hardness)	LA_{30} or better for natural aggregates and LA_{50} or better for blast furnace slag (MCHW 901.13).
Resistance to Freezing and Thawing (Durability)	The freezing and thawing (soundness) category shall be MS_{25} unless otherwise specified in contract-specific Appendix 7/1; The water absorption value of the coarse aggregate shall be determined in accordance with BS EN 13043. If the water absorption value of the coarse aggregate is greater than $WA_{24}2$, the soundness test shall be carried out on the material delivered to the site. (MCHW 901.14 – 901.17)
Cleanness	Not exceed the limits stated in PD 6691 Annex B, Annex C and Annex D, when tested in accordance with the washing and sieving method of BS EN 933-1. (MCHW 901.18)
Resistance to Polishing and Surface Abrasion	Required for surface courses only (MCHW 901.19 – 901.20). The specified PSV and AAV will depend on the type of surface course and the traffic level. Site category and Investigatory Level (IL) must also be considered when selecting the PSV. (CD 236 refers)
Binder in Asphalt Mixtures	
Binder	Paving grade bitumen shall comply with BS EN 12591. Polymer modified bitumen shall comply with BS EN 14023. Hard Paving Grade Bitumen in accordance with BS EN 13924 and the requirements specified in Volume 1, Specification for Highway Works, Series 900, Tables 9/6, 9/7 and 9/8.

2.3 BS EN 13108-1: Asphalt Concrete

2.3.1 Recipe Mixtures

Recipe mixtures can be considered as ‘off-the-shelf’ products. They adopt the principle of a declared target composition to produce mixtures traditionally used in England. The recipe mixture design is an example of ‘empirical specifications’ where the grading and binder content are identified from prescriptive limits.

Table 3 presents the main criteria and requirements that need to be considered for recipe mixtures. The single point binder content B_{act} represents both minimum and maximum binder content for categorisation purposes. For UK CA marking, the binder content needs to be corrected to determine the B_{min} as defined in BS EN 13108.

Table 3: BS EN 13108-1: Recipe Mixtures for Asphalt Concrete

Property – Target composition	Criteria
Example specification is provided in PD 6691 Annex B in accordance with BS EN 13108-1.	
Grading	The limits for target composition give a restricted envelope or a single point, around which compliance tolerances are applied.
Binder Content	The target binder content, B_{act}, is provided based on the mixture type and type of aggregate (limestone, basalt, other crushed rock, blast furnace slag of different bulk density, steel slag, and gravel).
A type-test report is required to include: • A declaration of the types/sources of constituent materials • Test data showing conformity of constituent materials with relevant requirements; and • A declaration of the target composition of the mixture.	

2.3.2 Designed Base and Binder Course Mixtures

The permitted base and binder course designed mixtures for flexible pavements are detailed in DMRB CD 226. They require full-scale trials to verify the air void content and deformation resistance. Table 4 presents the main criteria and requirements that need to be considered for the designed mixtures.

Table 4: BS EN 13108- 1: Designed Base and Binder Course Mixtures

Property	Design Criteria
Grading	The aggregate grading of the target composition needs to fall within the envelope given in the example specification in accordance with BS EN 13108-1 and PD 6691 Annex B.
Binder Content	PD 6691 Annex B defines the minimum target binder content for designed mixtures based on the type of aggregates such as limestone, basalt, other crushed rock, blast furnace slag of different bulk density, steel slag, and gravel.
Void Content	The design void content of the mixtures needs to meet the specified V_{min} and V_{max} in accordance with BS EN 13108-1 and PD 6691. These are determined from cores taken from a full-scale trial strip in accordance with BS 594987 Annex C.
Water Sensitivity	Required for mixtures to be used on trunk roads including motorways. The minimum Indirect Tensile Strength Ratio (ITSR) shall be in accordance with Volume 1, Specification for Highway Works, Series 900 Clause 908; $ITSR_{80}$ when produced as WMA or $ITSR_{70}$ when produced as HMA. ITSR is tested in accordance with BS EN 12697-12 Method A.
Deformation Resistance	The resistance to permanent deformation of the mixture needs to meet the appropriate class selected in accordance with PD 6691 Annex B and BS 594987 Annex D (trial strip).
Stiffness Modulus	The mean Indirect Tensile Stiffness Modulus (ITSM), determined from cores taken from a full-scale trial strip shall conform to category $S_{min1800}$ for mixtures with 40/60 grade binder and $S_{min2800}$ for mixtures with 30/45 grade binder. Noted that there is no design chart in DMRB CD 226 which allows the use of mixtures with 30/45 grade binder.

2.3.3 EME2 and BBA mixtures

EME2 and BBA mixtures include performance-related and performance-based tests as part of their specification. Table 5 shows the elements associated with EME2 and BBA mixture designs. It should be noted that however BBA mixtures are used mainly in airfield pavement applications.

Table 5: BS EN 13108- 1: Asphalt Concrete (EME2 and BBA Mixtures)

Property	EME2	BBA
Grading	The aggregate grading of the target composition shall fall within the envelope given in the example specification in accordance with BS EN 13108-1 and PD 6691 Annex B.	The aggregate grading of the target composition shall fall within the envelope given in the example specification in accordance with BS EN 13108-1 and PD 6691 Annex B.
Binder Content	Binder shall conform to BS EN 13924 grade 10/20 or 15/25. The minimum target binder content for each aggregate target composition is given in Table B.9 of PD 6691 Annex B.	Binder shall conform to BS EN 12591 paving grade bitumen 30/45, 40/60 or 70/100. Polymer modified bitumen shall conform to BS EN 14023. The minimum target binder content for each aggregate target composition is given in Table B.20 of PD 6691 Annex B.
Void Content	The void content of specimens of EME2 mixtures at target composition prepared in the laboratory in accordance with BS EN 12697-35 and compacted in the gyratory compactor in accordance with BS EN 12697-31, using the appropriate number of gyrations from Table B.10 of PD 6691 shall be V_{max} 6.0. The void content shall also be determined from cores taken from a full-scale trial strip.	The void content of specimens of BBA mixtures at target composition prepared in the laboratory in accordance with BS EN 12697-35 and compacted in the gyratory compactor in accordance with BS EN 12697-31, shall conform to Table B.21 of PD 6691.
Water Sensitivity	The compression ratio (i/C) of laboratory manufactured specimens at target composition shall not be less than 75% ($i/C_{min}75$) when tested in accordance with BS EN 12697-12 Method B.	The compression ratio (i/C) of laboratory manufactured specimens at target composition shall be a minimum of 70% ($i/C_{min}70$) for the binder course and 80% ($i/C_{min}80$) for the surface course when tested in accordance with BS EN 12697-12 Method B.
Deformation Resistance	The deformation resistance tested in accordance with the large wheel tracking test in BS EN 12697-22, large device, shall conform to category P7.5.	The deformation resistance tested in accordance with the large wheel tracking test in BS EN 12697-22, large device, shall conform to Table B.22 of PD6691.
Stiffness Modulus	The mean ITSM, determined from cores taken from a full-scale trial strip shall conform to category $S_{min5500}$.	The stiffness modulus of the mixture tested in accordance with the stiffness test in BS EN 12697-26, Annex C, shall conform to Table B.23.
Resistance to Fatigue	The resistance to fatigue of specimens prepared in accordance with BS EN 13108-20 and tested in accordance with BS EN 12697-24, Annex A (2PB-TZ, shall conform to category $\varepsilon_{6\text{-}130}$).	The resistance to fatigue of specimens prepared in accordance with BS EN 13108-20 and tested in accordance with BS EN 12697-24, Annex A (2PB-TZ, shall conform to Table B.24 of PD 6691).

2.4 BS EN 13108-2: Asphalt Concrete for Very Thin Layers (BBTM)

The target composition of the aggregates for Asphalt Concrete for Very Thin Layers (BBTM) are selected for surface courses in very thin layers with thickness values of 20 mm to 30 mm.

Table 6 shows the elements associated with the mixture design of Béton Bitumineux Très Mince (BBTM).

Table 6: BS EN 13108-2 Asphalt Concrete for Very Thin Layers (BBTM)

Property	Criteria
Grading	The target composition of the mix shall be within the grading envelope provided in BS EN 13108-2.
Binder Content	The minimum design binder content is provided in Table 9/10 in Volume 1, Specification for Highway Works, Series 900.
Void Content	The void content is defined when appropriate as categories selected from Table 3 (V_g) or Table 4 (V_i or V_v) of BS EN 13108-2.

Water Sensitivity	The retained strength of laboratory manufactured specimen at target composition shall be a minimum of 70% when tested in accordance with BS EN 12697-12.
Mechanical Stability	The resistance to permanent deformation of mixtures tested in accordance with EN 12697-22 is defined in Table 7 of BS EN 13108-2. The wheel-tracking levels of the thin surface course system are required to be Level 3 and should be declared under the CE Marking declaration of performance.

2.5 BS EN 13108-4: Hot Rolled Asphalt

2.5.1 Recipe Mixtures

Table 7 presents the main criteria and requirements that need to be considered for recipe mixtures.

Table 7: BS EN 13108-1 Recipe Mixtures for Hot Rolled Asphalt

Property	Criteria
Grading	Example specification is provided in accordance with BS EN 13108-4 and PD 6691 Annex C. The grading specifications give a single point or a very narrow envelope.
Binder content	The binder content, B_{act}, is specified based on the type of aggregate (limestone, basalt, other crushed rock, blast furnace slag of different bulk density, steel slag, and gravel).
A type-test report is required to include: • A declaration of the types/sources of constituent materials • Test data showing conformity of constituent materials with relevant requirements; and • A declaration of the target composition of the mixture.	

2.5.2 Designed Surface Course Mixtures

The aggregate grading of the target composition shall fall within the envelope given in the example specification in accordance with BS EN 13108-4 and PD 6691 Annex C. Design binder content is determined in accordance with BS 594987, Annex H; Protocol for determining the design binder content of designed Hot Rolled Asphalt (HRA) surface course.

2.5.3 HRA Performance-Related Mixtures

Table 8 shows the key elements for the mixture design of Hot Rolled Asphalt (Performance-related mixtures).

Table 8: BS EN 13108-4 Hot Rolled Asphalt (Performance-Related Mixtures)

Property	Criteria
Grading	Performance-related surface course mixtures shall be 35/14F.
Binder Volume	The minimum binder volume determined from the trial strip protocol in BS 594987:2015, Annex F, shall be category $B_{vol15,5}$.
Void Content	The void content of the mixture at target composition determined in accordance with the trial strip protocol in BS 594987:2015, Annex F, shall be as follows: • The average void content category of core pairs shall be $V_{max7,5}$; and • The average void content category of sets of six cores shall be V_{max5}.
Deformation Resistance	The resistance to permanent deformation is determined from tests with the small wheel tracking device on 200 mm diameter core specimens in accordance with BS 594987:2015, Annex F and need to meet the specified limits in Table C.3 of PD 6691.

2.6 BS EN 13108-5: Stone Mastic Asphalt (SMA)

Table 9 shows the elements associated with the mixture design of Stone Mastic Asphalt (SMA).

Table 9: BS EN 13108-5 Stone Mastic Asphalt (SMA)

Property	SMA Surface Course	SMA Binder Course
Grading	The aggregate grading of the target composition shall fall within the envelope given in the example specification in accordance with BS EN 13108-5 and PD 6691 Annex D.	The aggregate grading of the target composition shall fall within the envelope given in the example specification in accordance with BS EN 13108-5 and PD 6691 Annex D.
Binder Content	PD 6691 Annex D provided examples of the actual binder content based on the aggregate grading for an aggregate density in the mixture of 2,650 Mg/m^3.	PD 6691 Annex D provided examples of the actual binder content based on the aggregate grading for an aggregate density in the mixture of 2,650 Mg/m^3.
Void Content	The void content of the mixture needs to meet the specified $V_{min1.5}$ and V_{max5} in accordance with BS EN 12697-35:2004, Laboratory mixing.	The void content of the mixture at target composition determined in accordance with the trial strip protocol in BS 594987:2015, Annex G, shall be: • The average void content category of core pairs, V_{max} 6.0. • The average void content category of sets of six cores, V_{max} 4.0.
Deformation Resistance	The resistance to permanent deformation is determined from tests with the small wheel tracking device in accordance with BS 594987:2015, Annex G or in accordance with BS EN 12697-35:2004, Laboratory mixing. The resistance to permanent deformation needs to meet the criteria in Table D.2 of PD 6691.	The resistance to permanent deformation is determined from tests with the small wheel tracking device in accordance with BS 594987:2015, Annex G. The resistance to permanent deformation needs to meet the criteria in Table D.2 of PD 6691.

2.7 Thin Surface Course Systems (TSCS)

Thin Surface Course Systems (TSCS) are proprietary surface course materials, commonly used in the SRN, requiring a Product Acceptance Scheme (PAS) certification. TSCS are installed at a thickness level between 20 mm to 50 mm. TSCS materials provides high performance, rut resistant, low noise and skid-resistant layer that supports the high volume of traffic found on the strategic road network. TSCS conform to MCHW Clause 942. Table 10 details the key requirements for TSCS.

Table 10: Requirements for Thin Surface Course Systems (TSCS)

Property	Criteria
Material Requirement	TSCS shall comply with BS EN 13108 Part 1, 2 or 5. The specific coarse aggregate requirements are detailed in the current MCHW Clause 942.
Binder Content	The minimum design binder content is detailed in the current MCHW Clause 942.
Permanent Deformation	The resistance to permanent deformation of mixtures conforming to BS EN 13108 Parts 1 and 5 shall be in accordance with the appropriate class selected from Table B.4 or D.2 respectively of PD 6691.
Water Sensitivity	The minimum Indirect Tensile Strength Ratio (ITSR) shall be in accordance with Volume 1, Specification for Highway Works, Series 900 Clause 908; $ITSR_{80}$ when produced as WMA or $ITSR_{70}$ when produced as HMA. ITSR is tested in accordance with BS EN 12697-12 Method A.
Void Content	The design void content of the mixture Shall be V_{min}1% to V_{max}5%.

2.8 Identify Interdependencies with Pavement Designs

DMRB CD 226: *Design for new pavement construction* is used on all schemes involving the design of pavement construction for new build carriageways, widening of existing carriageways, or reconstruction of existing pavements on the SRN (i.e., motorway and all-purpose trunk roads). In accordance with DMRB CD 226, the standard asphalt materials to be used in the base and binder course layers (the main structural layers of a pavement) are:

- Dense and heavy-duty materials are specified in accordance with MCHW Clause 929 (AC 32 dense base or bin 40/60 des, AC 32 HDM base or bin 40/60 des).
- EME2 - specified in accordance with MCHW Clause 930 (designed mixtures) targeting a penetration value of 10/20 or 15/25.
- HRA binder courses - specified in accordance with MCHW Clause 943 (Performance-Related Design Mixtures) for flexible pavements with an HBM base.
- SMA binder course - specified in accordance with MCHW Clause 937 for flexible pavements with a HBM base.

Permitted asphalt surface course materials are selected in accordance with the England National Application Annex in DMRB CD 236 as follows:

- MCHW Clause 942 Thin Surface Course System
- MCHW Clause 943 Hot Rolled Asphalt
- MCHW Clause 938 Porous Asphalt (departure from the standard required and not to be used on flexible composite construction)

The asphalt surface course does not have a significant impact on the structural design of flexible pavements in DMRB CD 226, the design thickness of the layers for flexible pavements is determined based on traffic loadings (Design Traffic, T) the foundation class and the type of asphalt material. Figure 1 is used to determine the design thickness of the layers for flexible pavements in accordance with DMRB CD 226.

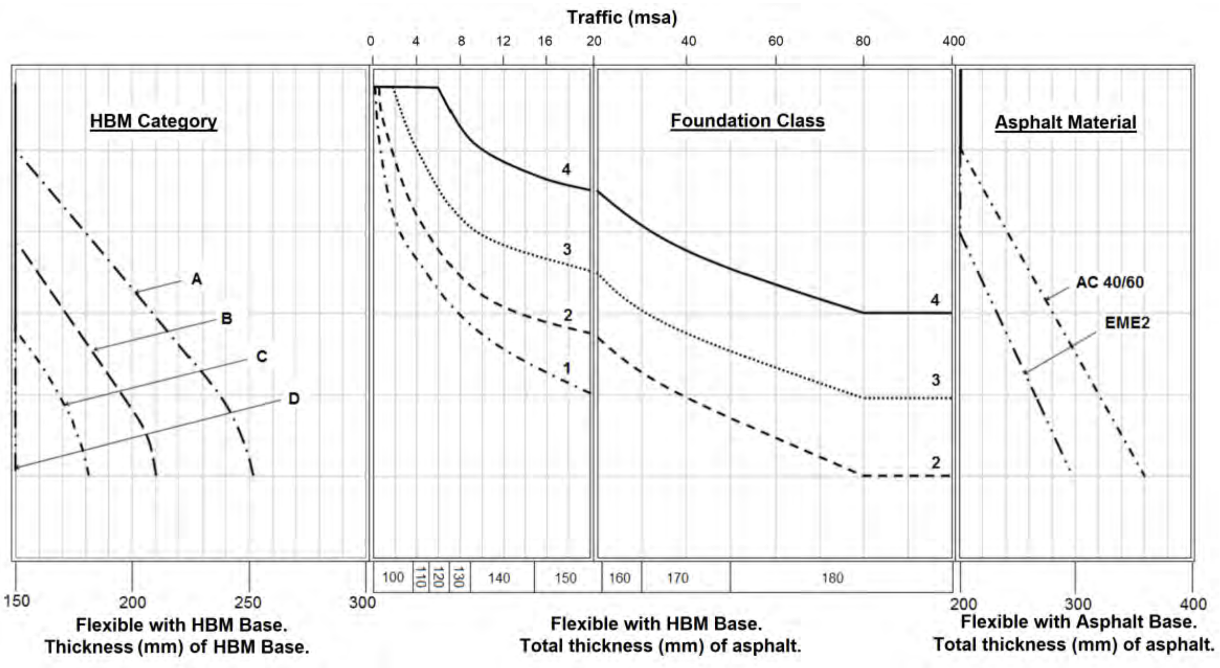

Figure 1: Nomograph for Determining the Design Thickness for Flexible Pavements (DMRB CD 226)

For flexible pavements with an asphalt base, the right-hand side of the nomograph is used to determine asphalt thickness values (comprising the surface course, binder course and base). It can be seen from Figure 1 that using asphalt materials such as EME2 results in a reduced design thickness in comparison to the use of AC 40/60 asphalt materials. The base and binder course layers need to use the same material type (both layers contain either AC 40/60 or EME2). Where a design for a flexible pavement with an asphalt base combines an EME2 layer with an AC40/60 layer, the design thickness should be based on the AC 40/60 line. In terms of constituent materials, DMRB CD 226 requires the use of only crushed rock or slag for the coarse aggregate in all asphalt materials where traffic exceeds 80 msa.

DMRB CD 226 sets out requirements and procedures for alternative designs that use analytical methods to model the stresses, strains and assumed material properties to determine design thicknesses. Any alternative design requires a 'departure from standard' approved by the Overseeing Organisation. For asphalt materials, the elastic stiffness moduli used for pavement design is the long-term stiffnesses determined at the reference condition of 20°C and 5 Hz. The values of long-term elastic stiffness modulus used in analytical pavement designs are shown in Table 11. It should be mentioned that these conditions are not the same as those used for the Indirect Tensile Stiffness Test (IT-CY) which uses the lower frequency of 2.5 Hz.

Table 11: Elastic Stiffness Moduli for Typical Asphalt Materials (at 20°C and 5 Hz)

Material	Stiffness (MPa)
TSCS	2000
HRA binder course	3100
AC 40/60 des (binder course or base)	4700
EME2 (binder course or base)	8000

The alternative designs provide a versatile approach that allows the use of materials beyond those permitted in DMRB CD 226 and DMRB CD 236. These materials can be characterised and tested to include:

- Effective stiffness modulus.
- Resistance to deformation.
- Fatigue resistance.

2.9 Discussions

The approach for asphalt mixture designs used in the MCHW is currently largely tailored to maintain the same mixtures which have been traditionally used over many years (empirical with known, acceptable performance). Following this review, key factors for consideration are detailed below:

1. The requirements of constituent materials are not generally linked to the level of traffic. The characteristics of aggregate materials are mainly specified based on the type of application. The current MCHW specifications only account for traffic levels when considering PSV and AAV values. The selection of binders lacks clear guidance linking the traffic and environmental conditions to performance-based criteria of binders.

2. The current mixture design approach does not present specific requirements for volumetric properties in obtaining the mechanical performance of asphalt mixtures against the design traffic.

3. The conformity requirements of asphalt mixtures (such as air voids, deformation resistance and stiffness) are mostly applied on full-scale compacted asphalt mixtures. A mixture design approach that considers the volumetric and mechanical properties allows the optimisation of the constituent materials and the resulting asphalt mixture.

3. Review of International Asphalt Mixture Design Methods

3.1 The Superpave Mix Design

The Superpave mix design method is considered one of the major advancements from the Strategic Highway Research Program (SHRP) to improve the performance of Hot Mix Asphalts (HMA). SHRP included two main parts: binder specifications and asphalt mixture design methods. The performance-based binder specifications include rheological tests and parameters that are linked to climate and traffic conditions. Certain aggregate characteristics are specified to improve the performance of the HMA. The performance of asphalt mixtures using Superpave is anticipated to be improved through the assurance of desirable limits for the volumetric and mechanical properties of the asphalt mixtures (Asphalt Institute, 2015).

3.1.1 Approach and Design Criteria

The Superpave volumetric mix design includes four basic steps: selection of materials, selection of the design aggregate structure, selection of the design asphalt binder content, and evaluation of the mixture for moisture sensitivity. A satisfactory mix design is required to meet all of the volumetric requirements based on the total traffic expected during the pavement service life expressed in Equivalent Single Axle Loads (ESALs). Figure 2 shows an overview of the Superpave mixture design process that needs to be followed during asphalt mixture design. Additional performance testing such as rutting and fatigue testing can be added depending on the traffic level and importance of the scheme to confirm the potential performance of materials.

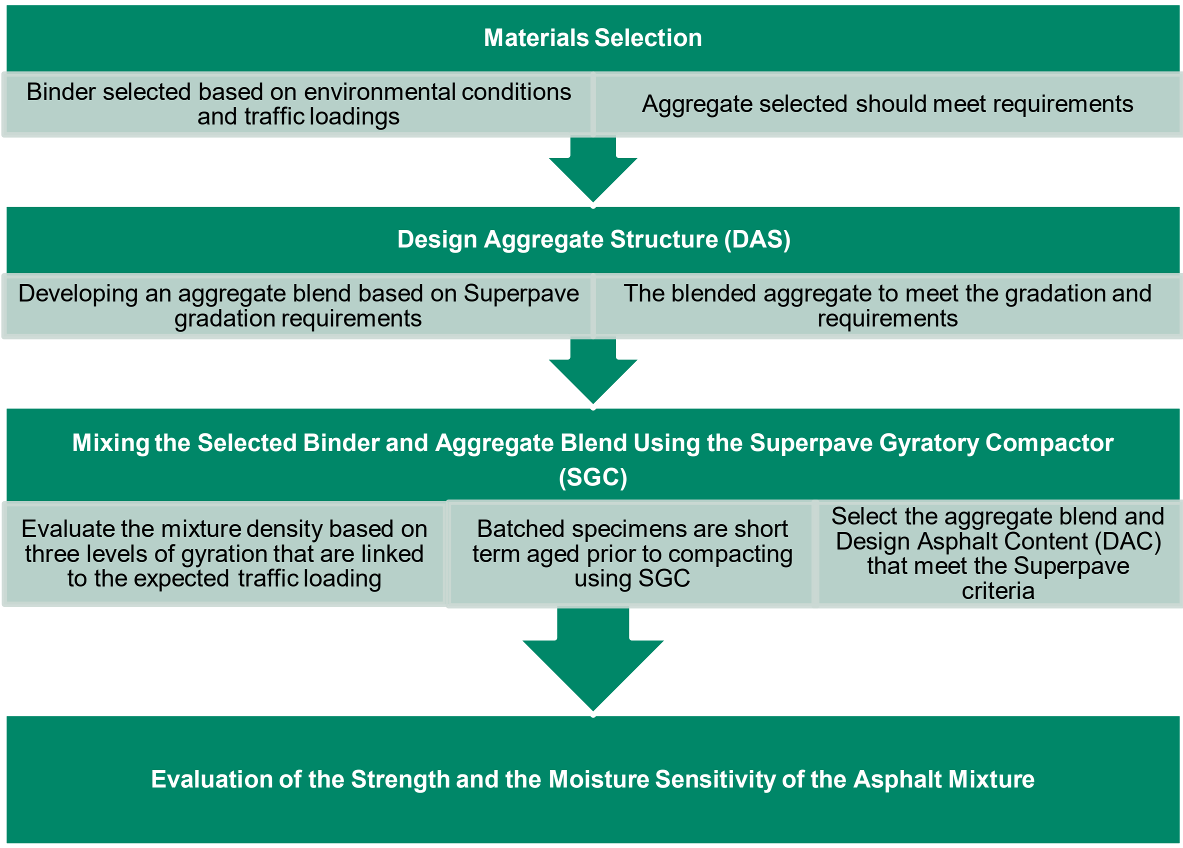

Figure 2: Main Elements of Superpave HMA Mixture Design Process

3.1.2 Aggregate and Binder Selection

The Performance Grade (PG) of a binder is selected based on environmental conditions and traffic loadings. A traffic load designator (S- Standard, H-Heavy, V-Very Heavy, or E-Extremely Heavy) is applied to the PG binder type according to traffic speed and load (AASHTO M332). The Superpave PG system comprises two numbers, written as PG xx-yy. The first number (xx) is the average seven-day maximum pavement temperature (°C) and the second (yy) is the minimum pavement design temperature likely to be experienced (°C). For example, a PG 64-22 is intended for use where the average seven-day maximum pavement temperature is 64°C and the expected minimum pavement temperature is -22°C.

Aggregate materials are usually selected based on their local availability and experience. However, the Superpave has set minimum criteria that the selected aggregate needs to meet. These criteria are divided into two categories: consensus properties and source properties (See Table 12 and Table 13). The consensus aggregate properties specified in the Superpave system are the following: coarse aggregate angularity; fine aggregate angularity; flat and elongated particles; and clay content (Sand Equivalent). The criteria for these properties are based on the traffic level and position within the pavement structure. Source properties of aggregate are typically specified to set limits on aggregate properties like toughness, soundness and deleterious materials.

Table 12: Superpave Aggregate Consensus Requirements (Asphalt Institute, 2015)

20-Year Design ESALs[a] (in Millions)	Coarse Aggregate Angularity (%), Minimum (CAA)		Uncompacted Void Content of Fine Aggregate Angularity (%), Minimum (FAA)		Sand Equivalent (%), Minimum (SE)	Flat and Elongated[c] (%), Maximum (F&E)
	≤ 100 mm[f]	> 100 mm[f]	≤ 100 mm	> 100 mm[f]		
<0.3	55/-	-/-	-[d]	-	40	-
0.3 to <3	75/-	50/-	40[e]	40	40	10
3 to <10	85/80[b]	60/-	45	40	45	10
10 to <30	95/90	80/75	45	40	45	10
≥ 30	100/100	100/100	45	45	50	10

Notes:
[a] Design ESALs are the anticipated project traffic level expected on the design lane over 20 years. Regardless of the actual design life of the roadway, determine the design ESALs for 20 years and choose the appropriate N_{des} levels.
[b] 85/80 denotes that 85 per cent of the coarse aggregate has one or more fractured faces and 80 per cent has two or more fractured faces.
[c] This criterion does not apply to 4.75-mm nominal maximum aggregate size mixtures.
[d] For 4.75-mm nominal maximum aggregate size mixture designed for traffic levels below 0.3 million ESALs, the minimum Uncompacted Void Content is 40.
[e] For 4.75-mm nominal maximum aggregate size mixture designed for traffic levels equal to or above 0.3 million ESALs, the minimum Uncompacted Void Content is 45.
[f] If less than 25 per cent of a construction lift is within 100 mm of the surface, the lift may be considered to be below 100 mm for mix design purposes.

Table 13: Recommended Superpave Property Tests and Typical Requirements (Asphalt Institute, 2015)

20-Year Design ESALs (in Millions)	Los Angeles Abrasion (Max. %)	Sodium or Magnesium Sulfate Soundness (Max. %)	Deleterious Materials*	
			Clay Lumps/ Friable Particles	Lightweight Particles
<0.3	45	25	<5	<5
0.3 to <3	40	20	<4	<4
3 to <10	30	15	<3	<3
10 to <30	30	15	<2	<2
≥ 30	25	<10	<1	<1

*Specific tests and property requirements to be determined locally

3.1.3 Design Aggregate Structure (DAS)

Superpave gradation requirements have control points based on the selected nominal size of the aggregate. Typically, three blends are developed ranging from the coarse to the fine side of the Superpave control points for a given nominal maximum size. After selecting a blend, the aggregate consensus properties must be confirmed as meeting the Superpave criteria. The most important part of designing an aggregate structure is the Voids in Mineral Aggregate (VMA) which forms a key requirement necessary to meet the volumetric criteria. The procedure is typically a trial-and-error process; however, some general guidelines will assist in achieving the VMA. These are highlighted below:

- The use of rough and crushed surface texture aggregate
- Moving the gradation away from the maximum density line
- Reducing the per cent of natural sand and using more per cent of the crushed sand
- Reducing the amount of filler

3.1.4 Superpave Gyratory Compactor (SGC)

Superpave volumetric mix design is conducted using a blending process to find a mixture with the appropriate properties at the design compaction level. The design compaction level is selected based on the design Equivalent Single Axle Loads (ESAL). The specimen size is 150 mm (diameter) by 115 mm (height). Three different levels of gyrations (density) are specified based on the expected traffic loading. These are referenced as N_{in}, N_{des} and N_{max}. These terms refer to the number of gyrations estimated to result in different levels of field densification where:

- N_{ini}: The number of gyrations used as a measure of mixture compactibility during construction. N_{ini} is a measure of the compactibility of the mix and is based on the estimated field density obtained behind the screed before compaction. A mixture designed for greater than or equal to 3 million ESALs with 4 per cent air voids at N_{des} should have at least 11 per cent air voids at N_{ini}. Mixtures that compact too quickly may be inherently tender to compact and would therefore be undesirable. The N_{ini} density specifications range from 89 to 91.5 per cent of the maximum density of the mixture, depending on the design traffic level. Mixtures with a high percentage of natural sand or low Fine Aggregate Angularity (FAA) and Coarse Aggregate Angularity (CAA) properties may fail this requirement (Tran, et al., 2019).

- N_{des}: The design number of gyrations required to produce a sample with the same density as that expected in the field after the indicated amount of traffic. A mix with 4 per cent air voids at N_{des} is desired in the mix design.

- N_{max}: The number of gyrations required to produce a laboratory density that should never be exceeded in the field. If the air voids at N_{max} are too low, then the field mixture may compact too much under traffic resulting in excessively low air voids and potential rutting. The air void content at N_{max} should never be below 2 per cent air voids.

Table 14 shows the Superpave compaction parameters based on expected traffic levels.

Table 14: Superpave Gyratory Compaction Levels (Asphalt Institute, 2015)

20-Year Design ESALs* (in Millions)	Compaction Levels		
	N_{ini}	N_{des}	N_{max}
<0.3	6	50	75
0.3 to <3	7	75	115
3 to <30	8	100	160
≥ 30	9	125	205
*Laboratory compaction parameters should be based on 20-year design ESALs, regardless of the pavement design life.			

3.1.5 Volumetric Properties

The binder content is considered one of the most important parameters affecting mixture performance. A binder content that is too high can lead to permanent deformation while binder content that is too low can cause cracking and durability problems (Tran, et al., 2019). The optimum binder content for a mixture is based on design air voids (V_a), typically 4.0 per cent compacted to N_{des}, and minimum VMA. Minimum VMA is specified based on Nominal

Maximum Aggregate Size (NMAS). Other important volumetric properties controlled in the Superpave mix design procedure include the per cent Voids Filled with Asphalt (VFA) and Dust Proportion (DP). Table 15 presents the specified levels of densification and the required Superpave volumetric parameters.

Table 15: Superpave Mixture Requirements (Asphalt Institute, 2015)

<table>
<tr><th rowspan="3">20-Year Design ESALs[a] (in Millions)</th><th colspan="3">Required Relative Density During Mix Design, Percent of Theoretical Maximum Specify Gravity</th><th colspan="5">Voids in the Mineral Aggregate (VMA), Percent Minimum</th><th rowspan="3">Voids Filled with Asphalt (VFA)[b] Range Percent</th><th rowspan="3">Dust to Binder Ratio (DP) Range[c]</th></tr>
<tr><th rowspan="2">N_{ini}</th><th rowspan="2">N_{des}</th><th rowspan="2">N_{max}</th><th colspan="5">Nominal Maximum Aggregate Size (NMAS), mm</th></tr>
<tr><th>37.5</th><th>25.0</th><th>19.0</th><th>12.5</th><th>9.5</th></tr>
<tr><td><0.3</td><td>≤91.5</td><td rowspan="5">96.0</td><td rowspan="5">≤98.0</td><td rowspan="5">11.0</td><td rowspan="5">12.0</td><td rowspan="5">13.0</td><td rowspan="5">14.0</td><td rowspan="5">15.0</td><td>70-80[d,e]</td><td rowspan="5">0.6-1.2</td></tr>
<tr><td>0.3 to <3</td><td>≤90.5</td><td>65-78[f]</td></tr>
<tr><td>3 to <30</td><td rowspan="3">≤89.0</td><td rowspan="2">65-75[e,f,g]</td></tr>
<tr><td>≥ 30</td></tr>
<tr><td><0.3</td><td>65-75[g]</td></tr>
</table>

Notes:

a) Design ESALs are the anticipated project traffic level expected on the design lane over 20 years. Regardless of the actual design life of the roadway, determine the design ESALs for 20 years.
b) For 37.5-mm nominal maximum aggregate size mixtures, the specified lower limit of the VFA shall be 64 per cent for all design traffic levels.
c) For 4.75-mm nominal maximum aggregate size mixtures, the dust-to-binder ratio shall be 1.0 to 2.0, for design traffic levels < 3 million ESALs, and 1.5 to 2.0 for design traffic levels ≥ 3 million ESALs.
d) For 4.75-mm nominal maximum aggregate size mixtures, the relative density (as a per cent of the theoretical maximum specific gravity) shall be within the range of 94.0 to 96.0 per cent.
e) For design traffic levels < 0.3 million ESALs and 25.0-mm nominal maximum size mixtures, the specified lower limit of the VFA range shall be 67 per cent, and for 4.75-mm nominal maximum aggregate size mixtures, the specified VFA range shall be 67 to 69 per cent.
f) For design traffic levels > 0.3 million ESALs and 4.75-mm nominal maximum aggregate size mixtures, the specified VFA range shall be 66 to 67 per cent.
g) For design traffic levels ≥ 3 million ESALs and for 9.5-mm nominal maximum aggregate size mixtures, the specified VFA range shall be 73 to 76 per cent.

If the aggregate gradation passes beneath the specified PCS Control Point, the dust-to-binder ratio range may be increased from 0.6–1.2 to 0.8–1.6 at the agency's discretion. Mixtures with VMA exceeding the minimum value by more than 2 per cent may be prone to flushing and rutting. Unless satisfactory experience with high VMA mixtures is available, mixtures with VMA greater than 2 per cent above the minimum should be avoided.

3.1.6 Moisture Sensitivity Tests

The asphalt mixtures produced at the design binder content and volumetric requirements are to be tested for their moisture sensitivity. Moisture sensitivity evaluation requires that the specimens are prepared and compacted to approximately 7.0 ± 0.5% air void content. The specimens are divided into two subsets with three of the specimens identified as the control specimens and another three samples as conditioned specimens. The ratio of the average Indirect Tensile Strength (ITS) of the conditioned subset to the control subset (retained strength) needs to be more than or equal to 80% to pass the moisture sensitivity requirements.

3.1.7 Balanced Mix Design

Additional mixture performance testing is not a formal requirement of the Superpave design system. However, many agencies recommend conducting performance testing, especially for important schemes or when heavily traffic loadings are expected. Additional performance testing may include one or more mixture tests such as a rutting test and a cracking test to balance the binder content and other design parameters between the two traditionally conflicting performances. Balanced Mix Design is conducted to define the optimum design parameters based on selected performance-related tests rather than merely defined using the volumetric properties.

Three design approaches have been proposed by the Federal Highway Administration (FHWA) Expert Task Group (ETD) on Mixtures and Construction founded a Balanced Mix Design (BMD) Task Force. Figure 3 shows the design process of the three approaches.

The three approaches are summarised as follows:

- Approach 1 (Volumetric Design with Performance Verification): This approach is the most common design method for BMD. The selected performance tests are used to prove the mix design already conducted using the volumetric criteria. If the designed mix cannot satisfy the performance criteria, the mix design will be repeated using different materials or mix proportions until passing the performance requirements.
- Approach 2 (Performance-modified Volumetric Mix Design): The mix design starts with Superpave volumetric design, but the volumetric design only provides the preliminary aggregate structure and binder content. The performance-related tests will be used to determine the final mix design parameters. Moisture susceptibility tests are carried out.
- Approach 3 (Performance Design): Performance tests are conducted at varying binder contents. Volumetric evaluation is determined and reported with no requirements to adhere to the existing limits.

An important concept of the BDM is the Performance Space Diagram (PSD). The PSD is formed by plotting the fatigue index and the rutting index in one diagram as shown in Figure 4. Performance tests such as the Hamburg test or the Disk-Shaped Compact Tension (DCT) can also be used in a PSD. The desirable mix design should fall into the “green area”, passing both the fatigue and rutting requirements.

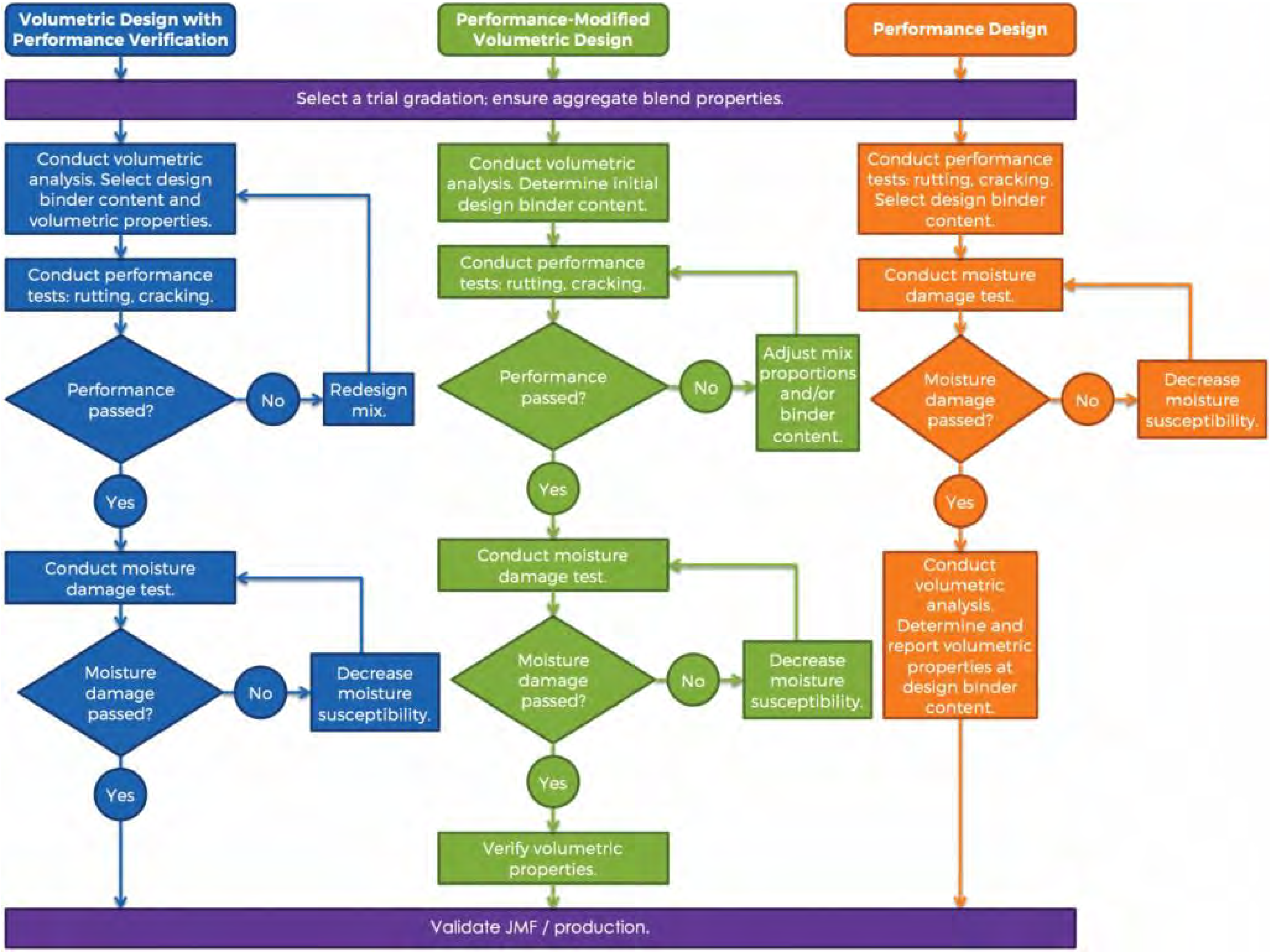

Figure 3: The Three BMD Approaches Proposed by ETD (West, et al., 2018)

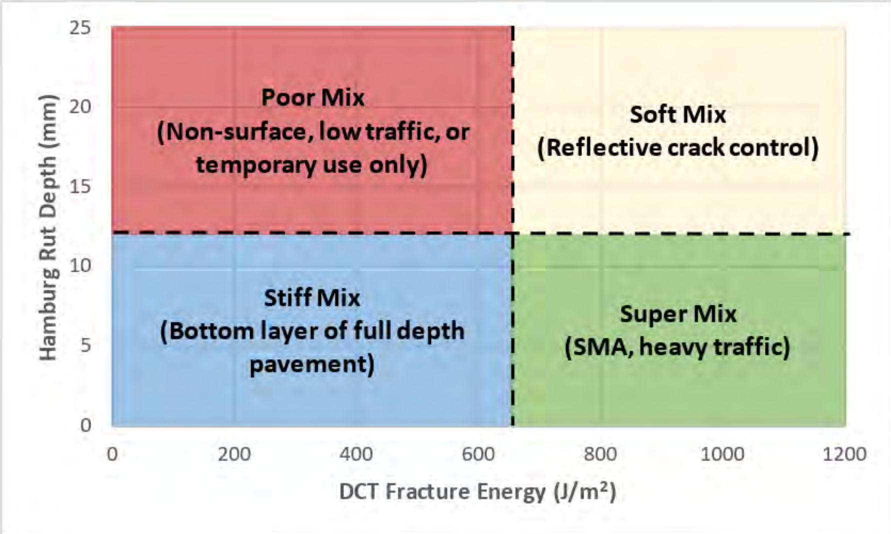

Figure 4: Example of Performance Space Diagram (PSD) (West, et al., 2018)

3.1.8 Discussions on Superpave Mix Design

The Superpave procedure offers unified volumetric requirements and design criteria for asphalt mixtures taking into account traffic and environmental conditions. The Superpave procedure effectively addresses the rutting problem for high traffic pavements by specifying a higher number of design gyrations, a higher grade of asphalt binder, and good quality aggregates. However, many highway agencies have concerns that the binder content designed in accordance with the Superpave mix design system produces dry mixes that result in durability issues. In response to this, some highways agencies have considered a modification to the Superpave mix design to increase the optimum binder contents. These modifications include reduced design gyrations (including the use of the 'locking point' to establish N_{des}), reduced design air voids, and increased minimum VMA criteria. The Federal Highway Administration (FHWA) recommends increasing the minimum VMA limits by 0.5 per cent for each NMAS level to increase the binder content. NCHRP Project 9-33 recommends increasing the design VMA by 1.0 per cent to produce mixtures with improved durability (Tran, et al., 2019).

The 'locking point' concept refers to the point at which the aggregate structure in a mixture "locks up" or reaches its maximum compaction where further compaction would lead to the degradation of the aggregate (Bahia et al. 1998). The design number of gyrations (N_{des}) recommended by Superpave was found to be much higher than the locking points of the mixtures as detailed in (Mohammad and Al-Shamsi 2007). In the same study, it was found that mixtures with dense aggregate structures designed based on the locking point maintained good resistance to permanent deformation and maintained an adequate level of durability (Mohammad and Al-Shamsi 2007). Alabama DOT defines the locking point as the point where less than 0.1 mm reduction in height is observed between successive gyrations. Alabama DOT found that most of their mixes "locked up" in the range of 45 to 55 gyrations and thus, then set the N_{des} at 60 gyrations (Tran, et al., 2019).

Another criticism of the Superpave procedure is that the Voids in the Mineral Aggregate (VMA) requirements are only based on Nominal Maximum Aggregate Size (NMAS) without taking into consideration the gradation of the mixture and the aggregate properties (specific gravity, shape, and absorption of aggregate). These are key parameters for controlling the film thickness of the asphalt binder (Mohammad and Al-Shamsi 2007). Suggestions for improvements to the Superpave procedure have included the use of the Bailey method to design the aggregate structures, locking point concept to define the N_{des}, and the use of the SGC curve to evaluate the constructability of the mixtures as well as their resistance to traffic loading (West, et al., 2018; Bahia, et al., 1998; Mohammad & Al-Shamsi, 2007).

Based on the survey of U.S. and Canadian highway agencies (49 survey agencies), the most common adjustment made to increase asphalt binder content was to decrease design gyrations N_{des} and increase minimum requirements for VMA (Tran, et al., 2019). The study also highlighted the importance of confirming that the values of bulk specific gravity of aggregate are accurately evaluated (Tran, et al., 2019).

3.2 French Asphalt Mix Design

3.2.1 Introduction

The French asphalt mix design (LCPC) provides a guide for asphalt mix design. LCPC covers most of the bituminous mixtures of EN 13108 series (EN 13108-1 Asphalt Concrete, EN 13108-2 Asphalt Concrete for Very Thin Layers and EN 13108-7 Porous Asphalt). The design of asphalt mixtures and their constituent materials (aggregates, fines, bituminous binders, mineral or organic additives) are based on the application thickness, layer position (surface, binder, upper and lower layer), traffic volume and type of asphalt mixture. There are five levels of testing as detailed in Figure 5.

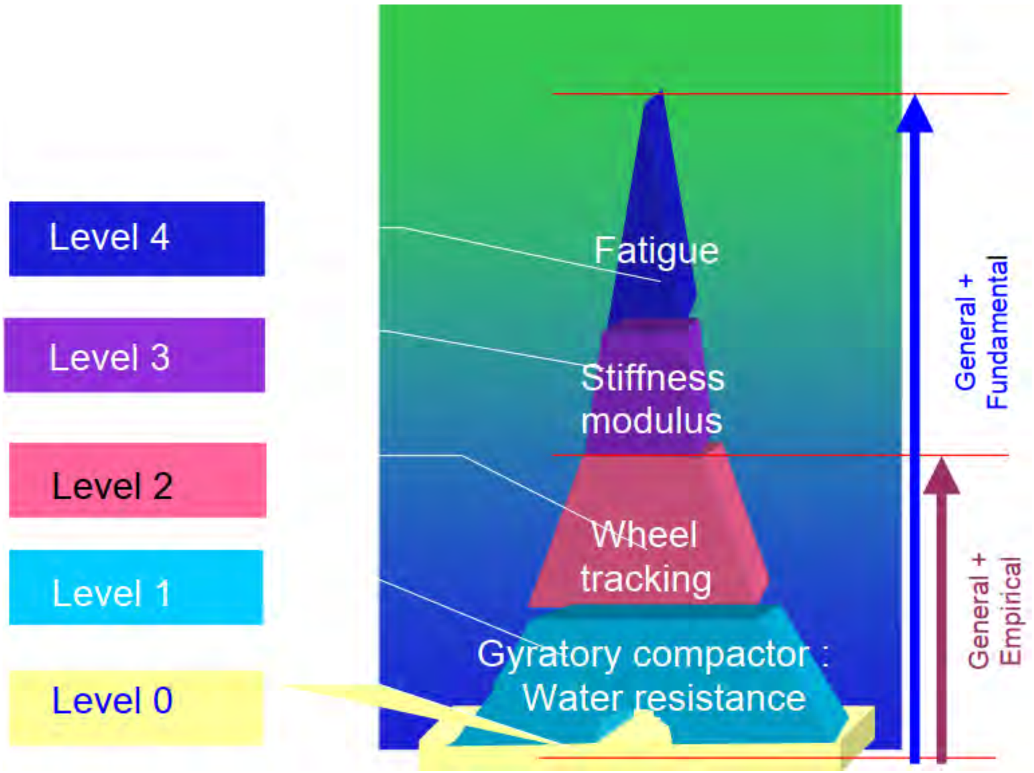

Figure 5: Level of Testing of the French Asphalt Mix Design (LCPC, 2007)

- Level 0 includes a description of the asphalt mixes that are related a grading and binder content without any type of test. This level is used only for asphalt mixes for non-trafficked areas.
- The design in Level 1 must be able to satisfy a full range of void percentages for use in the gyratory compactor test, as well as water resistance criteria. This level consists only of a volumetric design of the asphalt mixes with the verification of the effect of the water in the asphalt mix measured in accordance with EN12697-12, method B in compression. In the case of applications at low loading rates, Level 1 may be sufficient without the need for any further test.
- Level 2 comprises the Level 1 tests (Gyratory Compactor and water resistance) in addition to a wheel tracking test.
- Level 3 includes the specifications of previous levels in addition to the evaluation of the stiffness modulus of the asphalt mix. The stiffness value at 15°C, 10 Hz or 0,02 s is directly used in the structural design models of the pavement, corresponding to a level that is included in the fundamental approach of the European standards.
- Level 4 includes the determination of the fatigue resistance. This level must be considered when the asphalt mix is part of pavements for major roads and in a layer subjected to fatigue.
- According to the definitions of EN 13108-1, Level 0, Level 1 and Level 2 are relevant to the general + empirical approach. Level 3 and Level 4 are relevant to the general + fundamental approach.

3.2.2 Mixture Design Procedure

Figure 6 shows the main steps that are followed during the asphalt mixture design in accordance with the French mix design (LCPC, 2007). The mix design process begins by selecting the asphalt mixture components: aggregates, fines, binder, and additives. Knowing the characteristics of mix constituents is critical for the initial mix design phase and will also prove useful for all subsequent mix adjustments/refinements required if test results do not comply with specifications. The asphalt mixture components are then produced using the Gyratory Compactor to produce asphalt samples that meet the volumetric properties, grading and bitumen content requirements. The detail, recommendations and specification guidance associated with each stage are presented in the following sections.

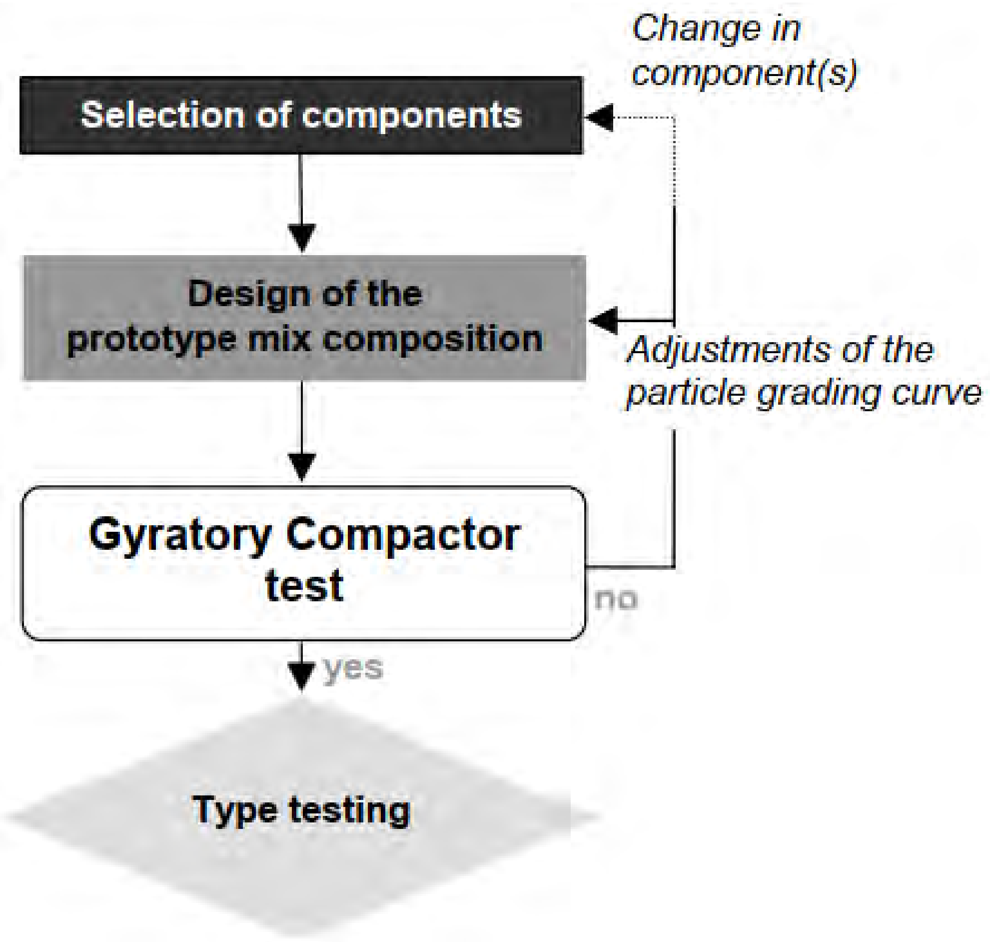

Figure 6: Asphalt Mixture Design Procedure (LCPC, 2007)

3.2.2.1 Materials Selection

The minimal constituent characteristics requirements for materials (coarse aggregate, fine aggregate, added filler and binder) are covered in Level 0 of the French mix design in addition to the minimum binder content and asphalt mixture grading. Fine aggregates should meet the requirements of the Methylene Blue Value (MBF) and grading requirements. Depending on the type of asphalt mixture and whether the coarse aggregate is used in the surface or binder courses, coarse aggregate should meet the minimal values of the following characteristics: resistance to fragmentation or to wear, polishing resistance, angularity, grading, flakiness, and fine content.

Table 16 presents the typical characteristics that are required for the filler, specification on fines from fine aggregate or mixed fillers (fines taken from fine aggregate and added fillers), and the minimum mechanical strength values and minimum production characteristics of coarse aggregates.

Table 16: Specifications and Minimum Requirements for Filler, Fines and Coarse Aggregates (LCPC, 2007)

<table>
<tr><th colspan="5">Typical Filler Characteristics for Asphalt Mixtures</th></tr>
<tr><td colspan="2">Particle Size Criteria</td><td>Harmful Fines</td><td colspan="2">Stiffening Properties</td></tr>
<tr><td>Sieve Size (mm)</td><td>Passing</td><td>MBF, in g/kg</td><td>(Rigden) V, in %</td><td>$\Delta_{R\&B}$, in °C</td></tr>
<tr><td>2</td><td>≥ 100</td><td rowspan="3">≤10
MB_F10</td><td rowspan="3">28 to 38
$V_{28/38}$</td><td rowspan="3">8 to 16
denoted
$\Delta_{R\&B}8/16$</td></tr>
<tr><td>0.125</td><td>85 to 100</td></tr>
<tr><td>0.063</td><td>≥ 70</td></tr>
<tr><th colspan="5">Specification on Fines from Fine Aggregate or Fines Taken from Fine Aggregate and Added Fillers</th></tr>
<tr><td>Characteristic</td><td>MBF in g / 1000g</td><td>(Rigden)V in %</td><td colspan="2">$\Delta_{R\&B}$ in °C</td></tr>
<tr><td>Specification EN 13043</td><td>≤10
MBF10</td><td>28 to 38
$V_{28/38}$</td><td colspan="2">8 to 16
denoted $\Delta_{R\&B}8/16$</td></tr>
<tr><th colspan="5">Indicative Minimum Characteristics of Coarse Aggregates</th></tr>
<tr><td colspan="2">Type of Use</td><td>Mechanical Strength EN 13043</td><td colspan="2">Production Characteristics</td></tr>
<tr><td colspan="2">Lower base layer</td><td>LA_{40} $M_{DE}35$; LA_{40} M_{DE35} (1)</td><td colspan="2">$G_C85/20$, $G_{25/15}$; FI_{25} ; f_1</td></tr>
<tr><td colspan="2">Upper Base layer</td><td>LA_{30} $M_{DE}25$; LA_{30} M_{DE25} (1)</td><td colspan="2">$G_C85/20$, $G_{25/15}$; FI_{25} ; f_1</td></tr>
<tr><td colspan="2">Thick binder layer (≥ 5cm)</td><td>LA_{30} $M_{DE}25$; LA_{30} M_{DE25} (1)</td><td colspan="2">$G_C85/20$, $G_{20/15}$, FI_{25} , f_1</td></tr>
<tr><td colspan="2">Thin binder layer (AC-BBM)</td><td>LA_{25} $M_{DE}20$; LA_{25} M_{DE20} (1)</td><td colspan="2">$G_C85/20$; $G_{20/15}$; FI_{25} ; f_1</td></tr>
<tr><td colspan="2">Thick surface course and lightweight airfield pavements</td><td>LA_{25} $M_{DE}20$; PSV_{50}; LA_{25} M_{DE20} (1)</td><td colspan="2">$G_C85/20$; $G_{20/15}$; FI_{25} ; f_1</td></tr>
<tr><td colspan="2">Thin surface course (BBTM and Porous Asphalt PA-BBDr) and heavy airfield pavements</td><td>LA_{20} $M_{DE}15$; PSV_{50}(2); LA_{20} M_{DE15} (1)</td><td colspan="2">GC85/15 (gap-graded grading); $G_C85/20$; $G_{20/15}$; FI_{20} ; $f_{0,5}$</td></tr>
<tr><td colspan="5">(1) With any potential application, when justified and given an explicit justification within the materials contract documents, a maximum compensation of 5 points between the LA and MDE characteristics. For example:
– an aggregate with LA = 25 is deemed compliant with [LA_{20}, M_{DE15}] if it exhibits an M_{DE} value of 10
– an aggregate with M_{DE} = 20 is deemed compliant with [LA_{20}, M_{DE15}] if it exhibits an LA value of 15
– an aggregate with M_{DE} = 18 is deemed compliant with [LA_{20}, M_{DE15}] if it exhibits an LA value of 17
(2) For several unique points, it becomes necessary to predict the PSV_{53} (declared) value, or even the PSV_{56} value.</td></tr>
</table>

The French standard application guide includes a table about the reuse rate of reclaimed asphalt versus the use and the degree of knowledge of the material.

Table 17 summarises the reclaimed asphalt characteristics to be identified for reuse purposes in accordance with the former French Standard XP P98-135 Reclaimed asphalt.

Table 17: Reclaimed Asphalt Characteristics (LCPC, 2007)

<table>
<tr><th rowspan="4">Use in the Pavement</th><th colspan="3">Type of Layer</th><th colspan="5">Reuse Rate (%)</th></tr>
<tr><td colspan="3">Surface course</td><td>0</td><td>0</td><td>10 subjects to (1)</td><td>30</td><td>40</td></tr>
<tr><td colspan="3">Binder layer</td><td>10</td><td>20</td><td>30</td><td colspan="2">40</td></tr>
<tr><td colspan="3">Base course</td><td>10</td><td>20</td><td>30</td><td colspan="2">40</td></tr>
<tr><td rowspan="6"></td><td rowspan="4">Asphalt binder</td><td rowspan="4">Residual characteristics (penetration or Softening point)</td><td>Penetrability 1/10 mm</td><td colspan="2" rowspan="4">Unspecified</td><td>≥ 5</td><td colspan="2">≥ 5</td></tr>
<tr><td>Penetration range</td><td>-</td><td colspan="2">≤ 15</td></tr>
<tr><td>R&B °C</td><td>≤ 77</td><td colspan="2">≤ 77</td></tr>
<tr><td>R&B range</td><td>-</td><td colspan="2">≤ 8</td></tr>
<tr><td rowspan="2">Aggregates</td><td rowspan="2">Particle size</td><td>Passing at D Range</td><td colspan="2" rowspan="2">Unspecified</td><td>80 - 99 ≤ 15</td><td colspan="2">85 - 99
≤ 10</td></tr>
<tr><td>Range of 2 mm passing</td><td>≤ 20</td><td colspan="2">≤ 15</td></tr>
</table>

			Range of 0,063 mm passing		≤ 6	≤ 4
		Intrinsic characteristics	Category	Unspecified		For example LA_{20}, $M_{DE}20$
			Angularity	-		$C_{90/1}$
(1) If the average external binder content of the reclaimed asphalt exceeds 5,5%, it is then considered that the mix is an asphalt concrete whose aggregates have been selected based on minimum criteria in the vicinity of the criteria sought for the recycled material. Nevertheless, no limestone aggregate should be used for the surface course.						

For the selected binder, the French mixture design guidance does not include specific characteristic requirements that are linked to traffic or environmental conditions. However, the French Standard Mix Application Guide includes suggestions for the selected paving grade bitumen as shown in Table 18.

Table 18: Suggestions for Binder Selection (LCPC, 2007)

Mixture Type	Loading Category	Binder Options
Mixes for wearing courses AC-BBSG, AC-BBM, BBTM, PA-BBDr and AC-BBA materials	Heavy	35/50, 50/70 (airfield pavement), 20/30 may be used for class 3 of AC-BBSG and AC-BBME
Mixes for wearing courses AC-BBSG, AC-BBM, BBTM and AC-BBA materials	Light	50/70, 70/100 at higher altitudes, and in continental zones and airfield zones submitted to lighter loads
Mixes for base courses/foundation layers	-	35/50
Notes: AC-BBSG denotes to Asphalt Concrete - Béton Bitumineux Semi-Grenu) AC-BBM denotes to Asphalt Concrete - Béton Bitumineux Mince BBTM denotes to Béton Bitumineux Très Mince PA-BBDr denotes to Porous Asphalt – Béton Bitumineux Drainant AC-BBA denotes to Asphalt Concrete - Béton Bitumineux Aéronautique)		

3.2.2.2 Preparation of Asphalt Mixture Specimens

The mix designer determines the initial composition for an asphalt mixture type based on the targeted particle size distribution curve and the bitumen content. The percentage of voids specified for each product are targeted based on the measured maximum density of the mixture. The Gyratory Compactor is used to prepare the mixture and evaluate the compactability and volumetric properties of asphalt mixtures. The volumetric properties are estimated to the percentage of voids attained on site. Following the completion of the Gyratory Compactor tests, the mix designer should be able to introduce enough elements to establish both the particle size distribution curve and binder content. For some materials, a void percentage requirement at 10 gyrations for the Gyratory Compactor test needs to be met.

3.2.2.3 Adjustments of the Mixture Compositions

The main parameters that determine the Gyratory Compactor test results are the upper sieve size of the mix, bitumen content, and percentage of fines. If the expected result is not the one ultimately obtained, the mix designer needs to modify the composition. The French mix design includes general advice about adjustments to the mixture composition (fine aggregates, discontinuity in the gradation, rounded aggregate, angularity, additives, bitumen grade and bitumen content) that can affect the mechanical characteristics (rutting, stiffness modulus, fatigue).

The effect of composition changes on the Gyratory Compactor results and guidance on the adjustments are shown in Table 19 to ensure that Gyratory Compactor voids are positioned within the target window.

Table 19: Composition Effect on Gyratory Compactor Test Results and Composition Adjustments (LCPC, 2007)

Composition Effects on Gyratory Compactor Test Results			
Parameter		**Effect on Air Voids**	**Observations**
Bitumen content – 0.25		+ 0.5 to + 0.6	Check water resistance
Bitumen content + 0.25		- 0.5 to – 0.6	Check rutting resistance
Fines content + 1		- 1.7 to – 0.5	
Fine aggregate volume + 10 %		- 1.0	
Passing the 2-mm sieve + 5 %		- 1.0 to – 1.5 %	
2/4 discontinuity (at a constant fine aggregate %)		-1.0	
2/6 discontinuity (at a constant fine aggregate %)		-3.0	
Mastic volume 16 % -> 23 %		+ 4 %	
+ 10 % rounded fine aggregate		- 1.5 to – 2.0	Potential rutting
Adjustments to the Composition to Ensure that Gyratory Compactor Voids are Positioned within the Target Window			
Much Lower Than the Target % (by > 5%)	**Lower Than the Target % (by 3%)**	**Above the Target % (by 3%)**	**Considerably Above the Target % (by > 5%)**
Decrease the % passing the 2-mm sieve by ~ 5 points and increase the 2/6.3 fraction	Decrease the bitumen % and decrease the % of total fines by 1.5% to 2.5%	Decrease the 2/6.3 fraction on the order of 10% and increase the 6.3/10 fraction	Increase the % passing the 2-mm sieve by ~ 5 points and decrease the 2/6.3 fraction introduce ground fine aggregate at a level of 10% or 15% (focus on rutting resistance) or rounded fine aggregate at a level of 10% (check the rutting resistance)

3.2.2.4 Asphalt Mixture Testing

The final stage of mixture design is the assessment of the mechanical properties of the designed asphalt mixtures using performance-related and performance-based tests. The Duriez test procedure is in accordance with Part B of EN 12697-12. Indirect Tensile Strength Ratio (ITSR) is used to evaluate the moisture sensitivity of mixtures for Level 1 testing. Resistance to permanent deformation test is conducted for Level 2 at 60°C using the Wheel Tracking Tester (large device) or in special cases (very thin layer asphalt concretes BBTM) the "mechanical stability" test (large device). For Level 3 testing, the stiffness of the asphalt mixture is determined by either a complex modulus test (sinusoidal loading on a trapezoidal or parallelepiped specimen) or a uni-axial tensile test (on a cylindrical or parallelepiped specimen). The test specification requires the stiffness modulus to be determined at 15°C and a frequency of 10 Hz or a loading time of 0.02 seconds. Finally, the fatigue test is conducted for Level 4 using the 2-point trapezoidal at 10°C and a frequency of 25 Hz. Figure 7 and Figure 8 show summary examples of product family descriptions taken from the LCPC Bituminous Mixtures Design Guide for conducting the type of level testing and specification requirements for bituminous mixtures design (LCPC, 2007).

AC-BBSG Asphalt Concrete – Béton Bitumineux Semi-Grenu

Definition	Bituminous mixture in accordance with EN 13108-1 characterized by a high coarse aggregate content and designed to yield surface or binder courses with a thickness of 5 cm or greater until 9 cm. Classification by the resistance to permanent deformation.					
Identification	AC10-BBSG or AC14-BBSG according EN 13108-1 Surface or binder course Empirical approach					
Designation	AC10-BBSG0 or AC14-BBSG0 AC10-BBSG1 or AC14-BBSG1 AC10-BBSG2 or AC14-BBSG2 AC10-BBSG3 or AC14-BBSG3					
Main characteristics						
Usual aggregate characteristics (minimal values)	Surface course	Fragmentation, Wear, Polishing resistance	A_{20} or LA_{25}, $M_{DE}15$ or $M_{DE}20$, PSV 50			
		Angularity Coarse; Fine aggregate	$C_{95/1}$ E_{CS} 35			
	Binder course	Fragmentation Wear	LA_{30}, $M_{DE}25$			
	Coarse aggregate	Grading requirement Flakiness Fine content	$G_C85/20$ or $G_{25/15}$; FI_{25}; f_2			
	Fine aggregate or All-in	Grading requirement Methylene blue value	G_F85 ; $G_{TC}10$; G_A85 MB_F10			
	Added Filler	Stiffness by ring and ball, Void of dry compacted filler	$\Delta_{R\&B}$ 8/16 ; $V_{28/38}$			
Type of binder	Paving grade bitumen		50/70 or 35/50			
Minimum binder content			AC10 : $B_{min5,2}$		AC14 : $B_{min5,0}$	
Grading : %	Sieve in mm	0,063	5 to 8			
		0,250	10 to 25			
		2,0	28 to 38			
		6,3	50 to 65			
		D	90 to 100			
Water sensitivity	Method B (I/C)		$ITSR_{70}$			
Gyratory	AC10	60 gyrations	V_{min5} V_{max10}			
	AC14	80 gyrations	V_{min4} V_{max9}			
Classification			AC-BBSG 0	AC-BBSG 1	AC-BBSG 2	AC-BBSG 3
Gyratory	10 gyrations		**$V10G_{min11}$**	Not applicable		
Wheel tracking test Large device 60°C	Nb of cycles	30000	No perf. determined	P_{10}	$P_{7.5}$	P_5
	Void content of slab (Vi= 5% Vs = 8%)					

Level 0

Level 1

Level 2

AC-BBME Asphalt Concrete – Béton Bitumineux à Module Élevé

Definition	Bituminous mixture in accordance with EN 13108-1 whose stiffness is higher than that of a BBSG mixture and designed to yield surface or binder courses with a thickness of 5 cm or greater until 9 cm. Classification by the resistance to permanent deformation and by the stiffness.				
Identification	AC10 or AC14 according EN 13108-1 Surface or binder course Fundamental approach				
Designation	BBME class 1 0/10 or 0/14 BBME class 2 0/10 or 0/14 BBME class 3 0/10 or 0/14				
Main characteristics					
Usual aggregate characteristics (minimal values)	Surface course	Fragmentation, Wear, Polishing resistance	LA_{25}, $M_{DE}15$, PSV 50		
		Angularity Coarse; Fine aggregate	$C_{95/1}$ E_{CS} 35		
	Binder course	Fragmentation Wear	LA_{30}, $M_{DE}25$		
	Coarse aggregate	Grading requirement Flakiness Fine content	$G_C85/20$ or $G_{25/15}$; FI_{25}; f_2		
	Fine aggregate or All-in	Grading requirement Methylene blue value	G_F85 ; $G_{TC}10$; G_A85 MB_F10		
	Added Filler	Stiffness by ring and ball, Void of dry compacted filler	$\Delta_{R\&B}$ 8/16 ; $V_{28/38}$		
Water sensitivity	Method B (I/C)		$ITSR_{80}$		
Gyratory	AC10	60 gyrations	V_{min5} V_{max10}		
	AC14	80 gyrations	V_{min4} V_{max9}		
Classification			BBME class 1	BBME class 2	BBME class 3
Wheel tracking test Large device 60°C	Nb of cycles	30000	P_{10}	$P_{7.5}$	P_5
	Void content of slab (Vi= 5% Vs = 8%)				
Stiffness	15°C, 10 Hz or 0,02 s Void content of slab (Vi= 5% Vs = 8%)		$S_{min9000}$	$S_{min11000}$	$S_{min11000}$
Fatigue	**2 points, 10°C, 25 Hz** Void content of slab (Vi= 5% Vs = 8%)		ε_{6-100}	ε_{6-100}	ε_{6-100}

Level 3

Level 4

Figure 7: Product Family Description of Asphalt Mixtures (AC-BBME and AC-BBSG Asphalt Concrete) (LCPC, 2007)

AC-BBM Asphalt Concrete – Béton Bitumineux Mince

Definition	Bituminous mixture in accordance with EN 13108-1 characterized by an average application thickness of between 3 cm and 5 cm. The material is designed to yield surface courses and possibly binder courses. The particle size distribution is most often gap-graded. Categories A, B, C depend on the "gap" of the grading curve. Classification by the resistance to permanent deformation.					
Identification	AC10 or AC14 according EN 13108-1 Surface or (binder) course Empirical approach					
Designation	AC-BBMA, AC-BBMB or AC-BBMC class 0 AC-BBMA, AC-BBMB or AC-BBMC class 1 AC-BBMA, AC-BBMB or AC-BBMC class 2 AC-BBMA, AC-BBMB or AC-BBMC class 3					
Main characteristics						
Usual aggregate characteristics (minimal values)	Surface course	Fragmentation, Wear, Polishing resistance	LA_{20} or LA_{25}, $M_{DE}15$ or $M_{DE}20$, PSV 50			
		Angularity Coarse; Fine aggregate	$C_{95/1}$ E_{CS} 35			
	Coarse aggregate	Grading requirement Flakiness Fine content	$G_C85/20$ or $G_{25/15}$; FI_{25}; f_2			
	Fine aggregate or All-in	Grading requirement Methylene blue value	G_F85; $G_{TC}10$; G_A85 MB_F10			
	Added Filler	Stiffness by ring and ball, Void of dry compacted filler	$\Delta_{R\&B}$ 8/16; $V_{28/38}$			
Type of binder	Paving grade bitumen		50/70 or 35/50			
	Polymer modified Bitumen		45/80-60 or 40/100-65			
Minimum binder content			$B_{min5,0}$			
Grading : %	Sieve in mm	0,063	5 to 8			
		0,250	10 to 23			
		2,0	27 to 37			
		4,0				
		6,3	30 to 40			
		D	90 to 100			
Water sensitivity Method B (I/C)			$ITSR_{70}$			
Gyratory	**Category of AC-BBM**		**AC-BBMA**	**AC-BBMB**	**AC-BBMC**	
	40 gyrations		V_{min8} V_{max11}	V_{min7} V_{max12}	V_{min8} V_{max13}	
Classification			**AC-BBM 0**	**AC-BBM 1**	**AC-BBM 2**	**AC-BBM 3**
Gyratory	10 gyrations		**$V10G_{min11}$**	Not applicable		
Wheel tracking test Large device 60°C	Nb of cycles	3 000 cycles	No perf. determined	P_{15}		
		10 000 cycles			P_{15}	
		30 000 cycles				P_{10}
	Void content of slab	AC-BBMA		(Vi= 7% Vs = 10%)		
		AC-BBMB or C		(Vi= 8% Vs = 11%)		

Level 0 / Level 1 / Level 2

AC-EME Asphalt Concrete – Enrobé à Module Élevé
(High-Modulus Asphalt Concrete)

Definition	Bituminous mixture in accordance with EN 13108-1 designed to yield lower and upper base courses with a thickness between 6 cm and 8 cm for AC10-EME, between 7cm to 13 cm for AC14-EME and between 9 cm and 15 cm for AC20-EME. High stiffness and fatigue resistance allow thickness reduction for the pavements. Classification EME1 or EME2 by Fatigue resistance.			
Identification	AC10-EME1 or AC10-EME2 according EN 13108-1 AC14-EME1 or AC14-EME2 according EN 13108-1 AC20-EME1 or AC20-EME2 according EN 13108-1 Lower or upper base course Fundamental approach			
Main characteristics				
Usual aggregate characteristics (minimal values)	Upper base course	Fragmentation, Wear,	LA_{30}, $M_{DE}25$	
	Lower base course	Fragmentation Wear	LA_{40}, $M_{DE}35$	
	Coarse aggregate	Grading requirement Flakiness Fine content	$G_C85/20$ or $G_{25/15}$; FI_{25}; f_2	
	Fine aggregate or All-in	Grading requirement Methylene blue value	G_F85; $G_{TC}10$; G_A85 MB_F10	
	Added Filler	Stiffness by ring and ball, Void of dry compacted filler	$\Delta_{R\&B}$ 8/16; $V_{28/38}$	
Classification			AC-EME1	AC-EME2
Water sensitivity Method B (I/C)			$ITSR_{70}$	
Gyratory	AC10-EME	80 gyr.	V_{max10}	V_{max6}
	AC14-EME	100 gyr.		
	AC20-EME	120 gyr.		
Void content of the slabs ↓			AC-EME1 {Vi= 7% Vs = 10%}	AC-EME2 {Vi= 3% Vs = 6%}
Wheel tracking test Large device 60°C	Number of cycles		30000	30000
	Category of rut depth		$P_{7,5}$	
Stiffness	15°C, 10 Hz or 0,02 s		$S_{min14000}$	
Fatigue	2 points, 10°C, 25 Hz		$\varepsilon_{6\text{-}100}$	$\varepsilon_{6\text{-}130}$

Level 3 / Level 4

Figure 8: Product Family Description of Asphalt Mixtures (AC-BBM and AC-EME Asphalt Concrete) (LCPC, 2007)

3.2.3 Discussions on the French Mixture Design

The French asphalt mixtures design does not offer a unified approach similar to that in the Superpave procedure. The specification requirements in terms of constituent materials, compactibility and volumetric properties, and performance-related tests or performance-based tests are assigned based on the type and application of the asphalt mixture. This results in having several product family descriptions for each type of asphalt mixture. The design of the asphalt mixtures involves mixture adjustments or refinements to the mixture compositions when the asphalt mixture properties do not comply with the specifications.

The traffic levels are not directly included in the process of mixture design, but the French manual includes general guidance on the selection of binder and mixture types associated with the traffic levels and the condition of the road. Based on the type of specified asphalt mixture, the performance-related and based tests (rutting, stiffness, and fatigue testing) are conducted to ensure the mixture design meets the performance test criteria.

The determination of asphalt mixture composition such as the bitumen type and content, aggregate grading, and type, are mainly obtained from the volumetric criteria while the performance tests are used for verification. The selected number of gyrations and the specified air voids are linked with the layer thickness. The specified air void content ranges for a given number of gyration and layer thickness. This is defined based on comparative studies between the laboratory-measured air voids using the gyratory compactor to the air voids obtained in the field using 'standard' compaction mode (approximately 16 passes). The shortcomings in this approach are traffic loading which influences the final density of the asphalt mixture is not considered while using this approach.

Finally, the French procedure does not include a detailed process to define the optimum binder content associated with fixed air void contents, VMA or defined mechanical properties. The minimum binder film necessary for the durability of mixtures is controlled by specifying a minimum bitumen content based on the standard maximum density of aggregate of 2.65 g/cm^3.

3.3 South Africa Mixture Design Method (SABITA, 2005)

3.3.1 Approach

The design philosophy of SABITA embraces the move from a more empirical-based mix design approach towards the implementation of a performance-related approach. Table 20 presents the traffic categories for the SABITA approach.

Table 20: Traffic Categories (SABITA, 2005)

Design Traffic E80	Description	Mix Design Level
< 0.3 million	Low/Light	Level IA
0.3 to 3 million	Medium	Level IB
>3 to 30 million	Heavy	Level II
>30 million	Very heavy – to Extreme	Level III

Four levels of designs are used as detailed in Figure 9. A volumetric design approach is used to select optimum binder content for design situations with low to medium traffic levels (Levels IA and IB). The binder content obtained at Level IA and IB serve as the starting point to select the optimum mix for design situations with moderately high to very high traffic volume with a high-level risk of structural damage (Level II and Level III). At these levels, the optimum binder content is selected based on performance-related tests.

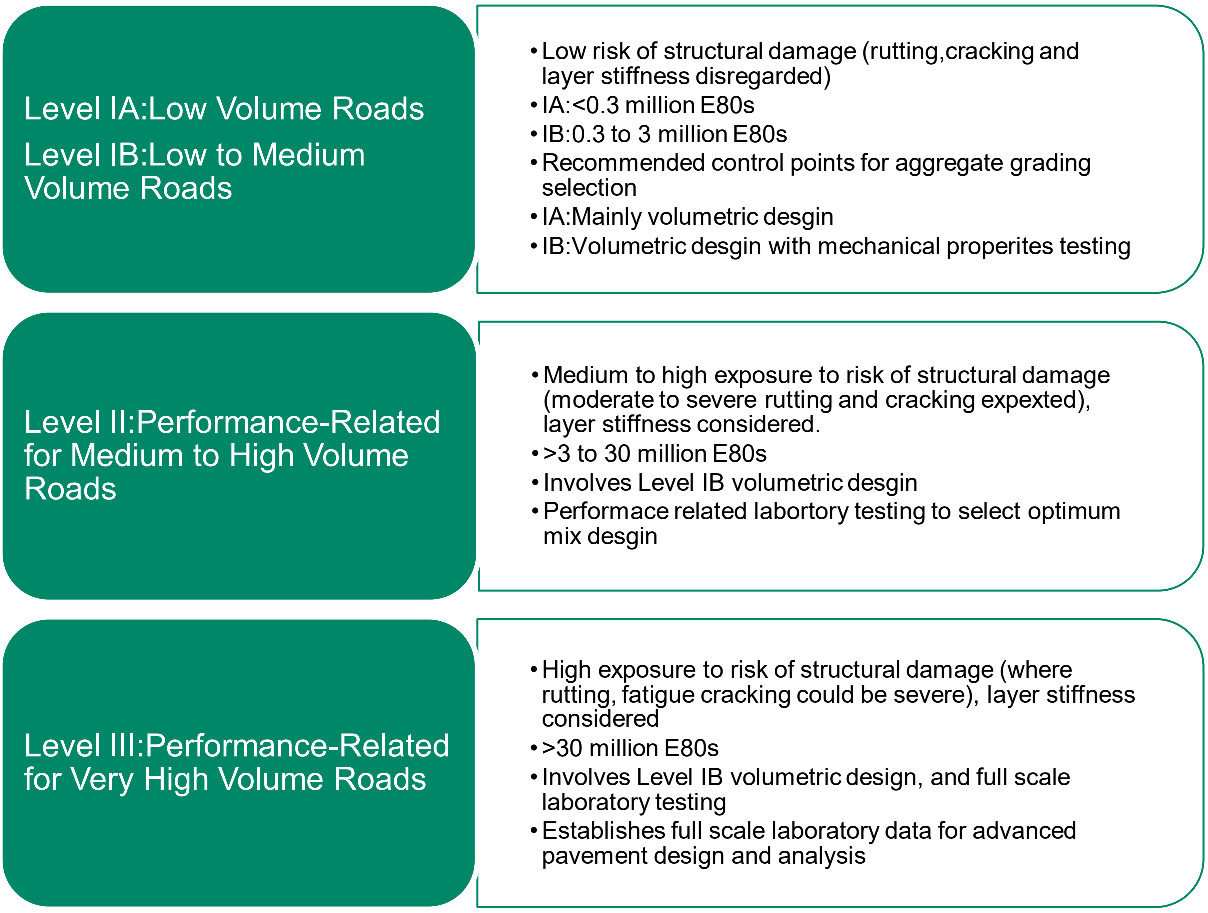

Figure 9: SABITA Approach (SABITA, 2005)

3.3.2 Selection of Asphalt Mixture Types

Asphalt mixtures are primarily grouped into a sand skeleton or stone skeleton based on their aggregate packing characteristics. The maximum aggregate particle size is selected based on the intended asphalt layer thickness. The Nominal Maximum Aggregate Size (NMAS) should be at most one-third of the layer thickness. Table 21 shows the recommended mixture type and the NMAS.

Table 21: Typical Nominal Maximum Aggregate Sizes (NMAS) Categories (SABITA, 2005)

Mixture Type	Application	Traffic	NMAS
Sand Skeleton	Wearing course	Light / Low	7 mm, 10 mm
		Medium to heavy[1]	10 mm, 14 mm
		Very heavy	14 mm, 10 mm
	Base course[2]	All traffic conditions	14 mm, 20 mm, 28 mm
Stone Skeleton	Wearing course	All traffic conditions	10 mm, 14 mm, 20 mm
	Base course	All traffic conditions	14 mm, 20 mm, 28 mm

[1] 14 mm is generally preferred to 10 mm;
[2] recommend using the largest practicable size that is economically justifiable.

3.3.3 Aggregate and Binder Selection

3.3.3.1 Aggregate

SABITA considers a move away from grading bands to control points for aggregate designs. This is required to enable additional flexibility in adjusting aggregate gradings to meet the volumetric requirements of the mixture. The Bailey method can also be used to optimize aggregate gradings and mix design criteria. The coarse aggregate components of any asphalt mixture should comply with the grading limits presented in Table 22 for the relevant grading class and NMAS.

Table 22: Grading Limits for Nominal Single Size Coarse Aggregate (SABITA, 2005)

	Nominal Maximum Aggregate Size (NMAS) (mm)											
NMAS (mm)	**28.0**		**20.0**		**14.0**		**10.0**		**7.0**		**5.0**	
Grading Class	1	2	1	2	1	2	1	2	1	2	1	2
Sieve Size (mm)	**Percentage Passing Sieve Size by Mass**											
37.5	100	100	-	-	-	-	-	-	-	-	-	-
28.0	85-100	85-100	100	100	-	-	-	-	-	-	-	-
20.0	0-20	0-35	85-100	85-100	100	100	-	-	-	-	-	-
14.0	0-5	0-5	0-20	0-35	85-100	85-100	100	100	-	-	-	-
10.0	-	-	0-5	0-5	0-20	0-35	85-100	85-100	100	100	-	-
7.0	-	-	-	-	0-5	0-5	0-20	0-35	85-100	85-100	100	100
5.0	-	-	-	-	-	-	0-5	0-5	0-20	0-35	85-100	85-100

The grading class applicable to the relevant mix types are as follows:

Grading Class 1:
- Continuously graded: stone skeleton
- High modulus asphalt (EME)
- Gap graded: stone skeleton mixes
- Ultra-thin friction courses (UTFC)
- Stone mastic asphalt (SMA)
- Porous asphalt

Grading Class 2:
- Continuously graded: sand skeleton
- Semi-gap: sand skeleton mixes
- Gap graded: sand skeleton mixes

Grading limits for the fine aggregate components of an asphalt mixture should comply with Table 23.

Table 23: Fine Aggregate Grading Limits (SABITA, 2005)

Aggregate Class	Class 1	Class 2
	Percentage Passing by Mass	
Sieve Size (mm)	Stone skeletal mixes	Sand skeletal mixes
7	100	85-100
5	90-100	70-90
2	65-90	45-70
1	45 - 70	28 - 50
0.6	30 - 50	19 - 34
0.3	18 - 30	12 - 25
0.15	10 - 21	7 - 18
0.075	5 - 15	5 - 15

Aggregates of various sizes are mixed in certain proportions. Proportions are defined by the particle shape, texture and size distribution. Table 24 provides examples of grading control points for four NMAS typically used to produce a sand skeleton (often continuously graded) asphalt mixes in South Africa. The examples are only used as guidelines and are not relevant to mixes such as stone skeleton types (including SMA).

Table 24: Aggregate Grading Control Points (SABITA, 2005)

Sieve sizes (mm)	Per Cent Passing Nominal Maximum Aggregate Size (NMAS)							
	NMAS = 28 mm		NMAS = 20 mm		NMAS = 14 mm		NMAS = 10 mm	
	Min	Max	Min	Max	Min	Max	Min	Max
37.5	100							
28	85	100	100					
20		85	85	100	100			
14				85	85	100	100	
10						85	85	100
7.1								85
2	19	45	23	49	28	58	32	67
0.075	4	7	4	8	4	10	4	10

The standard test methods and recommended criteria of aggregates for asphalt mix design are stated in Table 25.

Table 25: Recommended Tests and Criteria for Aggregate Selection (SABITA, 2005)

Property	Test	Standard	Criteria
Hardness/Toughness	Fines aggregate crushing test: 10% F_{ACT}	SANS 3001-AG10	Sand skeleton mixes: ≥ 160 kN Stone skeleton mixes: ≥ 210 kN
	Aggregate Crushing Value (ACV)	SANS 3001-AG10	Sand skeleton mixes ≤ 25 Stone skeleton mixes ≤ 21 Rolled in chippings ≤ 21
Soundness	Magnesium sulphate soundness	SANS 5839, SANS 3001-AG12	12% to 20% is normally acceptable. Some specifications require ≤ 12% loss after 5 cycles
Durability	Methylene blue adsorption indicator	SANS 6243	High quality filler: ≤ 5 > 5: additional testing and analysis needed
Particle Shape and Texture	Flakiness index	SANS 3001-AG4	• 20 mm and 14 mm aggregate: ≤ 25[1] • 10 mm and 7.1 mm aggregate: ≤ 30 • Rolled in chippings ≤ 20
	Polished Stone Value (PSV)	SANS 3001–AG11	Minimum 50[2]
	Fractured faces	SANS 3001-AG4	• Sand skeleton mixes: at least 50% of all particles should have three fractured faces • Stone skeleton mixes & rolled in chippings: at least 95% of all particles should have three fractured faces
Water Absorption	Coarse aggregate (> 5 mm)	SANS 3001-AG20	≤ 1% by mass
	Fine aggregate (< 5 mm)	SANS 3001-AG21	≤ 1.5% by mass
Binder absorption	Coarse and fine aggregate	SANS 3001-AS11	≤ 0.5% by mass
Cleanliness	Sand equivalency test	SANS 3001-AG5	≥ 50 total fines fraction
	Clay lumps and friable particles	ASTM C142–97	≤ 1%

[1]For certain types of mixes, e.g. UTFC, a maximum flakiness index of 20 is preferred.
[2]Consideration can be given to adopting a limiting value of 45, due to material availability, traffic, road geometry and climate.

3.3.3.2 Binder Selection

South Africa is in the process of transitioning from an industrial-grade type bitumen specification to a Performance Grade (PG) specification. Performance grade specifications for binders focus on the evaluation of binder properties in terms of traffic loading and environmental conditions (mainly temperature) which the binder will be subjected to in the field. The maximum pavement design temperatures adopted for South Africa are 58°C, 64°C and 70°C. While the minimum temperature in SA rarely falls below -10°C. Traffic in the PG specification is classified both in terms of volume, severity and speed. This is done to consider the fact that, for a given loading intensity, slow-moving traffic would exert more severe loading conditions.

The combined effect of traffic loading and speed are categorised in Table 26.

Table 26: Binder Grade Selection based on Traffic Speed and Volume (SABITA, 2005)

Design Traffic (msa)	Traffic Speed (km/h)			Asphalt Mixture Design Level
	<20	**20-80**	**>80**	
<0.3	S	S	S	IA
0.3 - 3	H	S	S	IB
>3 – 10	V	H	S	II
>10 - 30	E	V	H	
>30 - 100	E	E	V	III
>100	E	E	E	

S –refers to standard conditions; H – refers to Heavy conditions; V –refers to Very heavy conditions, and E –refers to Extreme conditions

3.3.4 Mix Design Levels

3.3.4.1 Level I Mix Design Process

The design process for Level I is shown in Figure 10.

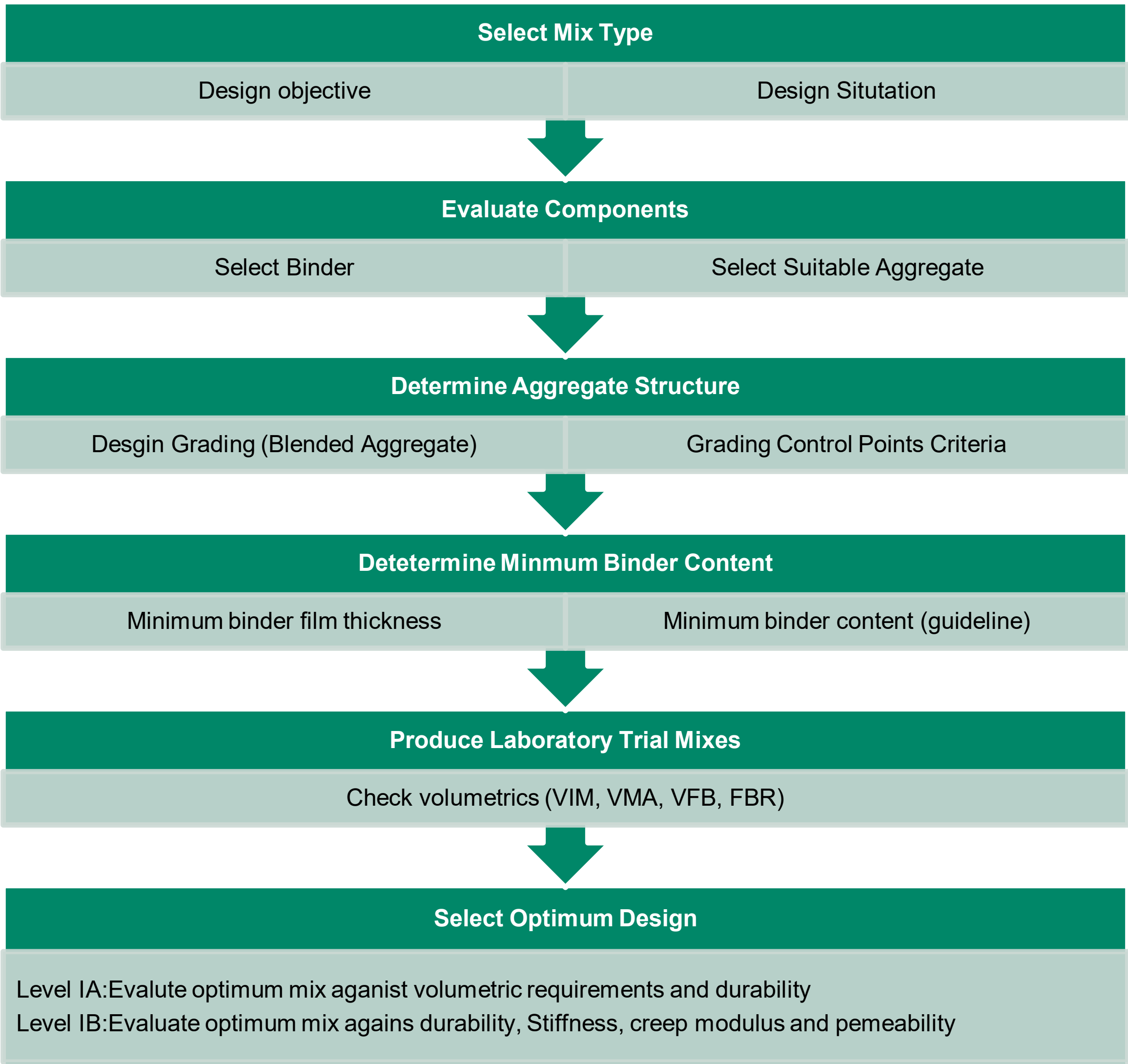

Figure 10: Level I Design Process (SABITA, 2005)

The design aggregate structure is established by (a) minimum binder content using the minimum requirements for binder film thickness based on the effective binder and (b) optimum asphalt mix design to meet the criteria for Levels IA and IB as shown in Table 27.

Table 27: Mix Design Criteria for Level I (SABITA, 2005)

Property	Level IA Criteria				Level IB Criteria			
Compaction	75/45[1] (Marshall method)				N_{des} 75 (Gyratory method)			
Air Voids (%)	3 - 5				4			
Minimum Percent VMA	Minimum VMA[2] for design voids							
	NMAS (mm)	3%	4%	5%	NMAS (mm)	3%	4%	5%
	25	11	12	13	28	11	12	13
	20	12	13	14	20	12	13	14
	14	13	14	15	14	13	14	15
	10	14	15	16	10	14	15	16
Percent VFB	70 to 80				65 to 75			

Moisture Resistance (Min TSR)	-	70% for base course and 80% for surface course
Stiffness (Indirect Tensile Strength)	-	900 kPa - 1650 kPa @ 25°C
Creep Modulus (Dynamic Creep)	-	10 MPa min. @ 40°C
Permeability (Air Permeability)	-	≤ 1×10^{-8} cm^2

[1] 75 blows on the first side + 45 blows on the reverse side
[2]Only values for continuously graded mixes

3.3.4.2 Level II and Level III Design Process

The design process for Level II and Level III is shown in Figure 11. Compared to Level II, a complete set of laboratory data is collected at Level III to predict stiffness, permanent deformation and fatigue characteristics. The purpose is to establish a direct link between mix design and pavement design. The criteria of asphalt mix design for Levels II and III are shown in Table 28.

The selection of optimum design at these levels involves the same sample preparation and determination of volumetrics as described for Level I except that only the Superpave gyratory (AASHTO T 312) test procedure is used. However, three binder contents should be used to evaluate the resistance to permanent deformation of the mix. These contents are the optimum binder content at 4% voids (determined in the volumetric design procedure for Levels II and III), optimum - 0.5%, and optimum + 0.5%. The fatigue life of the mixture is assessed using the design binder content obtained from permanent deformation evaluation.

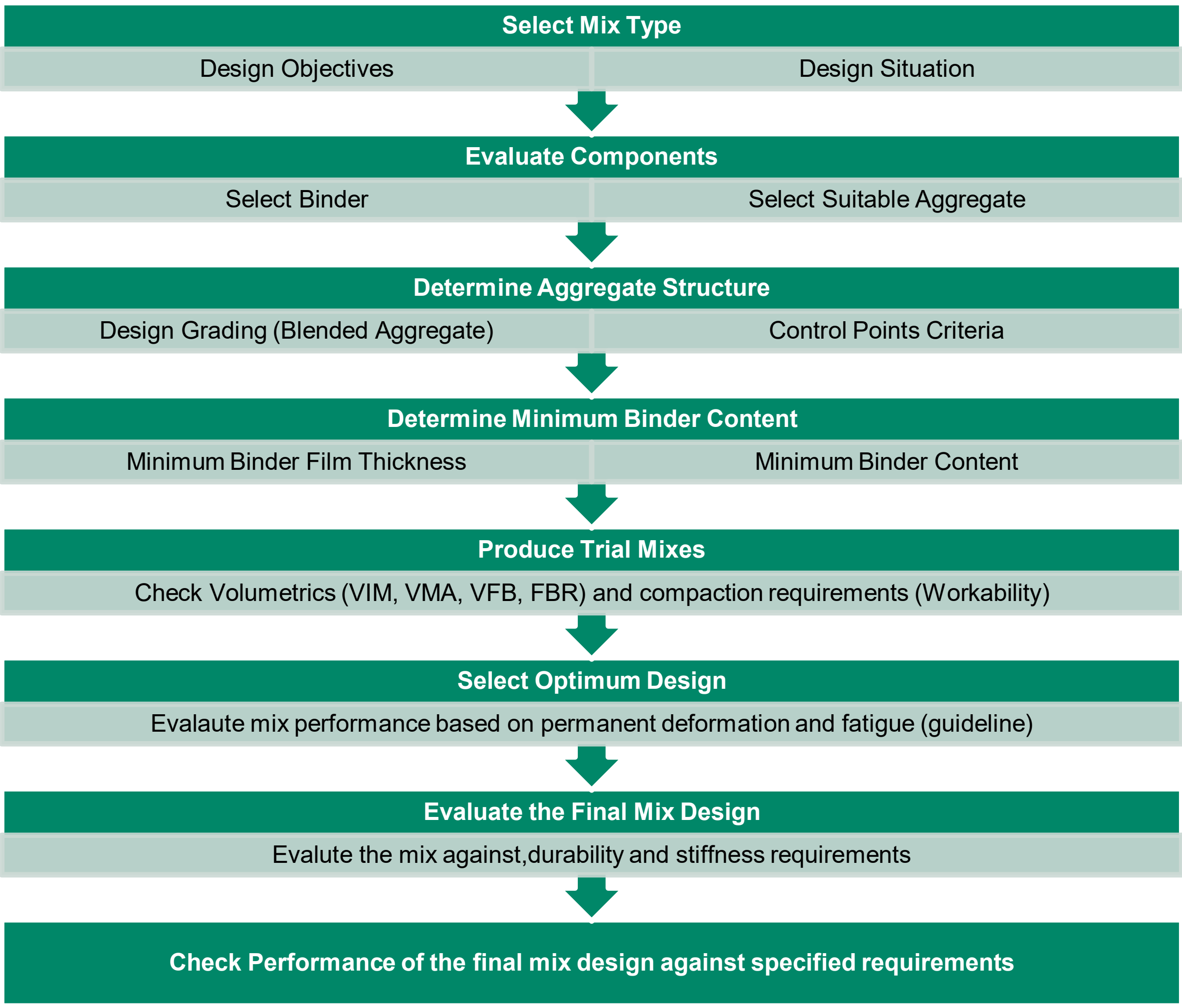

Figure 11: Level II and Level III Mix Design Process (SABITA, 2005)

Table 28: Mix Design Criteria for Level II and III. (SABITA, 2005)

<table>
<tr><th>Property</th><th colspan="2">Level II</th><th colspan="2">Level III</th></tr>
<tr><td>Compaction</td><td colspan="2">N_{des} 100</td><td colspan="2">N_{des} 125</td></tr>
<tr><td>Air Voids (%)</td><td colspan="4">4.0</td></tr>
<tr><td>VFB (%)</td><td colspan="2">65 to 75</td><td colspan="2">65 to 75</td></tr>
<tr><td>Moisture Resistance (Min TSR)</td><td colspan="4">70% for base course and 80% for surface course</td></tr>
<tr><td>Stiffness (Dynamic Modulus)</td><td colspan="2">frequency sweeps of 0.1, 0.5, 1, 5, 10, and 25 Hz at one test temperature of 20°C.</td><td colspan="2">frequency sweeps of 0.1, 0.5, 1, 5, 10, and 25 Hz at five temperatures (-5, 5, 20, 40 and 55°C).</td></tr>
<tr><td rowspan="4">Permanent Deformation Using Hamburg Wheel-Tracking Test (HWTT) as per AASHTO: T 324</td><td colspan="4">Criteria for permanent deformation for Level II and Level III</td></tr>
<tr><td>Maximum temperature zone</td><td colspan="2">Minimum number of passes to 6 mm rut</td><td>Minimum number of passes to stripping point (min)</td></tr>
<tr><td>64</td><td colspan="2">20 000</td><td>10 000</td></tr>
<tr><td>58</td><td colspan="2">16 000</td><td>10 000</td></tr>
<tr><td>Fatigue Life Using Four-Point Beam Fatigue Test</td><td colspan="2">at one test temperature of 10°C and a loading frequency of 10 Hz at three strain levels</td><td colspan="2">at three test temperatures of 5, 10 and 20°C at 10 Hz at three strain levels</td></tr>
</table>

3.3.5 Discussions on the SABITA Mix Design

The SABITA asphalt mixture design allows greater flexibility to the designer in terms of adjusting and selecting constituent materials to meet performance-related criteria through Levels II and Level III. Using control points for aggregate design and the Bailey method offers a unified approach to optimising the aggregate gradation and asphalt mix design for a wide range of applications. The Bailey method provides a clearer understanding of aggregate packing configurations taking into account the specific gravity of aggregate, particle shape, and texture that are not evident in particle size distributions.

The link between the asphalt mixture design and the traffic and environmental conditions are well established from the selection of constituent materials to the required properties of asphalt mixtures. The use of fundamental and performance-related characteristics of asphalt materials in terms of elastic response, permanent deformation (rutting) and fatigue provide a safeguard that the materials will perform adequately in a range of applications subject to traffic loadings and environmental conditions. However, the performance-related mix designs (Level II and Level III) are dependent on relatively stringent performance-related laboratory testing. Thus, to avoid an impractical repeat of asphalt mixture design on a contractual basis, individual suppliers can have several performance-related mixes certified for specific applications and performance expectations.

3.4 Australian and New Zealand Mix Design (Austroads, 2014)

3.4.1 Design Process

Figure 12 shows the general procedure for asphalt mix design adopted for dense-graded mixtures. The procedure shown in Figure 12 is used for gap and open-graded mixtures. There are specific requirements on aggregate grading, filler, and binder contents.

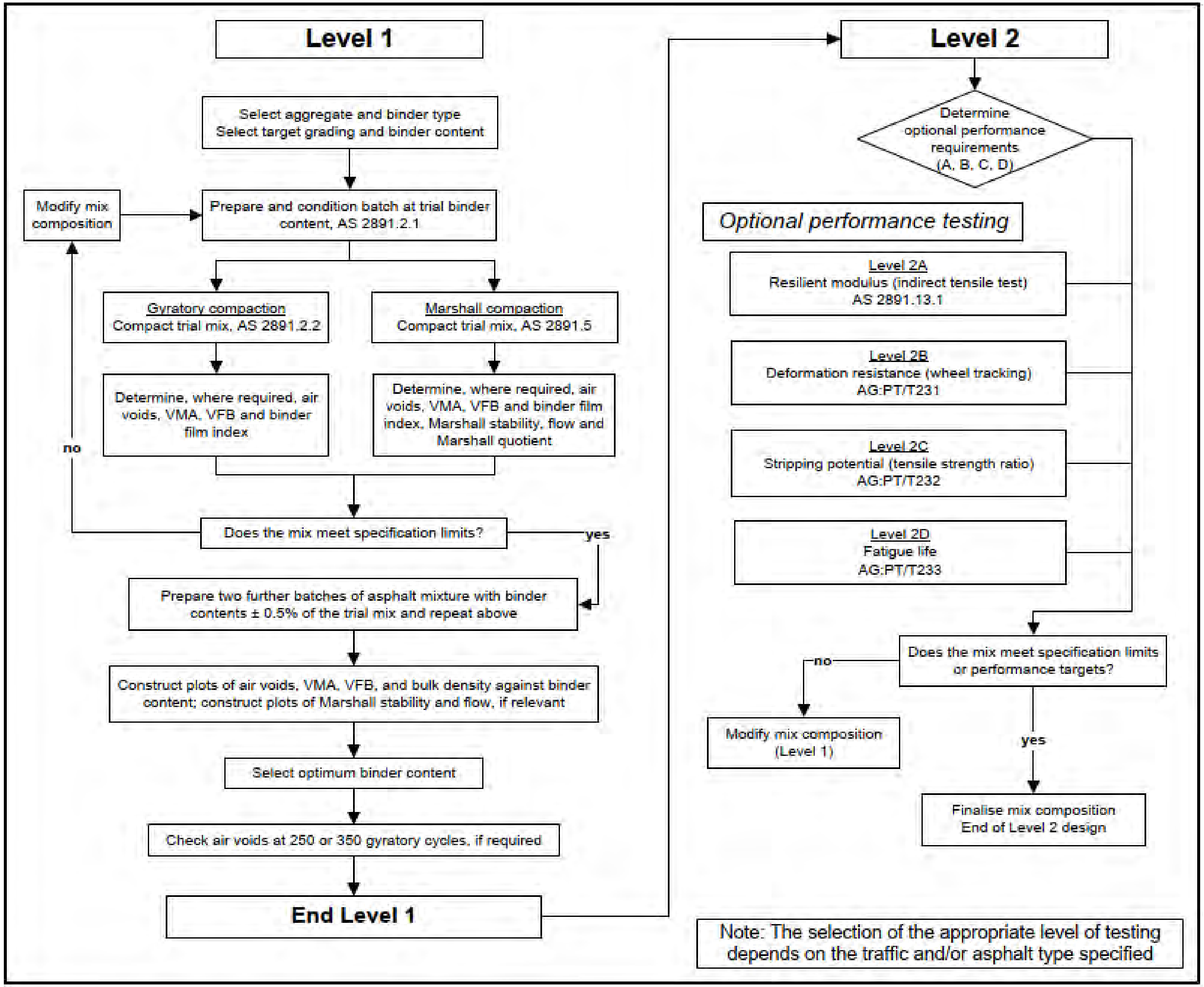

Figure 12: Mix Design Procedure (Austroads, 2014)

Table 29 provides general guidance where Level 2 mix design tests may be considered.

Table 29: Selection of Performance Testing for Level 2 (Austroads, 2014)

Mix Type		Resilient Modulus at 25°C	Dynamic Creep at 50°C	Moisture Sensitivity	Fatigue Life at 20°C and 400 microstrains	Wheel Tracking Test at 60°C
Traffic Category	Application					
Light	Wearing and base	Yes	No	No	No	No
Medium	Wearing and base	Yes	No	No	No	No
	High fatigue base	Yes	No	No	No	No
Heavy	Wearing and base	Yes	Yes	Yes	Yes	Yes
	High fatigue base	Yes	No	No	Yes	No
Very Heavy	Wearing and base	Yes	Yes	Yes	Yes	Yes

3.4.2 Selection of Asphalt Mixture Types

The asphalt mixture types are primarily classified based on the particle size distribution (grading) as follows:

- Dense Graded Asphalt (DGA), also called Asphalt Concrete (AC)
- Stone Mastic Asphalt (SMA)
- Open Graded Asphalt (OGA), also called open Graded Porous Asphalt (OGPA) and Open Graded Friction Course (OGFC)
- Fine Gap Graded Asphalt (FGGA)

The selected nominal size of the mix is determined by:

- Location of asphalt course in the pavement
- The proposed compacted thickness of the layer
- Functional requirements of the asphalt layer

Table 30 shows typical nominal aggregate sizes for different applications.

Table 30: Typical Nominal Aggregate Sizes (Austroads, 2014)

Application	Typical Mix Size
Dense graded wearing course • lightly trafficked pavements • medium to heavily trafficked pavements • highway pavements • heavy duty industrial pavements	 • 7 mm or 10 mm • 10 mm or 14 mm • Generally, 14 mm (also 10 mm) • 14 mm or 20 mm
Dense graded intermediate course	• The applicable largest size (based on the layer thickness) where the surface course is dense graded asphalt. • 14 mm where the asphalt surface is open-graded asphalt
Dense graded base course	Normally 20 mm. 28 mm may also be used depending on layer thickness and availability. 40 mm used in the past but now largely discontinued through difficulties associated with

	increased segregation in larger sized mixes and general unavailability
Dense graded corrective course	5 mm, 7 mm, 10 mm, 14 mm or 20 mm
Stone mastic asphalt wearing course	7 mm, 10 mm or 14 mm
Open-graded wearing course	10 mm or 14 mm
Open-graded base course (drainage layers)	14 mm, 20 mm or 28 mm
Fine gap graded asphalt	Generally, 10 mm (also 7 mm)
• Minor patching • Major patching	• 10 mm (also 5 mm, 7 mm, 14 mm and 20 mm) • All sizes as appropriate

A minimum layer thickness of at least three times the nominal size is particularly important in assisting compaction of coarse graded asphalt mixes including SMA and mixes with heavily modified binders. The maximum compacted layer thickness is generally limited to between four and five times the nominal mix size. Where the layer thickness exceeds four times the nominal size, it is often more cost-effective to use a larger nominal size mix, which may also provide greater flexural stiffness and deformation resistance.

3.4.3 Aggregate and Binder Selection

Coarse aggregate needs to comply with Australian Standard AS 2758 Part 5 with the application of those test properties specified in Table 31. The fine aggregate needs to be clean, hard, durable and free from lumps of clay and other aggregations of fine materials, organic material and any other deleterious material. These materials should have a minimum Degradation Factor, Crusher Fines of 60. Natural sands need to have a Sand Equivalent value of not less than 60.

Table 31: Aggregate and Filler Requirements (Austroads, 2014)

Coarse Aggregate Requirements for Hardness and Durability Based on Los Angeles Abrasion Loss (LA) and Unsound and Marginal Stone Content				
Test Property	Test value			
	Heavy/Very Heavy Traffic Mix Types		Other Mix types	
Los Angeles Abrasion Loss (% Maximum)	Rock type	LA	Rock type	LA
	All	25	Acid Igneous: • Granitic rocks • Others	 35 30
			Intermediate igneous	30
			Basic igneous	30
			Metamorphic	30
			Sedimentary	25
			Dense metallurgical slags	30
Unsound Stone Content (%)	3 maximum		5 maximum	
Marginal and Unsound Stone Content (%)	8 maximum		10 maximum	
Coarse Aggregate Requirements for Hardness and Durability Based on Wet Strength and Wet/Dry Strength Variation				
Test Property	Test value			
	Heavy/Very Heavy Traffic Mix Types		Other Mix types	
Ten Percent Fines Value (Wet) (kN)	150 minimum		100 minimum	
Wet/Dry Strength Variation (%)	35 maximum		35 maximum	
Other Coarse Aggregate Requirements				
Test Property	Test value			
	Heavy/Very Heavy Traffic Mix Types		Other Mix types	
Flakiness Index (% maximum)	25		35	
Weak Particles (% maximum)	1		1	
Water Absorption (% maximum)	2		2.5	

Polished Stone Value	48 minimum	45 minimum
Test Requirements for Materials for Use as Added Filler		
Filler Type	Test Type	Test requirements
All	Grading (sieve size 0.600 mm, 0.300 mm and 0.075 mm sieves)	Report
All	Voids dry compacted filler	Report
All	Moisture content	3% max.
Fly Ash	Loss on ignition	4% max.
Cement kiln Dust	Water-soluble fraction	20% max.

The classes of bitumen used in Australia, complying with AS 2008, are shown in Table 32. In Australia, the bitumen is classified based on its viscosity at 60 °C measured in Pascal seconds (Pa.s). Class 320 bitumen is predominantly used in asphalt manufacture. Class 170 bitumen is used to provide workable and durable asphalt mixture for lower traffic applications and cooler climate zones or to compensate for hardened binder in Reclaimed Asphalt (RA) when adding high proportions (> 20%). Class 450 is a slightly stiffer grade bitumen used in heavy traffic applications or warmer climates in some states only. Class 600 bitumen is used to provide greater stiffness in base course mixes or increased rutting resistance in wearing and for intermediate course mixes.

Bitumen in New Zealand are generally classified by penetration at 25 °C, as shown in Table 32. Bitumens are produced in two basic grades of 40-50 and 180-200. Intermediate grades such as 60-70, 80-100 and 130-150 are supplied for specific applications by blending the two basic grades.

Applications of penetration grades are generally:

- 180–200 – mostly used in sprayed seal work only
- 80–100 – used in general asphalt work
- 60–70 and 40–50 – harder grades for stiffer mixtures

Polymer modified binders (PMBs) are used in certain applications such as heavily trafficked pavement surfaces, areas of high shear stresses. Epoxy Modified Bitumen and Polyurethane Materials are used in speciality applications such as the surfacing of steel bridge decks.

Table 32: Bitumen Classes and Grades (Austroads, 2014)

The Classes of Bitumen Used in Australia			
Formal Grade Designation	**Informal Name**	**Viscosity at 60 °C (Pa.s)**	
		Pre RTFO Treatment	**Post RTFO Treatment**
Class 170	C170	140 - 200	N/A
Class 240	C240	190 - 280	N/A
Class 320	C320	260 - 380	N/A
Class 450	C450	N/A	750 - 1150
Class 600	C600	500 - 700	N/A
Multigrade 500	M500	400 - 600	N/A
Multigrade 1000	M1000	N/A	3500 – 6500
The Grades of Bitumen Used in New Zealand			
Grade	Penetration (at 25 °C, 100 g, five seconds)	Viscosity (Pa.s at 60 °C, minimum)	
180 - 200	180 - 200	36	
130 - 150	130 - 150	58	
80 - 100	80 - 100	115	
60 - 70	60 - 70	190	
40 - 50	40 - 50	330	

3.4.4 Mixing, Compaction and Testing of Asphalt Mixtures

Laboratory preparation and compaction of asphalt mixes are undertaken using either gyratory or Marshall compaction to produce asphalt specimens for volumetric analysis and performance tests. Depending on the traffic levels, layer application, aggregate nominal size and compaction method, the asphalt mixtures need to comply with the target volumetric properties listed in Table 33.

Table 33: Asphalt Mixtures Design Criteria (Austroads, 2014)

Level 1 Design and Refusal Density Requirements for Asphalt Mixes Prepared Using Gyratory Compaction				
Traffic Category	Application	Laboratory Compaction Level (cycles)	Design Air Voids - Target (%)	Air Voids at 250 cycles - min (%)
Light	Wearing and base	50	4.0	-
Medium	Wearing and base	80	4.0	-
	High fatigue base	80	3.0	-
Heavy	Wearing and base	120	4.0	-
	High fatigue base	80	3.0	-
Very Heavy	Wearing and base	120	5.0	2.0
Design Requirements for Asphalt Mixes Compacted by the Marshall Method (50 Blow Compaction[1])				
Traffic Category	Application	Design Air Voids - Target (%)	Stability - min (kN)	Flow (mm)
Light	Wearing and base	4.0	5.5	2 – 4
Medium	Wearing and base	5.0	6.5	2 – 4
	High fatigue base	3.0	6.5	2 – 4
Heavy	Wearing and base	5.0	6.5	2 – 4
	High fatigue base	5.0	6.5	2 – 4
Very Heavy	Wearing and base	6.0	7.0	2 – 4
Voids Mineral Aggregate (VMA)				
Mix Nominal Size (mm)	VMA (% minimum)			
	Gyratory Compaction	Marshall Compaction (50 blow[1])		
		Heavy/Very Heavy Traffic Wearing Course Mixes	Other Mix Types	
7	17	-	17	
10	16	17	16	
14	15	16	15	
20	14	-	14	
28	13	-	13	
40	12	-	12	

[1] A higher standard of compaction, involving 75 blows per face, is used for airfield work and some heavy-duty road pavements. Where 75 blow Marshall compaction is used, the air voids targets shall be reduced by 1 percentage point. A compaction level of 35 blows is sometimes used for paths and residential streets

All mixes need to be designed to have a minimum effective binder film thickness of 7.5 microns except for a high fatigue base material that shall have a minimum effective design binder film thickness of 10 microns. If all relevant requirements are met, and no further testing is required, Level 1 testing may be concluded at this point. Where further testing is required for the selection of optimum binder content or determination of the influence of variation in binder content on volumetric properties, Level 1 testing continues with the following:

- preparation and compaction of two further mixes with the same grading as the initial trial mix and with binder contents ±0.5% of the initial mix
- determination of volumetric properties and Marshall properties (if required) and preparation of a graphical presentation of the results with variation in binder content
- selection of optimum binder content satisfying required specified parameters

Level 2 testing includes several optional performance-related tests which may be used to determine:

- Mechanical properties used for the structural design: resilient modulus (stiffness) and fatigue life (resistance). Standard resilient modulus conditions are 5% voids and 25 °C. Standard test conditions of fatigue testing are 5% voids and 20 °C and a strain level of 400 με. Testing at other strain levels can lead to a more complete understanding of the performance.
- Resistance to permanent deformation: wheel tracking. Standard test conditions are 5% voids and 60 °C.
- Moisture sensitivity: resistance to stripping. Standard test conditions are 8% voids and 25 °C. An optional freeze-thaw conditioning cycle is generally applied to heavy-duty applications.

The Level 2 testing limits are specified by the road agency.

3.4.5 Discussions on the Austroads Mixture Design

The Austroads provides two alternatives including the Marshall method and the Gyratory compaction for designing the volumetric properties of asphalt mixtures. The performance-related test and performance-based tests are also included based on the traffic level and application of asphalt mixtures. The Austroads also guides the selection of the constituent materials and link their required properties to the level of traffic.

3.5 Japanese Mixture Design Method

3.5.1 Mixture Design Procedure

Figure 13 illustrates the Japanese asphalt mixture design method. Asphalt mixtures are selected based on the required performance, site of application, the layer of the application, traffic volume, environmental conditions, regional properties, economic factors, and workability.

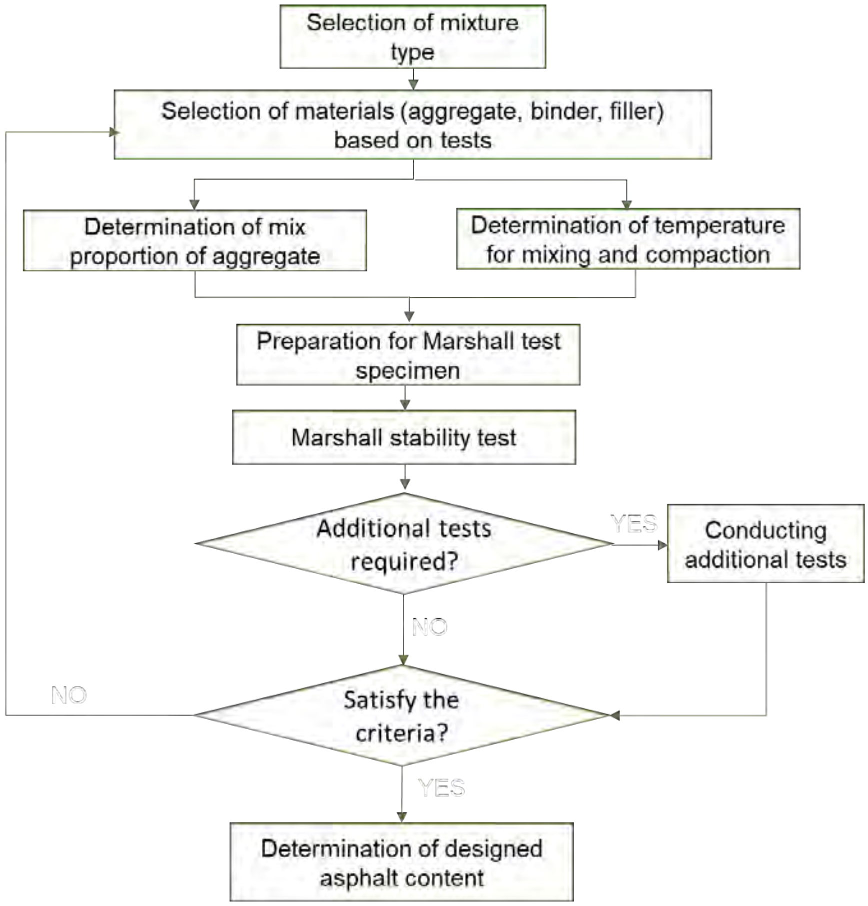

Figure 13: Japanese Asphalt Mixture Design Procedure (Japan Road Association, 2019)

The Marshall method is adopted in Japan for designing asphalt mixtures. Japan has a limited number of asphalt mixture types as shown in Table 34. For binder and base course layers, a coarse-graded asphalt mixture is the preferred option. For surface courses, there are different options of mixtures divided into two groups depending on the geographic region and climatic conditions.

Asphalt mixtures with a suffix of 'F' are considered rich in abrasion resistance and used in cold snowy areas where rutting is not an issue. There are mainly four different paving grade bitumens used in Japan including 40/60, 60/80, 80/100 and 100/120. The paving grade bitumen is selected based on the traffic and geographic region.

Table 34: Type of Asphalt Mixtures Used in Japan (Japan Road Association, 2019)

Course	Ordinary Regions	Snowy Cold Regions
Binder Course	1. Coarse-graded asphalt mixture (20) [4.5 - 6]	
Surface Course	2. Dense-graded asphalt mixture (20,13) [5 - 7] 3. Fine-graded asphalt mixture (13) [6 - 8] 4. Dense and gap graded asphalt mixture (13) [4.5 - 6] 9. Open-graded asphalt mixture (13) [3.5 – 5.5]	5. Dense-graded asphalt mixture (20F,13F) [6 - 8] 6. Fine and gap graded asphalt mixture (13F) [6 - 8] 7. Fine graded asphalt mixture (13F) [7.5 – 9.5] 8. Dense and gap graded asphalt mixture (13F) [5.5 – 7.5]

Notes:

( ) indicate maximum particle sizes

F indicates that much filler is used

[ ] binder content %

3.5.2 Marshall Design Criteria

Table 35 introduces the Marshall design criteria required for typical Japanese asphalt mixtures. Asphalt mixtures are prepared after the selection of constituent materials using the Marshall method. The optimum binder content is specified based on the outcome of the Marshall mix design method for a particular blend or gradation of aggregates, i.e. relationship between the binder content with the volumetric properties, stability, and flow.

In addition to the mixture design criteria listed in Table 35, the following points need to be considered for the designed asphalt mixture:

- Recommended dust to binder ratio (DP) is 0.8-1.2 for ordinary regions and 1.3-1.6 in cold snowy regions.
- Mixtures with high flexibility and durability should be used for roads with low traffic.
- A smaller value of design bitumen content between the median and lower limit is recommended for large traffic and a larger value between the median and upper limit for light traffic.
- Determination of design asphalt content of open-graded asphalt mixture is based largely on visual observation and experience.

Table 35: Marshall Design Criteria (Japan Road Association, 2019)

<table>
<tr><th colspan="2">Type of mixture</th><th>[1] Coarse-graded asphalt mixture (20)</th><th>[2] Dense-graded asphalt mixture (20), (13)</th><th>[3] Fine-graded asphalt mixture (13)</th><th>[4] Dense and gap graded asphalt mixture (13)</th><th>[5] Dense-graded asphalt mixture (20F), (13F)</th><th>[6] Fine and gap graded asphalt mixture (13F)</th><th>[7] Fine-graded asphalt mixture (13F)</th><th>[8] Dense and gap graded asphalt mixture (13F)</th><th>[9] Open graded asphalt mixture (13)</th></tr>
<tr><td rowspan="2">Number of blows</td><td>T>1,000</td><td colspan="4">75</td><td colspan="4" rowspan="2">50</td><td>75</td></tr>
<tr><td>T<1,000</td><td colspan="4">50</td><td>50</td></tr>
<tr><td colspan="2">Percentages of air voids (%)</td><td>3 - 7</td><td colspan="2">3 - 6</td><td>3 - 7</td><td colspan="2">3 -– 5</td><td>2 - 5</td><td>3 - 5</td><td>-</td></tr>
<tr><td colspan="2">Voids ratio filled with asphalt (%)</td><td>65 - 85</td><td colspan="2">70 - 85</td><td>65 - 85</td><td colspan="2">75 — 85</td><td>75 - 90</td><td>75 - 85</td><td>-</td></tr>
<tr><td colspan="2">Marshall stability kN</td><td>4.90 or more</td><td>4.9 (7.35) or more</td><td colspan="4">4.90 or more</td><td>3.43 or more</td><td>4.90 or more</td><td>3.43 or more</td></tr>
<tr><td colspan="2">Flow value mm</td><td colspan="6">2 -– 4</td><td>2 - 8</td><td colspan="2">2 - 4</td></tr>
</table>

[Note 1] Planned pavement traffic volume (vehicles/day/direction)
[Note 2] For pavement in snowy cold regions and where rutting is likely to occur despite 1,000≤T<3,000, only 50 blows are required.
[Note 3] The figures in parenthesis apply to the roads of T>1,000 in which case 75 blows are required.
[Note 4] Where the mixture is subject to the influence of water, or where the mixture is placed in an area subject to the influence of the water, the retained stability, computed should be the following formula, be 75% or more.
Residual stability = [Marshall stability after 48 hours of water immersion of 60°C (kN) / Marshall stability (kN)]x 100
[Note 5] When an open-graded asphalt mixture is used for the surface course of permeable pavement or walkway, the number of blows should be 50.

3.5.3 Special Measures for Hot Mix Asphalt

The Japanese asphalt mixture method primarily relies on empirical specifications Marshall method. However, additional mechanical and performance-related testing are included, where required depending on the application, to confirm the performance of the designed asphalt mixture. Figure 14 shows the process considered where additional performance-related tests are required. The main additional test is the measure of rutting resistance through dynamic stability (DS) obtained from the wheel tracking test. Target DS is set based on the rut depth predicted for a certain application. Where additional rutting test is required, Marshall stability should be at least 7.35 kN and stability/flow value should be higher than 2500 kN/m. Other measures required also include abrasion resistance and stripping resistance.

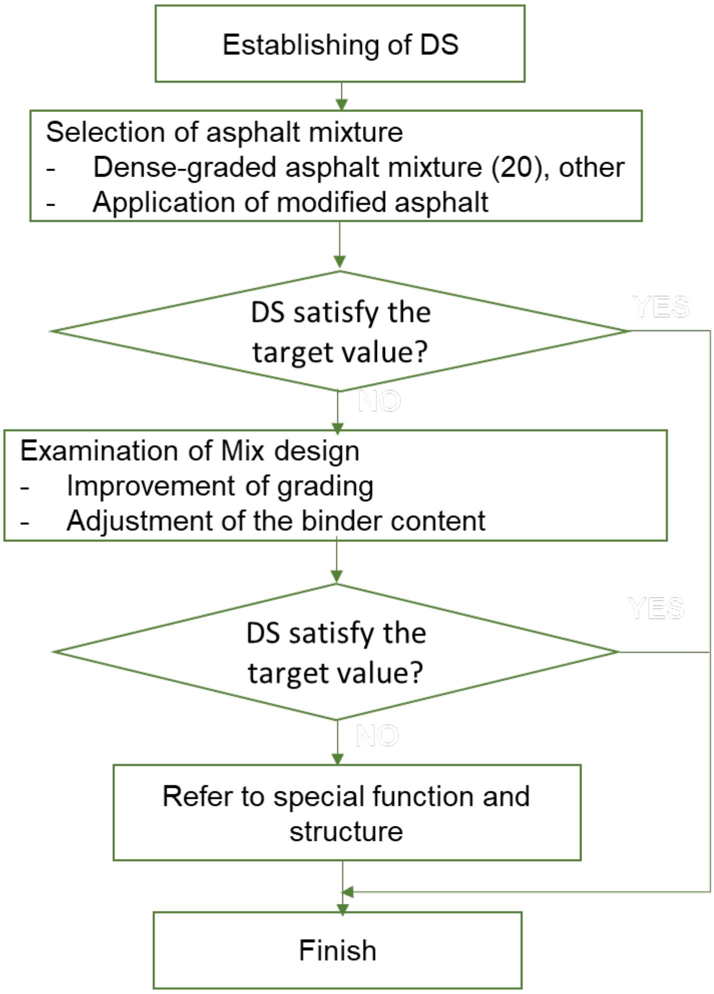

Figure 14: Procedure for Additional Performance-Related Testing (Japan Road Association, 2019)

3.5.4 Discussions on Japanese Asphalt Mixture Design

Japanese asphalt mixture design mostly follows an empirical approach. The Marshall method is primarily used. There is no provision available for performance-based criteria. The Japanese guidance puts more emphasis on producing durable mixtures with high binder content for light traffic or mixtures placed in cold snowy regions. This is achieved by specifying a lower number of blows and relatively low values for marshal stability requirements. Additional performance-related tests are only required where there is the need to improve one or more of the following performances: rutting resistance, abrasion resistance and stripping resistance.

4. Comparative Study and Gap Analysis

Table 36 presents the comparative study and gap analysis between the asphalt mixture design in England and findings from the detailed review of international asphalt mixture designs.

Table 36: Comparative Analysis for the Selected International Asphalt Mixture Design Procedures.

		England	United States (Superpave)	France (LCPC)	South Africa (SABITA)	Japan	Australian and New Zealand
	Specification Approach	Mainly empirical standards. Limited mixtures require performance testing	Empirical standards. Additional mixture performance testing is not a formal requirement	Hierarchy approach. Performance testing is required for some asphalt mixtures	Hierarchy approach. Performance testing is required based on traffic level and risk of structural damage	Empirical standards. A limited number of mixtures (Depending on the layer and geographic region).	Empirical standards. Performance testing is required based on traffic category and the application of asphalt mixture
Material Selection	**Binder Selection**	The general guidance for binder selection is based on a particular type and size of the asphalt mixture. Paving grade bitumen with classification 40/60 is most used. However, there is an increasing trend to use PMB in the surface course	The binder is selected based on performance-based criteria considering the environmental and traffic loading.	The general guidance for binder selection is based on a particular type and size of the asphalt mixture.	The binder is selected based on performance-based criteria considering the environmental and traffic loading.	The paving grade bitumen is selected based on the traffic and the climate zone	The paving grade bitumen is selected based on the traffic and the climate zone.
	Aggregate Minimum Requirement	The required criteria are defined based on the type of application. Only PSV and AAV for the surface course are linked to traffic.	The required criteria are defined based on the traffic and type of application.	The required criteria are defined based on the application and the type of asphalt mixture.	The required criteria are defined based on the application and the type and size of the asphalt mixture.	The required criteria are defined based on the application	The required criteria are defined based on the traffic load
Mixture Properties	**Compaction Method**	Marshall or Gyratory Laboratory evaluation is limited to specific mixtures	Gyratory, the level of compaction is specified based on traffic load for workability and performance level.	Gyratory, the level of compaction is specified based on traffic load for workability and performance level.	Gyratory, the level of compaction is specified based on traffic load.	Marshall The level of compaction depends on the traffic level	Marshall or Gyratory The level of compaction is specified based on traffic load

	Volumetric Properties	For the designed mixtures, the air voids need to meet the specified criteria from cores taken from a full-scale trial strip. Laboratory evaluation is limited to specific mixtures	Air void, VMA and VFA are linked with traffic load. Volumetric properties are laboratory evaluated.	Minimum and maximum air void content with gyration number and layer thickness.	Air void, VMA and VFA are linked with traffic load. Volumetric properties are laboratory evaluated	Marshall mixture design	Air void, VMA and VFA are linked with traffic load and type of application. Volumetric properties are laboratory evaluated
	Binder Content	Prescriptive or guidance about the minimum binder content depending on the type of aggregate and asphalt mixture. Designed binder content is defined based on laboratory volumetric properties for limited mixtures	Designed based on air void, 4% compacted to N_{des}.	The designed binder content is identified to meet the volumetric properties taking into account the minimum binder content applied for each mixture.	Design Level 1 based on Volumetric. Design Level II, III based on the performance-related test.	Designed based on Volumetric, Marshall stability and Flow.	Designed based on Volumetric, Marshall stability and Flow (if relevant).
Mixture Performance	**Moisture Sensitivity Test**	Required based on mixture type and application.	Required $ITS_{80\%}$	Level 1 or above (level is dependent on traffic).	Dependent on traffic (Level IB, II, III)	Dependent on the application	Design Level 2 (Type of test is related to traffic level and application).
	Permanent Deformation (Wheel Tracking)	Required for most designed mixtures	No formal requirement, many agencies recommend on (Project Important, high traffic loading)	Required depending on the mixture type.	Depend on traffic load (Design Level II, III)		
	Additional Testing • **Stiffness Modulus** • **Fatigue**	Required depending on the mixture type.					

5. Protocol for a Proposed New Mixture Design Procedure

5.1 Introduction

Previous sections introduced the details and procedures currently adopted for designing asphalt mixtures internationally as well as the design approach used in England. The main aim of this work is to develop a proposal towards a unified asphalt mixture design approach that can offer greater flexibility to accommodate recycled and waste-derived materials for the SRN. The viewpoint is to move towards a more fundamental approach such as volumetric and performance-related/based mixture design and not over-reliant on empirical designs as the means to manage risks associated with the use of these materials.

The work presented in the previous sections identified key areas that need to be considered in the proposed protocol. The key areas are as follows:

1. The current asphalt mixture design used in England is largely dependent on field trial testing to ensure the conformity of specification criteria derived from laboratory assessments. Thus, enhancing laboratory assessments in the new protocol will contribute to optimising the performance of asphalt mixtures and promoting the sustainability of the designed asphalt mixtures.

2. The current asphalt mixture design used in England may not directly consider the traffic loading and environmental conditions in the design process of asphalt mixtures. In comparison, the traffic loading and environmental conditions are used in the international asphalt mixture design procedures as inputs to inform the selection of material, the level of compaction, the type and criteria of performance testing.

The next section introduces a new mixture design procedure proposed for use in the new construction and maintenance of roads in England.

5.2 Asphalt Mixture Design Approach

The proposed approach embraces a hierarchy approach associated with the level of traffic and the risk of damage. The adopted approach should be selected by the mixture designer based on the level of traffic, type of application, type of asphalt mixture and the risk of structural damage. Figure 15 shows the main hierarchal approaches considered for the new asphalt mixture procedures (prescriptive, empirical, performance-related, and performance-based). It should be noted that the performance-based approach is being discussed as an aspirational asphalt mixture design which can be expected to offer the widest flexibility in catering for the needs associated with the future evolution of materials and progression to analytical pavement design in England. In the absence of an established performance-based approach, the performance-related method can be considered in the interim.

Table 37 and Table 38 guide on selecting the appropriate approach based on level of traffic, risk of damage and the type of asphalt mixture. The risk of damage includes mainly rutting, fatigue, and reflective cracking. For a new construction, the risk of damage can be assessed based on the pavement thickness and structure, the depth of material within pavement layers, the severity of loading and the environmental conditions. For an existing construction or maintenance purposes, the historical performance of the pavement section, such as those obtained from surface and/or structural condition surveys (DMRB CD 230) and/or the Highways Agency Pavement Management System (HAPMS) records, should also be considered when assessing the risk of damage, in addition to those considered for a new construction. The range of traffic levels proposed in Table 37 is a reconstituted form of site classifications by traffic and site category which are currently being adopted in MCHW NG900 Table 9/25, Table 9/26 and Table 9/27 for AC, TSCS and HRA respectively.

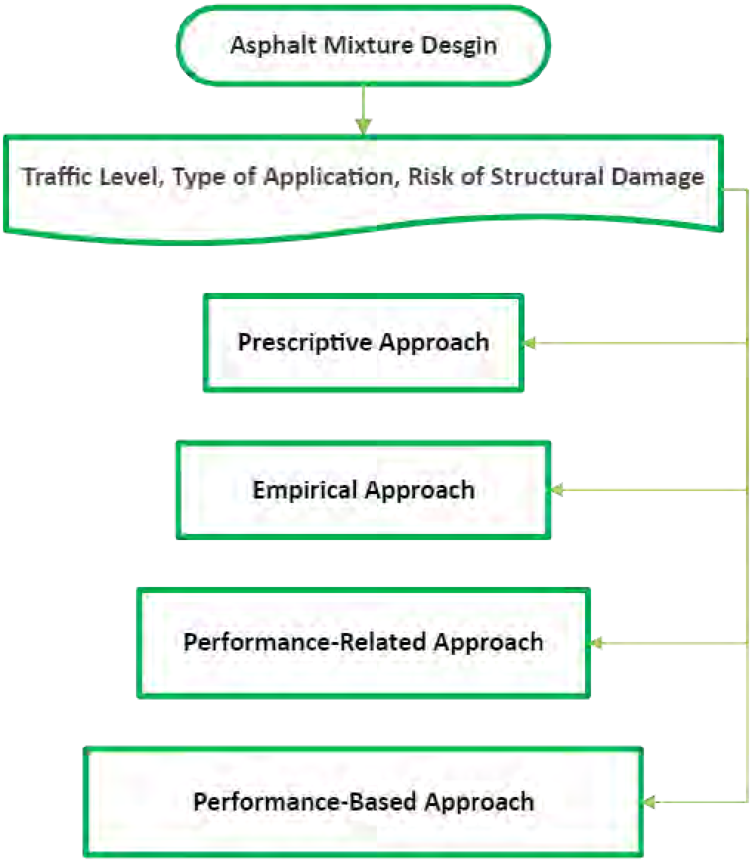

Figure 15: Proposed Asphalt Mixture Design Approach

Table 37: Proposed Asphalt Mixture Design Approach Based on Traffic Level and Risk of Damage

<table>
<tr><th rowspan="2">Scheme Condition</th><th colspan="4">Traffic Level (cv/lane/day) at Design Life</th></tr>
<tr><th>< 100</th><th>100 to 1000</th><th>1000 to 3000</th><th>> 3000</th></tr>
<tr><td>New construction/low risk of damage</td><td>Prescriptive</td><td>Empirical</td><td colspan="2">Performance-related</td></tr>
<tr><td>New construction/moderate risk of damage</td><td colspan="2">Empirical</td><td>Performance-related</td><td>Performance-based</td></tr>
<tr><td>New construction/high risk of damage</td><td colspan="2">Performance-related</td><td colspan="2" rowspan="2">Performance-based</td></tr>
<tr><td>Strengthening/maintenance</td><td colspan="2">Performance-related</td></tr>
</table>

Table 38.: Mixture Type and Design Approach

<table>
<tr><th rowspan="2">Type of Mixtures</th><th colspan="4">Mixture Design Approach</th></tr>
<tr><th>Prescriptive</th><th>Empirical</th><th>Performance-related</th><th>Performance-based</th></tr>
<tr><td>Asphalt Concrete (AC)</td><td colspan="4">☑</td></tr>
<tr><td>Hot Rolled Asphalt (HRA)</td><td colspan="4">☑</td></tr>
<tr><td>Stone Mastic Asphalt (SMA)</td><td>☒</td><td colspan="3">☑</td></tr>
</table>

5.2.1 Prescriptive Approach

The prescriptive approach is considered for asphalt mixtures used in low traffic areas where the risk of structural damage is low. Figure 16 shows the mixture design details and requirements that are associated with the prescriptive approach without additional mechanical testing. In this approach, the main asphalt mixture compositions are the evaluation of binder content and grading. These are prescribed as 'recipe mixtures' in accordance with BS EN 13108-1, BS EN 13108-4 and PD 6691.

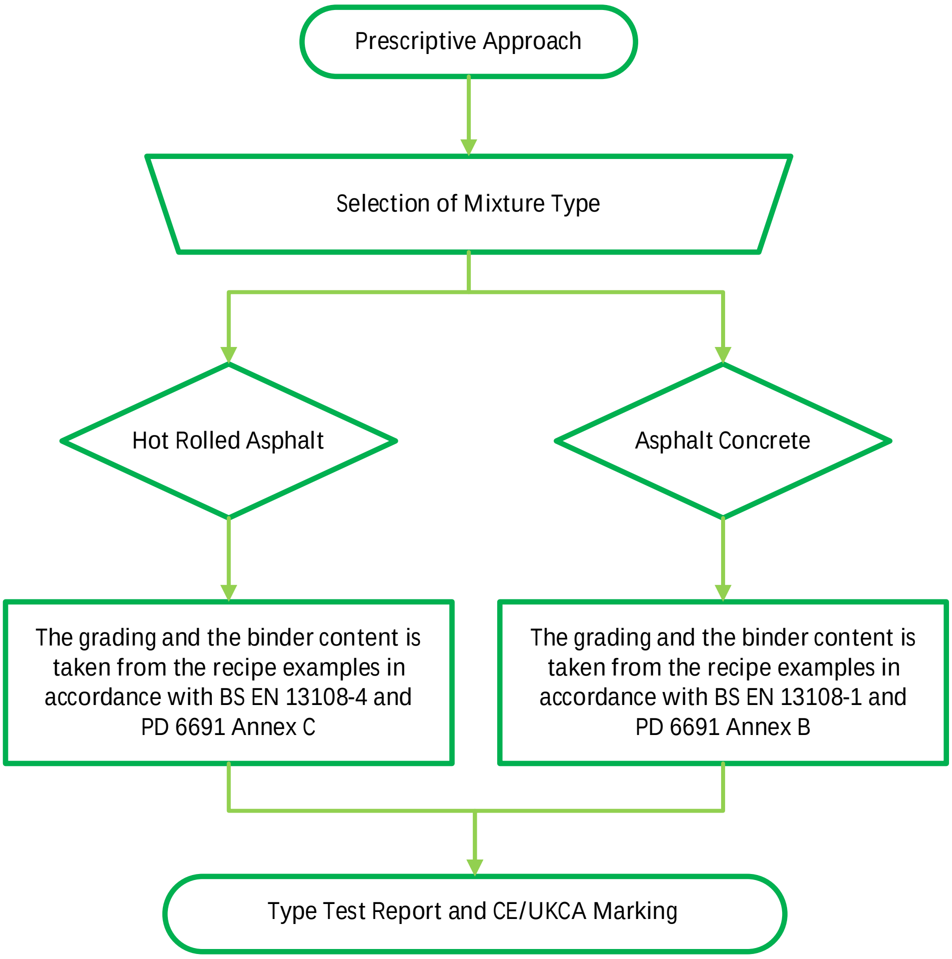

Figure 16: Prescriptive Approach

5.2.2 Empirical Approach

The design process for the empirical approach is illustrated in Figure 17. The empirical approach is intended for mixtures with moderate traffic levels and moderate risk of structural damage. The empirical approach allows both Marshall and Gyratory methods for manufacturing the asphalt mixtures. The empirical approach can be summarised as follows:

- Select constituent materials that comply with the required standard and specification (MCHW).
- Identify the target grading and the minimum binder content based on PD 6691 specification examples and EN 13108 series.
- Determine volumetric properties including air void content, bulk density, VMA and VFB.
- For the Marshall method, determine the stability and flow (in addition to the above volumetric properties).
- Assessment of volumetric and, the Marshall properties (if relevant), to see if they meet the specified requirements.
- Assessment of water sensitivity against the specified requirements.

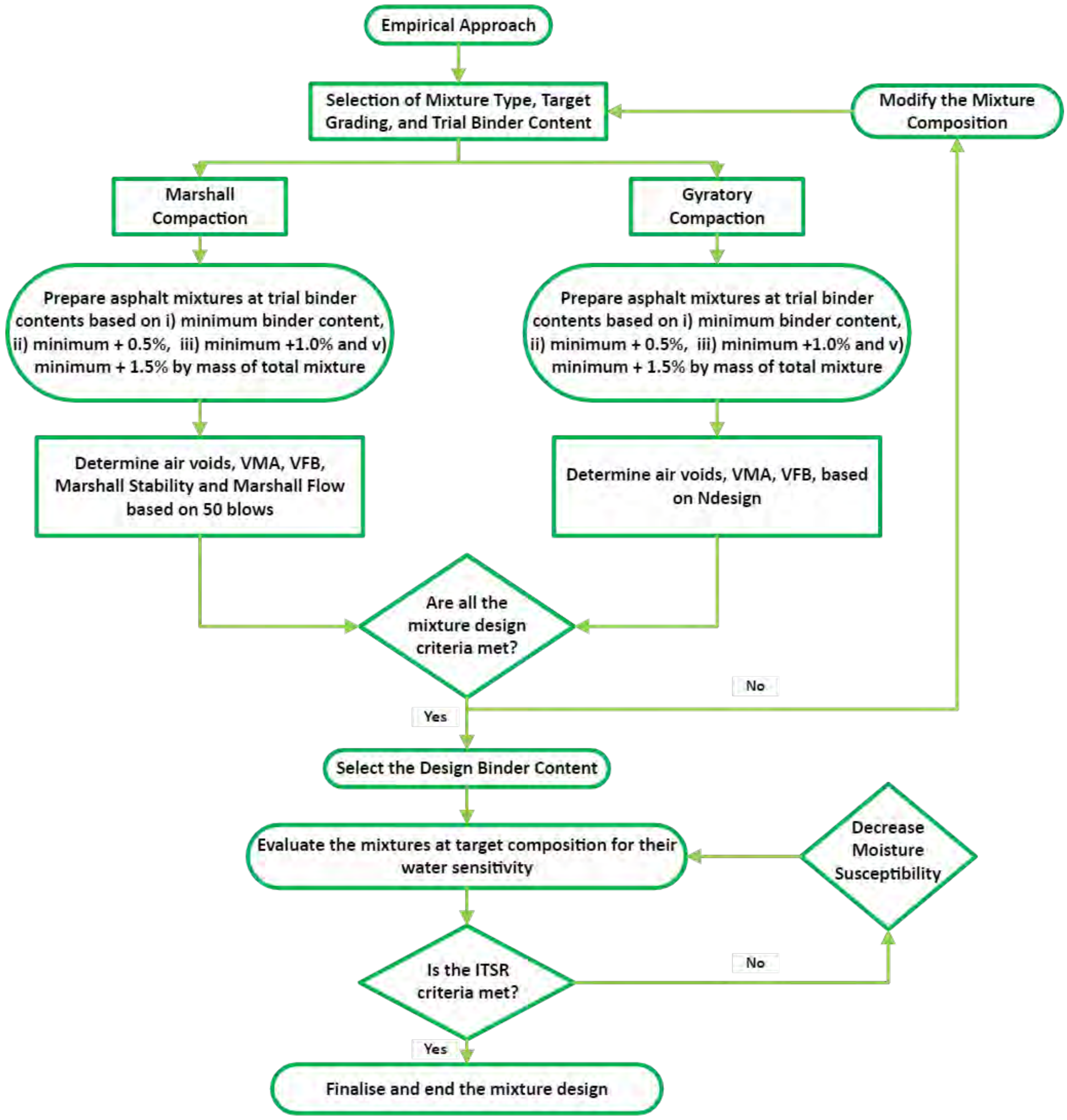

Figure 17: Empirical Approach

The design criteria and limits detailed in Table 39 to Table 41 are examples based on international practices. Follow up works are strongly recommended to assess these values against laboratory generated data and validate them for traffic loading and environmental conditions which are expected on the SRN.

Table 39: Indicative Design Requirements for Asphalt Mixes Prepared Using Gyratory Compaction

Design Requirements for Asphalt Mixes Prepared Using Gyratory Compaction; Specimen Size is 150 mm (Diameter) by 115 mm (Height)			
Traffic Level (cv/lane/day)	**Application**	**Laboratory Compaction Level (gyration)**	**Design Air Voids - Target (%)**
<100	Surface and base	50	4.0
100 - 1000	Surface course	75	4.0
	Base/binder course	75	3.0

Table 40: Design Requirements for Asphalt Mixes Prepared Using Marshall Method

Design Requirements for Asphalt Mixes Prepared Using Marshall method (50 blow compaction) per side				
Traffic Level (cv/lane/day)	**Application**	**Design Air Voids - Target (%)**	**Stability - min (kN)**	**Flow (mm)**
<100	Surface and base	4	5.5	2 - 4
100 - 1000	Surface course	4	6.5	
	Base/binder course	3	6.5	

Table 41: Volumetric Properties Requirements for Marshall and Gyratory Methods.

Property	Marshall method			Gyratory method		
Minimum Percent VMA	**Minimum VMA for design voids**					
	NMAS (mm)	3%	4%	NMAS (mm)	3%	4%
	32	11	12	32	11	12
	20	12	13	20	12	13
	14	13	14	14	13	14
	10	14	15	10	14	15
Percent VFB	65 to 75					
Moisture Resistance (Min TSR)	70% for base or binder course and 80% for surface course					
Mixtures with VMA greater than 2 per cent above the minimum should be avoided. NMAS – Nominal Maximum Aggregate Size						

5.2.3 Performance-Related Approach

The performance-related approach is considered for asphalt mixtures used in relatively low to medium traffic areas where there is a high risk of structural damage requiring strengthening or major maintenance. Application to cater for higher traffic will be limited to sites with lower risk, as illustrated in Table 37. For HRA mixtures, the Marshall mixture design method can be used for determining void content, binder volume and resistance to permanent deformation in accordance with Annex F BS 594987. Other asphalt mixtures are designed using the Gyratory method.

The performance-related approach is illustrated in Figure 18 and can be summarised in the following design procedure:

- Selection of constituent materials that comply with the respective specifications for the asphalt mixture type.
- Identifying the target grading and the minimum binder content based on PD 6691 specification examples and EN 13108 series. However, it is recommended to use the Bailey method to optimise aggregate proportions (for AC and SMA).
- Determination of volumetric properties including air voids, bulk density, VMA and VFB based on N_{des}
- Assessment of volumetric properties to see if they meet the specified requirements.
- Assessment of the resistance to permanent deformation against the specified requirements.
- Assessment of water sensitivity against the specified requirements.

The design criteria and limits shown in Table 42 and Table 43 are examples based on international practices (SABITA, 2005; Austroads, 2014; Asphalt Institute, 2015). These values would need to be established and validated for conditions in England. For SMA mixtures, fibres and/or polymer-modified bitumen have been used to prevent excessive draining of the binder and/or performance improvement. The mixture composition adjustments may include fine aggregate content, discontinuity in the gradation, rounded aggregate, angularity, additives, and bitumen type and grade.

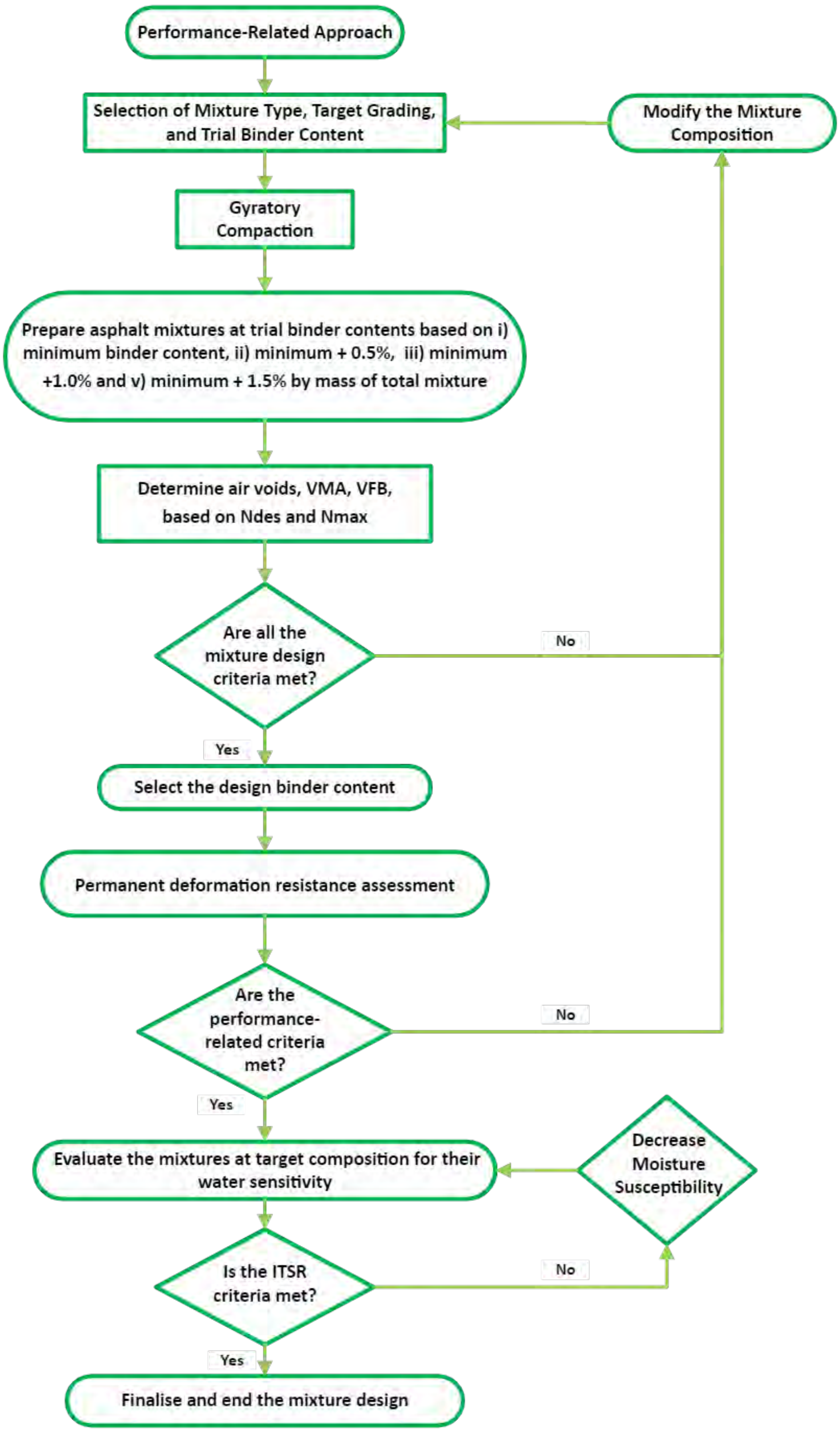

Figure 18: Performance-Related Approach

Table 42: Compaction Levels for Asphalt Mixtures Prepared Using Gyratory Compaction

Design Requirements for Asphalt Mixes Prepared Using Gyratory Compaction; Specimen Size is 150 mm (Diameter) by 115 mm (Height)					
Traffic Level (cv/lane/day)	**Application**	**Laboratory Compaction Level (gyrations)**	**Design Air Voids - Target (%)**	**N_{max}**	**Minimum Air Voids at N_{max} (%)**
<100	Surface and base	50	4.0	75	2.0
100 - 1000	Surface course	75	4.0	115	
	Base/binder course	75	3.0	115	
1000-3000	Surface course	100	4.0	160	
	Base/binder course	80		120	
>3000	Surface course	120		205	
	Base/binder course	100		160	

Table 43: Volumetric Properties Requirements for Gyratory Methods

Property	Gyratory method		
Minimum VMA (%)	**Minimum VMA for Design Voids**		
	NMAS (mm)	3%	4%
	32	11	12
	20	12	13
	14	13	14
	10	14	15
VFB (%)	65 to 75		
Moisture Resistance (Min TSR)	70% for base or binder course and 80% for surface course		
Mixtures with VMA greater than 2 percent above the minimum should be avoided. NMAS – Nominal Maximum Aggregate Size			
Permanent deformation testing types and criteria are specified based on mixture type, traffic level and application in accordance with SHW series 900, EN 13108 series, PD 6691, EN 13108-20, EN 13108-21 and BS 594987.			

5.2.4 Performance-Based Approach

The performance-based approach is being considered an aspirational asphalt mixture design that aims to account for the future evolution of asphalt materials. It is expected that this approach can facilitate accelerated design and approval process for innovative products and, in line with the increased trends in digitalisation in design, the results can be used to improve the predictive model of the materials which can be linked to analytical pavement design.

The performance-based asphalt mixture design approach can be considered for specialist asphalt mixture applications such as those for use in relatively high traffic areas with a high risk of structural (pavement) damage, and where selected mechanical properties of the mixtures will be required to inform analytical pavement design (such as for strengthening and major maintenance). The asphalt mixture design process uses the Gyratory compaction method to assess the volumetric properties. The performance-based approach can offer more flexibility to include high contents of recycled and waste-derived material in the asphalt mixture where their mechanical performance and durability can be demonstrated through the nominated performance-related and performance-based tests. The asphalt mixture design for the performance-based approach follows the same principles of the performance-related approach as detailed in Section 5.2.3 of this report but with additional requirements. The main difference is the inclusion of additional performance testing which can provide fundamental properties of the tested asphalt mixtures, such as changes in stress and/or strains during fatigue and stiffness tests; Figure 19 refers.

The design criteria and limits shown in

Table 44 and Table 45 are examples based on international practices (SABITA, 2005; Austroads, 2014; Asphalt Institute, 2015). These values would need to be established and validated for conditions in England. For SMA mixtures, fibres and/or polymer-modified bitumen have been used to prevent excessive draining of the binder and/or performance improvement. The mixture composition adjustments may include fine aggregate content, discontinuity in the gradation, rounded aggregate, angularity, additives, and bitumen type and grade.

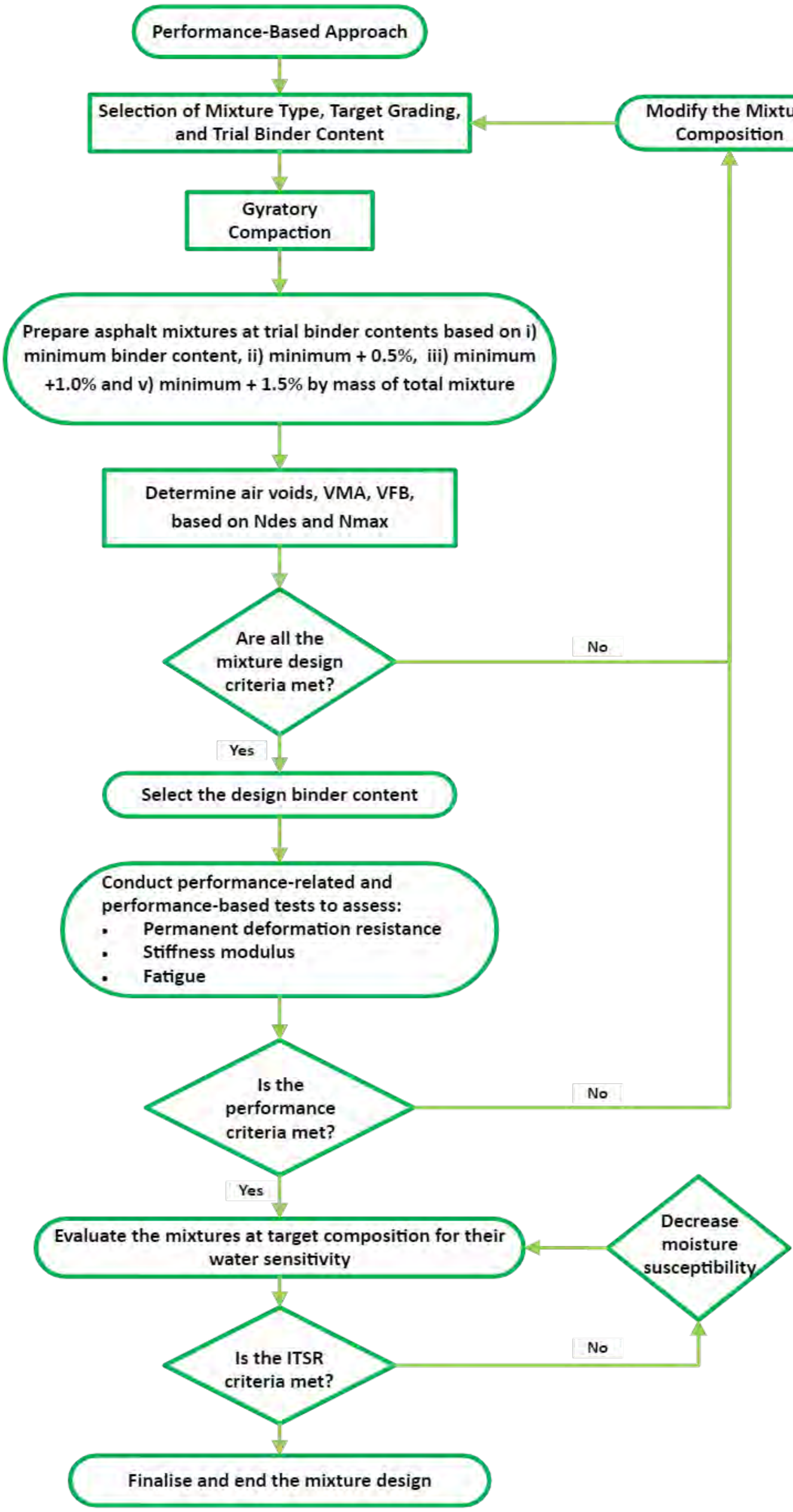

Figure 19: Performance-Based Approach

Table 44: Compaction Levels for Asphalt Mixtures Prepared Using Gyratory Compaction

<table>
<tr><th colspan="6">Design Requirements for Asphalt Mixes Prepared Using Gyratory Compaction; Specimen Size is 150 mm (Diameter) by 115 mm (Height)</th></tr>
<tr><th>Traffic Level (cv/lane/day)</th><th>Application</th><th>Laboratory Compaction Level (gyration)</th><th>Design Air Voids - Target (%)</th><th>N_{max}</th><th>Minimum Air Voids at N_{max} (%)</th></tr>
<tr><td><100</td><td>Surface and base/binder</td><td>50</td><td>4.0</td><td>75</td><td rowspan="7">2.0</td></tr>
<tr><td rowspan="2">100 - 1000</td><td>Surface course</td><td>75</td><td>4.0</td><td>115</td></tr>
<tr><td>Base/binder course</td><td>75</td><td>3.0</td><td>115</td></tr>
<tr><td rowspan="2">1000-3000</td><td>Surface course</td><td>100</td><td rowspan="4">4.0</td><td>160</td></tr>
<tr><td>Base/binder course</td><td>80</td><td>120</td></tr>
<tr><td rowspan="2">>3000</td><td>Surface course</td><td>120</td><td>205</td></tr>
<tr><td>Base/binder course</td><td>100</td><td>160</td></tr>
</table>

Table 45: Volumetric Properties Requirements for Gyratory Methods

<table>
<tr><th>Property</th><th colspan="3">Gyratory Method</th></tr>
<tr><td rowspan="6">Minimum Per cent VMA</td><td colspan="3">Minimum VMA for Design Voids</td></tr>
<tr><td>NMAS (mm)</td><td>3%</td><td>4%</td></tr>
<tr><td>32</td><td>11</td><td>12</td></tr>
<tr><td>20</td><td>12</td><td>13</td></tr>
<tr><td>14</td><td>13</td><td>14</td></tr>
<tr><td>10</td><td>14</td><td>15</td></tr>
<tr><td>Percent VFB</td><td colspan="3">65 to 75</td></tr>
<tr><td>Moisture Resistance (Min TSR)</td><td colspan="3">70% for base or binder course and 80% for surface course</td></tr>
<tr><td colspan="4">Mixtures with VMA greater than 2 per cent above the minimum should be avoided.
NMAS – Nominal Maximum Aggregate Size.</td></tr>
</table>

Permanent deformation, fatigue and stiffness testing types and criteria are specified based on mixture type, traffic level and application in accordance with SHW series 900, EN 13108 series, PD 6691, EN 13108-20, EN 13108-21 and BS 594987.

5.3 The Inclusion of Reclaimed Asphalt (RA) and Waste-Derived Materials

To enhance product sustainability, there have been proposals for the addition of increased content of Reclaimed Asphalt (RA) and the use of waste-derived materials (such as crumb rubber or processed plastic additives) as novel additives or components for asphalt pavements.

5.3.1 The Inclusion of RA in Asphalt Mixtures

Incorporating RA in asphalt mixtures contributes to promoting sustainability and reducing the carbon footprint associated with their life cycle. RA is obtained by processing site-won asphalt (crushing and screening to remove oversized particles and separating them into size fractions). In England, the limits that normally apply to RA inclusion (without additional validation requirements) are detailed below:

- PD 6691: Surface course - 20%
- PD 6691: Lower course materials - 50%
- Draft MCHW to allow up to 20% of RA in the surface course

Typical RA properties to be established are summarised below:

- The particle size and properties of the aggregate (RA d/D)

- Known source and properties of the reclaimed asphalt (such as PSV/AAV properties)
- Binder content
- The properties of the binder
- The foreign matter in the reclaimed asphalt

The penetration value of the recovered bitumen should meet the requirements as detailed in PD 6691. If more than 25% RA is used in the base or binder course, cores are required to assess their stiffness in accordance with BS EN 12697-26 and as detailed in MCHW Clause 902.

A more detailed mix design approach should be considered when assessing asphalt mixtures with high contents of RA. The performance-related approach as detailed in Section 5.2.3 or the performance-based approach presented in Section 5.2.4 can be adopted to design asphalt mixtures incorporating an increased amount of RA. This forms a unified mixture design approach for RA mixtures.

5.3.2 The Inclusion of Waste-Derived Materials

The use of waste-derived materials as novel additives or components for asphalt should first be evaluated using the filtering protocol detailed in Collaborative Research Project, Task 1-979: Sub-Task 2: End of product life - waste/additive assessment and filtering protocol. This protocol covers three stages of assessments:

- Stage 1: General end of waste/by-product assessment
- Stage 2: Pavement industry specific assessment
- Stage 3: Development of product in accordance with Technology Readiness Level

The report detailing the above stages of assessments can be found using this link: https://aecom.com/uk/wp-content/uploads/2021/06/report_highways-england_60618808_1-979_subtask-2.pdf

A detailed and unified mix design approach should be considered when assessing the properties of asphalt mixtures incorporating waste-derived materials under Stage 3 of the above protocol. The performance-related approach as detailed in Section 5.2.3 or the performance-based approach presented in Section 5.2.4 can be adopted to design asphalt mixtures incorporating waste-derived materials. This provides a sound approach to demonstrate the required mechanical and performance properties of the designed materials.

Additional reference documents about incorporating RA and waste-derived materials are detailed below:

- Best practice guides for recycling asphalts into thin surfacings are provided by TRL Road Note 43
- Proposed guidance using RA (incorporating reclaimed PMB), virgin aggregate and virgin PMB were introduced in Work Package 1-979 Sub-Task 1. The report can be found using this link: https://aecom.com/uk/wp-content/uploads/2021/06/report_highways-england_60618808_1-979_subtask-1.pdf

5.4 The Use of Warm Mix Asphalts (WMA)

Warm Mix Asphalts (WMA) are asphalt mixtures that are manufactured at lower temperatures up to 40°C lower than conventional hot mix asphalt while having equivalent properties and performance. The application of WMA in SRN projects is specified in accordance with MCHW Clause 908. The use of WMA can improve productivity, provide carbon reduction and aligns with aspirations towards achieving net-zero carbon emissions across the industry. WMA materials may be produced in accordance with Clause 908 and the following:

- Clause 906 Dense Base and Binder Course Asphalt Concrete with Paving Grade Bitumen (Recipe Mixtures).
- Clause 912 Close Graded Asphalt Concrete Surface Course.
- Clause 929 Dense Base and Binder Course Asphalt Concrete (Design Mixtures).
- Clause 930 EME2 Base and Binder Course Asphalt Concrete.

- Clause 937 Stone Mastic Asphalt (SMA) Binder Course and Regulating Course.
- Clause 942 Thin Surface Course Systems.

The asphalt mixture design approaches presented in previous sections (prescriptive, empirical, performance-related and performance-based) can be used to design WMA subject to meeting the requirements of the above MCHW clauses and the following points:

- WMA conforming to Clause 942 should have a Product Acceptance Scheme certification for their installation in compliance with sub-Clause 104.16 and Clause 942 to demonstrate their performance.
- The Indirect Tensile Strength Ratio (ITSR) shall be $ITSR_{80}$ using BS EN 12697-12 Test Method A for WMA conforming to Clause 929, 937 and 942.
- For WMA conforming to Clause 930 (EME2), the minimum water sensitivity when tested in accordance with Method B of BS EN 12697-12 shall be i/C_{75}.
- A cradle-to-gate carbon footprint analysis needs to be conducted in accordance with TRL PPR 575 – Protocol. As a potential alternative, a new framework assessment tool has been developed in WP1/WP2 of the current collaborative research.
- The minimum rolling temperatures for WMA's are detailed in Table 9/1C of MCHW Clause 908.

5.5 Scope of the Protocol to Enhance Sustainability Measurement and Performance

Some outputs from this work (WP3) can feed into Stage 1 of Work Package 2 (WP2) by providing more details on mixture composition (% bitumen, % aggregate, % RA), production methods (hot mix vs warm mix technology) and durability (life expectancy). The details will vary with the different level of design approaches as outlined in WP3.

In combination with the outputs of WP2, early data gathering, and sustainability impact assessment/scoring might be carried out in parallel with the mixture design process. This can be achieved by assigning indicative impact values depending on selected sources of components to embed the need for relevant data. Inputs gathered at the design stage can be collated and verified for/from full-scale trial and production prior to validation of full Life Cycle Impact Assessment (LCIA) at a scheme level.

6. Conclusions and Recommendations

6.1 Conclusions

The main findings and conclusions are presented below:

- Current approach for asphalt mixture design in England is mostly dependent on prescriptive and empirical specifications. Most international specifications reviewed have adopted performance specifications.
- International asphalt mixture designs and specifications reviewed in this project showed that aggregate materials were selected based on the traffic load and location within the asphalt pavement structure (surface, binder or base course layer). In the current asphalt mixture designs and specifications used in England, only PSV and AAV aggregate properties for the surface course are linked with traffic loadings.
- Many international specifications currently allow performance-based tests (stiffness and fatigue resistance) to design asphalt mixtures, especially for critical schemes with high traffic loadings. In England, only EME2 and BBA asphalt mixtures consider the fatigue and stiffness tests albeit being used in a simplified version.
- A full-scale trial strip for a Site Installation Performance Trial (SIPT) is adopted for Thin Surface Course Systems to confirm the required properties (e.g., volumetrics, resistance to permanent deformation and stiffness). This is considered good practice for Initial Type Testing, laboratory assessments and optimisation prior to the full-scale trial could further enhance the process and ultimately improve the performance and durability of asphalt mixtures.
- There is no explicit guidance in the current specification to select the binder considering climatic conditions and traffic level. Some international specifications specified binders based on environmental and traffic loadings.
- The proposed asphalt mixture designs as detailed in Sections 5.2.1 to 5.2.4 presents a protocol that considers the level of traffic and risk of damage in line with international asphalt mixture design methods. By selecting the most appropriate asphalt mixture designs as detailed in Sections 5.2.1 to 5.2.4, the durability and performance of the designed mixture can be optimised.
- It is anticipated that the aspirational asphalt performance-based design can offer more flexibility to include reclaimed and waste-derived material into asphalt mixtures. In addition to this, the proposed guidance supports the use of WMA which is important in promoting sustainability and reducing the carbon footprint associated with the construction of roads.

6.2 Recommendations

The following recommendations are:

1. The proposed asphalt mixture design protocol has been developed based mostly on the international review of international best practices. It is recommended to conduct a 'Questionnaire type survey' for asphalt industry specialists and pertinent stakeholders in England to obtain feedback and suggestions about the proposed new asphalt mixture design methods. This includes assessing the complexity and readiness of the new mixture design methods for adoption.
2. The impact of introducing the new mixture design methods should be evaluated. This can be done in three stages:
    a) Laboratory assessment to assess the performance of asphalt mixtures produced using the new design protocol against mixtures produced using the current specification.
    b) Undertake cost evaluations.
    c) Validate the laboratory results using a full-scale field trial.
    d) Conduct Life Cycle Impact Assessment to assess the impact of the new protocol.
3. This project recommends the validation of the proposed mix design approach to establish the specification criteria and limits for use in England.

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