Transportation Association of Canada

Synthesis of Quality Management Practices for Canadian Flexible Pavement Materials and Construction

May 2007

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Abstract:

The *Synthesis of Quality Management Practices for Canadian Flexible Pavement Materials and Construction* provides a review and synthesis of practices for the quality management of the materials, production and placement for flexible pavement construction.

The synthesis describes the detailed quality management for the flexible pavement materials and construction, as follows:

- Design considerations;
- Flexible pavement materials: granular subbase/base; hot-mix asphalt aggregates and asphalt cements (typical performance graded asphalt cements); and miscellaneous materials such as reclaimed asphalt pavement, tack coat, fillers, fibres and polymer modified asphalt cements;
- Subgrade preparation;
- Placement and compaction of granular subbase and base;
- Hot-mix asphalt production and transportation, including environmental control; and
- Hot-mix asphalt paving and compaction: trial section, substrate preparation, tack coats, material transfer devices, joint construction and working with polymer modified asphalts.

The document also offers recommendations for a quality management system template based on a contractor's quality control plan and an agency's quality assurance plan. The template is, however, subject to the specific requirements of an agency for a project's flexible pavement materials and construction. The importance of contractors' and agencies' commitment to quality and teamwork, at all stages of flexible pavement materials and construction methods, for enhanced life-cycle costs and performance, are emphasized throughout.

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- Pavement Design
- Construction of Pavements and Surfacings
- Quality Assurance
- Flexible pavement
- Material (Construction)
- Construction
- Hot Coated Material
- Bitumen
- Roadbase
- Specification (Standard)
- Specifications

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Résumé

Cette *Synthèse des pratiques de gestion de la qualité des matériaux souples de revêtement et de construction de chaussées au Canada* propose une analyse des pratiques de gestion de la qualité des matériaux, des méthodes de production des matériaux souples et de la construction de routes au moyen de ces matériaux.

La synthèse décrit de façon détaillée les méthodes de gestion de la qualité en contexte de revêtement et de construction de chaussées au moyen de matériaux souples. Concrètement, la synthèse décrit de façon détaillée les matériaux et les pratiques de construction des routes en contexte de gestion de la qualité, à savoir :

- considérations conceptuelles;
- matériaux souples de construction de chaussées : sous-fondation/fondation granulaire, enrobés bitumineux à chaud et bétons bitumineux (rendement type des bétons bitumineux classifiés), divers matériaux tels les chaussées bitumineuses recyclées, couches d'enduit d'adhérence, produits de remplissage, fibres et bétons bitumineux modifiés au moyen de polymères;
- préparation de la sous-fondation;
- pose et compactage de la sous-fondation et de la fondation granulaire;
- production et transport des enrobés bitumineux à chaud, y compris le contrôle de l'environnement, et
- pose et compactage des enrobés bitumineux à chaud : section d'essai, préparation du substrat, couches d'adhérence, dispositifs de transferts de matériaux, construction au moyen de bitumes modifiés par l'ajout de polymères.

Ce document de synthèse propose également des recommandations pour la mise en place d'un modèle de système de gestion de la qualité fondé sur un plan de contrôle de la qualité des entrepreneurs de même que d'un plan d'assurance de la qualité des organisations visées. Le modèle en question est néanmoins assujetti aux exigences spécifiques des organisations en regard d'un projet de construction d'une chaussée au moyen de matériaux souples. On ne saurait trop souligner l'importance de l'engagement des entrepreneurs et des organisations vis-à-vis de la qualité, incluant leurs équipes respectives, et ce à toutes les étapes des processus de revêtement et de construction de chaussées souples, le tout par souci d'améliorer les coûts associés à la durée de vie utile des chaussées et à leur rendement.

Mot-clés

- Dimensionnement des chaussées
- Construction des chaussées et des revêtements
- Assurance de qualité
- Matériaux
- Construction (Exécution)
- Enrobé chaud
- Bitume
- Couche portant
- Norme
- Recommandation

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EXECUTIVE SUMMARY

The purpose of this *Synthesis of Quality Management Practices for Canadian Flexible Pavement Materials and Construction* was to review, evaluate and synthesize best practices for the quality management of the materials, production and placement for flexible pavement construction and to provide recommendations for a paving project quality management system (QMS) template based on contractor's quality control (QC) and agency's quality assurance (QA). Flexible pavement materials considered are the prepared subgrade, granular subbase, granular base and hot-mix asphalt. The quality control, quality assurance and quality management system concerns considered can be readily extended to incorporate complementary rehabilitation and maintenance technologies such as in-place recycling (cold in-place recycling, full depth reclamation and hot in-place recycling), crack sealing, fog sealing, slurry sealing, chip sealing and microsurfacing.

The roles and responsibilities of contractors, suppliers, agencies and consultants for quality management are reviewed within the context of current Canadian agency specification practices and flexible pavement material and construction quality assurance attributes. Some documents from the United States such as National Cooperative Highway Research Program's documents were reviewed as well. Most Canadian agencies have adopted, or are implementing, end result specifications with quality control/quality assurance and with several enroute to performance-related specification for flexible pavement materials and construction quality. Quality management concepts are then introduced with focus on quality management systems in terms of responsibilities, requirements, contractor process and quality control and agency quality assurance, including statistical process control. This provides the basis for a detailed review of the quality management approach and practices of Canadian agencies for flexible pavement materials and construction, with attributes, specifications, inspection and testing trends identified for the subgrade, granular subbase, granular base and hot-mix asphalt. This review provides a basis for agencies to select those attributes and specification requirements appropriate to their specific experience and projects.

A major component of this document is the detailed quality management for the flexible pavement materials and construction as follows:

1. Design considerations;
2. Flexible pavement materials: granular subbase/base; hot-mix asphalt aggregates and asphalt cements (typical performance graded asphalt cements); and miscellaneous materials such as reclaimed asphalt pavement, tack coat, fillers, fibres and polymer modified asphalt cements;
3. Subgrade preparation;
4. Placement and compaction of granular subbase and base;
5. Hot-mix asphalt production and transportation, including environmental control; and
6. Hot-mix asphalt paving and compaction: trial section, substrate preparation, tack coats, material transfer devices, joint construction and working with polymer modified asphalts.

The quality control and quality assurance sampling, testing and inspection associated with each of these materials and methods are summarized in terms of technician and testing equipment/laboratory requirements to monitor compliance with flexible pavement project quality requirements.

Recommendations for a quality management systems template for a flexible pavement project, based on the contractor's quality control plan and agency's quality assurance plan, are provided. This template is, however, subject to the specific requirements of an agency for the project's flexible pavement materials and construction.

The importance of contractor's and agency's commitment to quality, and teamwork, at all stages of flexible pavement materials and construction methods, for enhanced life-cycle costs and performance, is emphasized throughout.

SOMMAIRE

Le but de la présente *Synthèse des pratiques de gestion de la qualité des matériaux souples de revêtement et de construction de chaussées au Canada* était d'étudier, d'évaluer et de préparer une synthèse des meilleures pratiques de gestion de la qualité desdits matériaux, des méthodes de production de ces derniers et des techniques de construction des chaussées souples ainsi que de préparer des recommandations pour l'élaboration d'un système de gestion de la qualité fondé sur la qualité des entrepreneurs ainsi que sur les pratiques d'assurance de la qualité des administrations. Les matériaux souples de construction de chaussées qui ont été étudiés pour les fins de cette synthèse s'entendent des matériaux des sous-fondations, des sous-fondations granulaires, des fondations granulaires et des enrobés bitumineux à chaud. Les contrôles de la qualité, l'assurance de la qualité et le système de gestion de la qualité dont il est ici question peuvent en outre englober sans difficulté des techniques complémentaires de réfection et d'entretien, par exemple le recyclage sur place (recyclage sur place à froid, la valorisation en profondeur des déchets et le recyclage sur place à chaud), le colmatage des fissures, l'application d'un scellant bitumineux, l'application d'un coulis bitumineux, l'application d'un enduit superficiel et le microsurfaçage.

Les rôles et les responsabilités des entrepreneurs, des fournisseurs, des administrations et des consultants en matière de gestion de la qualité sont examinés dans le contexte des spécifications des pratiques courantes qu'appliquent les organisations canadiennes de même que des règles d'assurance de la qualité des travaux de revêtement et de construction des chaussées souples. Des documents provenant des États-Unis, notamment du Programme national coopératif de recherches routières, ont également été consultés. La plupart des organisations canadiennes ont adopté ou appliquent des spécifications finales assorties de mesures de contrôle/d'assurance de la qualité, y compris l'application en cours d'exécution de plusieurs spécifications de rendement et de qualité concernant les matériaux pour chaussées souples et la construction de ces dernières. Les notions de gestion de la qualité sont ensuite analysées dans ladite synthèse, notamment en ce qui a trait au système de gestion de la qualité et aux questions connexes de responsabilités, d'exigences, de processus d'adjudication de contrat aux entrepreneurs, au contrôle de la qualité et à l'assurance de la qualité appliquée par les organisations, incluant le contrôle statistique des processus. Tous ces éléments fournissent les bases nécessaires à un examen détaillé des pratiques de gestion de la qualité et des méthodes appliquées par les organisations canadiennes à plusieurs égards : revêtement et construction de chaussées souples, attributs, spécifications, inspection et tendance des techniques d'essai concernant les sous-fondations, les fondations granulaires, les bases granulaires et l'application d'enrobés bitumineux à chaud. L'examen contenu dans la présente synthèse fournit des éléments d'information de base dont les organisations pourront s'inspirer pour définir leurs besoins en attributs et spécifications adaptés à leurs expériences et projets spécifiques.

Un important volet de la synthèse est l'analyse détaillée des questions de gestion de la qualité en contexte de revêtement et de construction de chaussées au moyen de matériaux souples, à savoir :

1. considérations conceptuelles,
2. matériaux souples de construction de chaussées : sous-fondation/fondation granulaire, enrobés bitumineux à chaud et bétons bitumineux (rendement type calculé en fonction des bétons bitumineux), divers matériaux tels les chaussées bitumineuses recyclées, couche

d'enduit d'adhérence, produit de remplissage, fibres et bétons bitumineux modifiés au moyen de polymères,

3. préparation de la sous-fondation,
4. pose et compactage de la sous-fondation et de la fondation granulaire,
5. production et transport des enrobés bitumineux à chaud, y compris le contrôle de l'environnement, et
6. pose et compactage des enrobés bitumineux à chaud : section d'essai, préparation du substrat, couches d'adhérence, dispositifs des transferts de matériaux, construction au moyen de bitumes modifiés par l'ajout de polymères.

Le contrôle et l'assurance de la qualité, les essais et les inspections associés à chacun des matériaux précités et des méthodes connexes sont résumés dans la synthèse au regard de plusieurs paramètres : besoins en techniciens, besoins en matériel d'essai/de laboratoire, le tout dans le but de s'assurer du respect des exigences de qualité des projets de revêtement de chaussées souples.

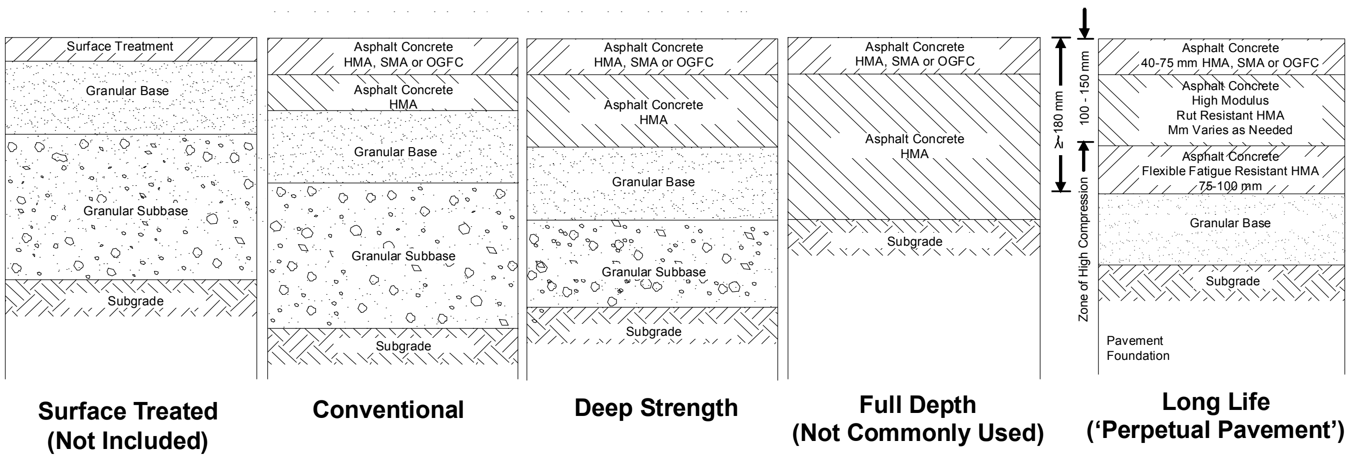
Des recommandations visant les systèmes de gestion de la qualité pour un projet de construction d'une chaussée souple, recommandations fondées sur un plan de contrôle de la qualité de l'entrepreneur et un plan d'assurance de la qualité d'une organisation sont également énoncées. La liste des recommandations ici visées est néanmoins assujettie aux exigences spécifiques d'une organisation au regard des matériaux souples de revêtement et de construction d'une chaussée.

Tout au long du document, plusieurs aspects importants sont soulignés : engagement de l'entrepreneur et de l'organisation en matière de qualité, incluant leurs équipes respectives, et ce à toutes les étapes des processus de revêtement et de construction de chaussées souples, le tout par souci d'améliorer les coûts associés à la durée de vie utile des chaussées et à leur rendement.

1 INTRODUCTION

1.1 Background

The purpose of this document is to review, evaluate and synthesize Canadian best practices for the quality management of the production and placement of materials for flexible pavement construction, maintenance and rehabilitation. These materials, prepared subgrade, granular subbase, granular base and hot-mix asphalt as well as the flexible pavement types considered are shown in Figure 1.



Notes:
1. Schematics, not to scale.
2. The subgrade can be improved material such as cement modified or lime treated.
3. The granular subbase/base (GSB/GB) can be other combinations of GSB, GB, treated granular base (TGB-lime, cement, emulsion, foamed asphalt or combinations), processed reclaimed material (reclaimed asphalt concrete and reclaimed concrete including blended), lean concrete base (LCB) and/or open graded drainage layer (OGDL-crushed aggregate, cement treated or asphalt cement treated).

Figure 1 – Flexible Pavement Types

The quality of the materials and construction directly influences the life-cycle performance and cost of pavements, levels of service (smoothness and safety for instance) and user costs. This quality imperative is shown quite clearly in Table 1 in terms of the quality levels for hot-mix asphalt compaction, thickness, and smoothness achieved, and resulting impacts on flexible pavement performance in terms of functional service life (adapted from Weed, 2001)[a]. Photographs 1 through 5 in Appendix B also illustrate the typical asphalt concrete performance deficiencies that result from poor construction quality and provide practical confirmation of the quality imperative.

With increasing traffic volumes and truck loadings, limited capital and maintenance funding, and pavement networks in need of maintenance and improvement, it is critical that enhanced materials and construction quality levels are achieved. This has resulted in an agency emphasis on overall quality management (QM)[b] for pavement materials and construction quality assurance(QA) with contractors (including suppliers and subcontractors) required to take

[a] A list of references is provided at the back.
[b] Definitions, acronyms and abbreviations are provided in Appendix A.

increasing responsibility for quality control (QC) to achieve project quality requirements. This in turn requires contractors to develop their own quality control capabilities, with appropriate inspection, sampling and testing, and technically qualified staff, to meet the quality imperative. The synthesis provides agencies and contractors with the key quality management considerations for flexible pavement materials and construction, and outlines of appropriate contractor pavement materials and construction quality control plans as well as generic quality management systems.

Table1 – Importance of Materials and Construction Quality to the Performance of a HMA Pavement (Adapted from Weed, 2001)

INTUITIVE MODEL FOR COMPACTION, THICKNESS: AND SMOOTHNESS OF HMA PAVEMENT			
Quality Levels		Functional Service Life Impact	
poor in any one characteristic		some loss	
poor in any two characteristics		greater loss	
poor in all three characteristics		substantial loss	
PAVEMENT PERFORMANCE SURVEY RESULTS			
Initial Quality Levels			Functional Service Life
Smoothness	Compaction	Thickness	Years
Good	Good	Good	20.0[a]
Good	Good	Poor	15.0
Good	Poor	Good	11.6
Good	Poor	Poor	8.7
Poor	Good	Good	16.1
Poor	Good	Poor	11.9
Poor	Poor	Good	9.3
Poor	Poor	Poor	6.8
a – given as a reference point.			

1.2 Scope and Objectives

The synthesis objectives include the examination of the roles and responsibilities of the stakeholders (agency, contractor, consultant, etc.) for quality management, and encompass both quality control and quality assurance. The recommendations derived from this synthesis can be used subsequently to develop a contractor quality management template for use by agencies and contractors involved in the production and placement of paving materials.

1.3 Approach, Methodology and Organization

Quality management as it applies to the production and placement of paving materials covers the procedures, processes and methods adopted by the agency and contractor (including suppliers and subcontractors) to achieve the desired quality of pavement. The interacting relationships and responsibilities for quality are generally defined by project specifications and achieved by implementation of contractor quality control systems in conjunction with agency quality assurance verification and acceptance at appropriate points in the production and placement process. As there is sometimes confusion with the general concepts of quality assurance and quality control, and QC/QA interaction, the key points of QA versus QC are given in Table 2 for use throughout this document.

Table 2 – Quality Assurance (QA) Versus Quality Control (QC)
(Adapted from TRB, 2005a)

Quality Assurance	Quality Control
Making sure the quality of a product is what it should be. An agency responsibility. Includes QC. Doing the right things. Motivates good QC practices.	Making the quality of a product what it should be. A contractor (including suppliers and subcontractors) responsibility. A part of QA. Doing things right. Motivated by QA and acceptance procedures.
Means a system or series of activities carried out by the agency to ensure that the materials and construction received from the contractor (including suppliers and subcontractors) meet the requirements specified in the contract documents.	Means a system or series of activities carried out by the contractor (including suppliers and subcontractors) to ensure that the materials and construction supplied to the agency meet the requirements specified in the contract documents.

It is important to recognize that different types of highway materials and construction specifications are in use across Canada (North America), and the quality management functions vary accordingly. With materials and methods specifications (prescriptive specifications), contractors are generally instructed on what to use, what to do and how to do it, with quality control responsibilities essentially assumed by the agency. Under the common QC/QA statistical quality assurance (SQA) end result specifications (ERS) approach, QC responsibility is clearly with the contractor and QA responsibility with the agency to verify the quality achieved by the contractor. The key aspect of an ERS is giving overall responsibility for quality to those best able to control the material and construction processes involved – contractor, suppliers and subcontractors. Consequently, quality management for the production and placement of flexible paving materials places emphasis on the processes used by construction material producers (suppliers) and the contractors (including subcontractors) placing these materials. This QM typically includes the QC steps taken to ensure that the materials production and construction equipment is operated properly, and appropriate inspection, sampling and testing is completed to monitor the processes (including process control charts), with qualified testing and inspection staff (preferably certified) and certified laboratories involved throughout.

Quality assurance inspection and testing is the agency's required component of the quality management. This QA involves sufficient inspection and testing (auditing), typically including the QC results (process control data for instance) to verify specification requirements are being met.

The current agency quality management practices for flexible pavement materials and construction vary widely across Canada, ranging from materials and methods (prescriptive specifications) to mainly QC/QA based end result specifications (ERS), with some agencies enroute to performance specifications (e.g. long-term warranties).

The requirements for quality control (QC) also vary greatly across Canada given the range in specification types for flexible pavement materials and construction. Since the mid 90s, the Ministère du transport de Québec (MTQ) has required all highway materials suppliers and paving contractors have ISO 9002 registration. In contrast, there are still agencies that do not require contractor or supplier quality plans or QC, hence relying on agency inspection and testing for quality control. Since 1998, the Ontario Ministry of Transportation (MTO) has required comprehensive contractor core quality plans covering all materials production and construction, with project-specific amendments submitted to reflect specific project, supplier and subcontractor requirements. QA inspection and testing is then completed by the MTO (contract administrator) to verify the contractor's QC. In some cases, the contractor's QC test results are used for acceptance purposes, including payment adjustments.

Some agencies have also introduced performance limits, both on construction completion for acceptance and during operations, to define minimum levels of service (performance) for criteria such as smoothness, rutting and surface frictional properties. These performance specification approaches for pavement quality are an important component of an agency's quality assurance for long-term warranty and design-build-operate projects for instance.

With this very broad range of quality management for flexible pavement materials and construction practices, it was necessary for this Synthesis to determine the range of practices that are currently used by federal, provincial, and municipal agencies, and the road building industry across Canada. These Canadian QM practices were also reviewed within the broader context of North American experience. The recent National Cooperative Highway Research Program (NCHRP) Synthesis 346, *State Construction Quality Assurance Programs* (NCHRP, 2005) and NCHRP 447 *Testing and Inspection Levels for Hot-Mix Asphaltic Concrete Overlays* (NCHRP, 2001a) that included five Canadian Provinces (Manitoba, Newfoundland, Nova Scotia, Ontario and Québec), were particularly helpful.

Overall quality management is a significant component of transportation infrastructure projects developed under various design-build-finance-operate-transfer mechanisms and public-private partnerships (P3s), especially where the project involves an extended concession period, typically 25 to 30 years. In these projects, the design-build team, the operations and maintenance team, the concessionaire and the agency all have an interest in ensuring that the highest overall quality is achieved at all stages of the project, including at hand-back. Consequently, for this synthesis, it was important to obtain and review the quality management practices that have been, or are being, adopted for various design-build type projects for comparison with traditional contracting practices.

A literature review, together with technical experience, was used to supplement direct contact with agencies, contractors and materials suppliers. This included reviewing quality management systems that have been developed by the paving industry such as the National Asphalt Pavement Association (NAPA), Asphalt Institute (AI), Bitume Québec (BQ) and the Ontario Hot Mix Producers Association (OHMPA), some agencies and design-build contractors.

The Synthesis provides information on the elements of quality management systems for flexible paving materials and construction. It covers the quality roles, responsibilities and interaction of agencies and contractors (including suppliers and subcontractors). The Synthesis addresses QC requirements at each key stage of the production process for flexible paving materials (granular subbase, granular base and hot-mix asphalt) and pavement construction (including subgrade preparation). The complementary role of QA inspection and testing, to verify supplier and contractor QC results and for acceptance purposes is outlined in detail. The Synthesis of quality management practices also forms a basis for recommended quality control plans and a future quality management system template.

2 SPECIFICATIONS AND QUALITY MANAGEMENT CONCEPTS

2.1 Specifications

The selection of an appropriate specification type, and associated quality management approach, for flexible pavement materials and construction requires an understanding of the applicability, advantages and limitations of each available specification type. This is a rather complex and lengthy task as indicated in Figure 2 for end result specifications, method specifications, designated source lists and warranty (performance) specifications. For this reason, the development of specifications for highway materials and construction tends to be evolutionary (Weed, 2005). From a broad perspective, the specification should be: incentive based for good quality; and disincentive based for poor quality (Weed, 2001). It is important to note that while a specification type may have the potential to yield higher quality (end result where there is an incentive through pay adjustment versus method, for example), the quality levels required/ specified by the agency are what ultimately govern (Kopac, 2005).

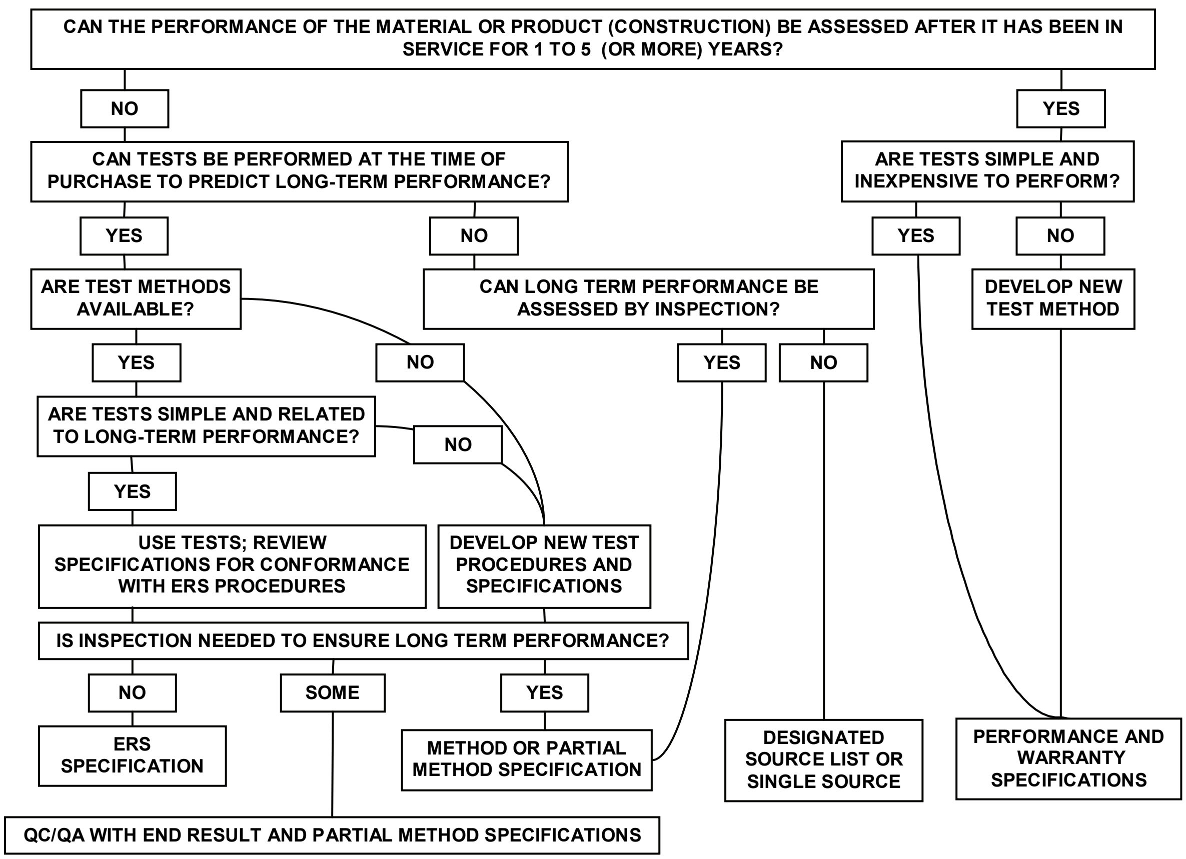


Figure 2 – Flow Chart for the Selection of an Appropriate Specification Type for a Material or Product

2.1.1 Method Specifications

Method specifications (also called materials and method or 'recipe specifications') are prescriptive specifications based on engineering judgment (TRB, 2005a). Contractors (including material suppliers and subcontractors) are generally instructed what to do and how to do it (materials and procedures), with minimal or no quality levels generally specified. The quality control responsibilities are essentially assumed by the agency as part of overall quality assurance and acceptance. The contractor's[c] responsibility is essentially to follow the specified procedure with little or no incentive for enhanced quality, technology improvement or innovation. Experience has shown that this tends to require the agency to accept the completed work regardless of the quality achieved. Materials and method specifications, typically in association with designated source lists and often as part of end result specifications, are still necessary for materials and construction activities that require inspection to ensure desired performance, as shown in Figure 2.

2.1.2 Designated Sources for Materials

There are highway construction materials, products and components that have inspection and testing requirements that preclude work site acceptance, and generally require prequalification by the agency (e.g. asphalt binders and liquid antistripping additives). This is typically handled through designated source lists that: have been developed specifically for the project; are agency standards (MTO[d], *Designated Sources for Materials Manual* (MTO, 2006b)); or are provincial standards (OPSS, *Product Management Committee*, and OGRA, *Road Authority* for instance). The NCHRP Synthesis 346, *State Product Evaluation Programs* (NCHRP, 2004b), which includes Canadian experience, provides considerable information on evaluation processes for designated sources.

2.1.3 End Result Specifications

End result specifications (ERS), based on measurable properties of the work involved and statistical quality assurance (SQA), place direct responsibility on the contractor for the quality of materials and construction involved (AASHTO, 2003; TRB 2005a). They describe the requirements for the completed work and typically have payment adjustment incentives ('penalty/bonus') for contractors to improve quality, adopt new technology and innovate. The contractor develops a QC system of inspection, sampling, testing and process monitoring in order to control the operations and monitor the quality achieved. End result specifications also require the agency to develop a QA and acceptance system involving inspection, sampling, testing, payment adjustment (factors) retesting and referee protocols. Some agencies such as MTO now use the contractor's QC testing as part of their acceptance, including payment factors (NCHRP, 2005a; MTO, 2006a; OPSS, 2006).

The major limitation of end result specifications is the general lack of direct relationship between tested properties and long-term performance. Detailed technical guidance on the development of an SQA based ERS, including advantages and disadvantages, are given in AASHTO Designation: R9-97, *Standard Recommended Practice for Acceptance Plans for Highway Construction*

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[c] The contractor is considered to include material suppliers and subcontractors throughout.

[d] A list of acronyms for agencies and associations, with sites, is provided in Appendix A.

(AASHTO, 2005a) and in *Optimal Procedures for Quality Assurance Specifications* (Burati et al, 2003). The Federal Highway Administration maintains a site, www.specs.fhwa.dot.gov, with FHWA standard specifications and US state specifications that can be used for practical flexible pavement materials and construction ERS information.

2.1.4 Performance Specifications

There is considerable current activity with the development of pavement construction, rehabilitation and maintenance performance specifications that define quality requirements on the basis of short and long-term performance characteristics (NCHRP, 1995; NCHRP, 2004a; Weed, 2005). Examples of performance characteristics for flexible pavements include rutting, smoothness, frictional characteristics and tire-pavement interaction noise (urban routes). The key to implementing performance specifications is the development of practical test methods to measure as-constructed quality characteristics directly affecting long-term pavement performance. It should be noted that performance specifications address the major limitation of end result specifications – a general lack of direct relationship between tested properties during construction and long-term performance.

Performance specifications for flexible pavements are becoming increasingly important with the North American highway contracting trend to more warranties, maintenance contracts, term contracts, design build projects and public private partnering (NCHRP, 2005; Dunn, 1997; Gransberg, 2004; NCHRP, 2004a; Richter, 2004; Bradford, 2005; Weed 2005; TRB, 2006). Some of the key factors to consider when applying performance specifications to projects include:

- Description of work required;
- Warranty length, performance indicators and thresholds;
- Bond requirements;
- Contractor responsibilities and agency responsibilities, particularly with respect to project elements with potential risk;
- Methods of monitoring performance;
- Basis of payment;
- Corrective actions, maintenance period and procedures for emergency situations; and
- Conflict resolution procedures.

Pavement performance specifications should be established in such a way that user costs, safety, and the preservation of the asset value are considered. These issues include:

- User costs: ride quality and delays;
- Safety considerations: rutting and frictional resistance;
- Asset value: surface distresses (potholes and cracking) and load carrying capacity.

New projects, reconstruction or major rehabilitation requiring durable, long-term interventions are candidates for full warranty performance specifications. However, for certain rehabilitation projects where contractors cannot modify the existing pavement structure, warranties should be limited to specific characteristics or material properties.

Contractors must have construction control of the work attributes that affect performance, and performance criteria should be measurable, quantifiable, and not cover deficiencies that are unrelated to the required work.

There are two types of performance specifications: performance based and performance related.

2.1.4.1 Performance-Based Specifications

Performance-based specifications describe the desired levels of fundamental engineering properties (e.g. resilient modulus, creep properties and fatigue properties of asphalt concrete) that are predictors of performance and appear in primary performance prediction relationships. Performance-based specifications for flexible pavement construction are still at the development stage (NCHRP, 2004a).

2.1.4.2 Performance-Related Specifications

Performance-related specifications describe desired level of materials and characteristic factors that have been found to correlate with fundamental engineering properties that predict performance. These factors are amenable to control and acceptance testing at the time of construction. Examples of these characteristic factors are segregation, ride quality, mat density, longitudinal joint density and mat permeability. Performance-related specifications are at the implementation and improvement stage (NCHRP, 2006).

2.1.5 Specification Selection for Flexible Pavement Materials and Construction Quality

While the selection and development of any Canadian agency's specification for asphalt pavements will probably reflect North American trends, it is still very important to consider the type in terms of responsibility for quality, level of inspection and testing required, and relationship to performance, as indicated in Figure 3 adapted from TRB, 2005a. There is an overlap in this: an end result specification for responsibility may be a statistical specification for testing and intuitive specification with respect to performance. The current, developing, and future trend in specification types, based on practical experience, technical literature, and the questionnaire responses for this Synthesis, are also shown on Figure 3. It is clear that QC/QA based specifications (quality assurance specifications) combining mainly an end result specification with some method (inspection) requirements, are the trend, enroute to performance specifications with performance-related being currently implemented (AASHTO, 1996a; AASHTO, 1996b; AASHTO, 2003; MTO, 2004). The pressure to implement performance specifications will continue with the growth in warranty use and new methods of contracting such as the Sea to Sky Highway in British Columbia and the Anthony Henday Drive in Alberta.

2.2 Quality Management

Total quality management (TQM) is a management philosophy that seeks continuous improvement in all business activities of an organization. TQM requires a solid customer focus, a preventive proactive approach to the attainment of quality, an understanding of process related variation, decisions based on measurement, and the commitment of all employees at all levels of the organization. A TQM approach to the achievement of quality flexible pavement materials and construction was initiated in NAPA's 1995 *Guide for Getting Started with Total Quality*

Management (TQM), (NAPA, 1995). The key component of a TQM for construction is a quality management system and quality control plans.

2.2.1 Quality Management Systems

Specifications with reasonable tolerances applied are necessary to define the quality desired by the agency (contractor's client). Quality systems are the procedures and processes applied by the contractor to achieve this desired quality. Quite simply, specifications and tolerances focus on the target, while quality systems focus on increasing the likelihood of hitting this target. A quality system should:

- Document processes and procedures (say what you do);
- Implement processes and procedures (do what you say); and
- Record performance of processes and procedures to provide evidence that the required results have been delivered (prove what you did).

The implementation of a quality management system takes time as it must be developed incrementally. In addition, quality management systems have to be supported by management at all levels with responsibilities, authority, procedures and resources determined on a consistent basis throughout the system. Roles and responsibilities have to be defined separately for contractors and clients with a total commitment from everyone involved. All processes in the system must be controlled with priority placed on those that affect performance.

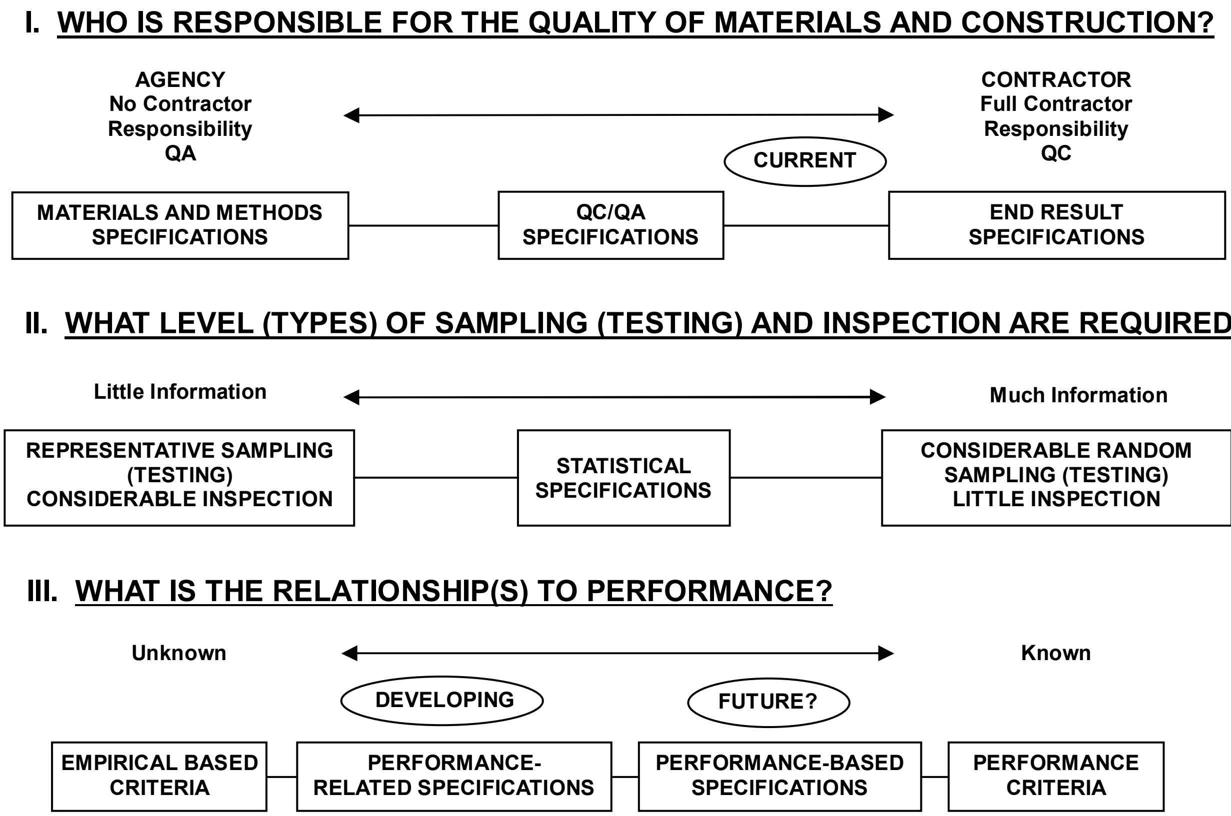

Figure 3 – Classifying Highway Construction Specifications According to: Who is Responsible for the Quality of Materials and Construction; the Levels (Types) of Sampling (Testing) and Inspection Required; and the Relationship(s) Between Quality Criteria and Constructed Facility Performance (TRB, 2005a).

A common management concern is the cost involved with the development and implementation of an agency or company quality management system. There may be an initial increase in the total cost of quality as shown in Figure 4 adopted from Dobb, 1996 due to requiring staff to follow procedures and participate in quality training. However, practical experience indicates a significant reduction in the total cost of quality (costs off the bottom line) when an effective, efficient and economical quality management system is in full use.

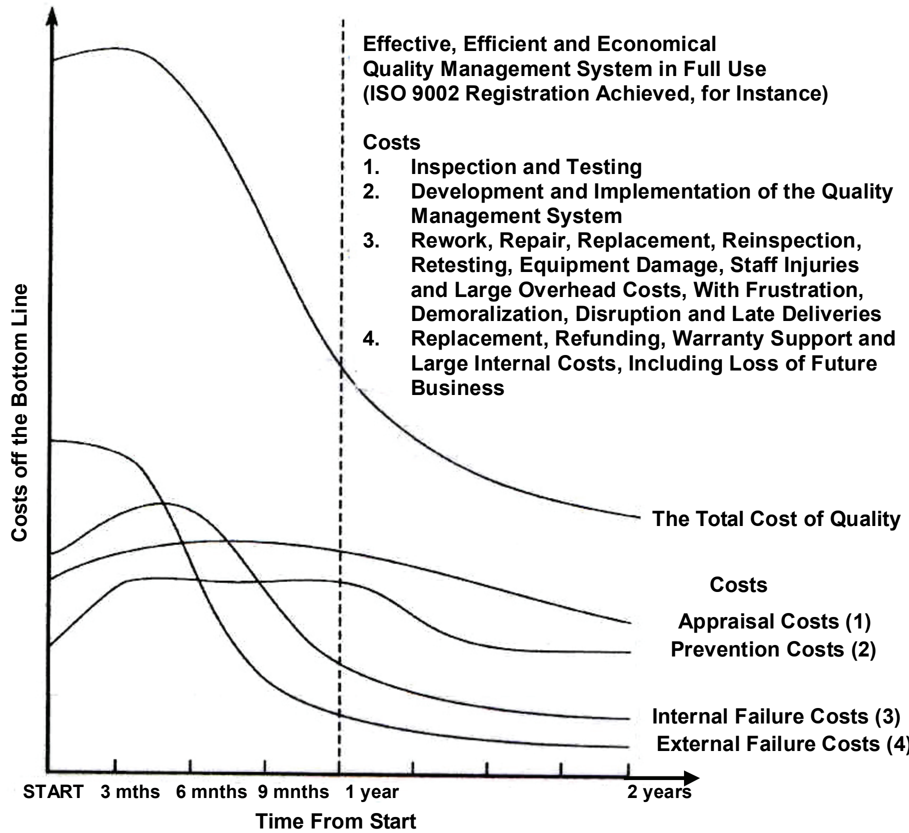

Figure 4 The Costs of Quality and Potential Savings with a Quality Management System (Dobb, 1996)

2.2.2 Quality Plans

A quality plan defines how the supplier[e] plans to provide products[f] that meet the client's[g] quality expectations and the supplier's quality standards, thus eliminating the potential for unsatisfactory product or service performance. The process or methods, as well as the activities to control and verify the specific products and services provided comply with relevant quality standards, are normally specified in a quality plan. It is the lowest documentation level (out of four) that has been established to ensure control of a quality management system conforming to ISO 9000 (Dobb, 1996; ISO, 2000).

2.2.3 Quality Manuals

A quality manual based on the ISO 9000 system typically includes a quality policy, reference to quality objectives, organization structure and elements of the quality management system, as well

[e,f,g] For this Synthesis and quality management systems, the terms ‘supplier’ and ‘products’ mean contractors, suppliers and subcontractors, and materials and construction, respectively. The term ‘client’ means owners and agencies.

as the scope and methods for maintaining the quality management system. To ensure that the current and relevant version of the quality manual and attachments are used, the document has to be controlled. The outline content of a typical generic quality management system manual that is ISO 9001:2000 compliant is given in Table 3.

Table 3 – Contents of a Typical Generic Quality Management System (QMS) Manual that is ISO (ISO 9001:2000) Compliant
(Note: The full table of Contents if given in Appendix G, with an associated typical project specific construction quality plan (matrix) for flexible pavement construction in Appendix H)

QMS CONTENT
Introduction Scope Normative References Terms and Definitions Quality Management System Requirements Management Responsibility Resource Management Product and/or Service Realization Measurement, Analysis and Improvement
APPENDICES FOR SPECIFIC SITE AND/OR PROJECT DESIGN, DEVELOPMENT, PRODUCTION, INSTALLATION AND SERVICES
Contract Requirements Organization Chart System Level Procedures Quality Procedures Quality Plans Work Instructions

2.2.4 ISO 9001:2000

ISO 9001:2000 is a most comprehensive, yet straightforward, international standard for a quality management system that applies to all types of organizations to help them achieve standards of quality by establishing a business management system, evaluating the system performance and providing ongoing improvement. It is focused on enabling organizations to become more responsive to changes, to improve its internal communications and ultimately to provide high quality services that consistently meets customer satisfaction. The key components of the ISO 9001:2000 system are discussed in the following sections.

2.2.4.1 Quality Management System Requirements

In order to ensure that products conform to the requirements of clients, it is essential for an organization to establish a quality management system (QMS), meeting the requirements of ISO 9001:2000, for instance, that will be implemented, maintained and improved as necessary. To ensure the effectiveness of the QMS, a quality policy should be developed and implemented, to enable the organization to achieve its quality objectives and ensure the products conform to the client requirements. In addition, the documentation needs to be maintained to ensure conformity of the organization’s products and services to the specified requirements of a specific contract (see list of appendices in Table 3). The control of quality documents required for the operation, management, maintenance and rehabilitation of the control work, and records established and maintained to provide evidence of conformity to organization, client and/or contract requirements, as well as overall QMS requirements, should be established.

2.2.4.2 Management Responsibility

To achieve continual improvement of the QMS, management of the organization must be committed to carrying out the quality planning, process control, inspection and testing status, and continuous quality improvement. The client's needs and expectations should be determined and converted into requirements with the aim of achieving confidence of clients through the quality planning procedures. The clients' requirements must be fully understood and met to provide satisfactory services. A quality policy that serves the organization's purpose, facilitates the development of quality objectives and commits to continuous improvement should be established and communicated to the organization's employees and suppliers who are directly involved in the completion of the work. Quality planning, through quality objective formulation, should be performed, and the control of the quality system should be established by defining the responsibilities and authorities of personnel, appointment of management representatives, and developing and maintaining procedures for internal communication between various levels within the organization. Management review of the QMS at planned intervals should be completed by qualified personnel to ensure its continuing suitability and effectiveness in satisfying the requirements of ISO 9001:2000 and the organization's stated quality policy and objectives. Records of these reviews are maintained with corrective actions generated upon identification of non-compliance.

2.2.4.3 Resource Requirements

Resource requirements for the continual improvement of the organization's QMS are reviewed during the management review process. In addition, the resources necessary for the completion of assigned tasks, including communication and liaison with other functions, purchased and subcontracted products and other services, and selection and training of employees should be identified. Competent and trained personnel for management, performance of work and verification activities, as required to fulfill any contractual requirements, are provided. The organization should identify all personnel performing activities affecting quality and ensure training is provided. These personnel must be aware of the relevance and importance of their activities and what their impact is for the achievement of the organization's quality objectives. The infrastructure required to achieve conformity of contract work should be defined, provided and maintained. Finally, adequate and safe facilities should be maintained to ensure that the work environment is conducive to achieving conformity of the contract work.

2.2.4.4 Product and Service Realization

The processes required to realize the successful completion of contract work must be determined, planned and implemented, considering the outputs from quality planning. The requirements of clients are delineated in contract agreements and reviewed by the specified personnel in the organization. Effective organizational and technical interfaces between the organization and its clients should be provided. Controlled product development can be achieved by design planning, defining design inputs, generating design outputs, carrying out design reviews, performing design verifications, conducting design validations and managing design changes. Purchasing and operational activities should be controlled to ensure quality products and services are purchased, and that the production and servicing processes which directly affect quality are carried out under controlled conditions. Inspection, measuring and test equipment used to assess, control quality or gather data must be capable of the required precision and accuracy. Test equipment or measuring devices should be validated based on the established frequency to ensure required precisions are met.

2.2.4.5 Measurement, Analysis and Improvement

The measurement, monitoring, analysis and improvement process should be defined, planned and implemented by the organization to ensure that the QMS, process, and products and services conform to requirements. The effectiveness of measures implemented must be periodically evaluated. In order to identify areas for improvement of the overall efficiency and effectiveness of the QMS, regular internal audits should be performed to identify deficiencies, as well as to verify the conformance to contract requirements. Suppliers, together with the organization, are both responsible for identifying, controlling and correcting all nonconforming work within their control and for recording the disposition and correction of nonconformance. Records of nonconforming products should be maintained. Procedures for the determination of the effectiveness of the QMS should be documented and retained, so that information pertaining to the QMS can be analyzed. The organization should commit to continuous improvement of the QMS by taking both corrective and preventive actions.

2.2.4.6 ISO/IEC 17025 General Requirements for the Competence of Calibration and Testing Laboratories

This ISO/IEC 17025 standard was designed for use by laboratories to develop their management system for quality, administrative and technical operations. Laboratory customers, regulatory authorities and accreditation bodies may also use it in confirming or recognizing the competence of laboratories.

ISO/IEC 17025:1999 was recently amended to align itself with ISO 9001 and incorporates improved requirements for management systems, continuous improvement and enhanced internal communication to ensure compatibility between the two standards. The growth in the use of management systems generally has increased the need to ensure that laboratories, which form a part of larger organizations or offer other services, can operate to a quality management system that is seen as compliant with ISO 9001 as well as ISO/IEC 17025. The amendment clarifies that meeting the requirements of ISO/IEC 17025 does not mean that all ISO 9001:2000 requirements are met, however care has been taken to incorporate those requirements of ISO 9001 that are relevant to testing and calibration services.

2.3 Quality Responsibilities

The quality activities and responsibilities are generally defined in terms of quality control (QC), quality assurance (QA) and independent third-party verification (referee testing) as follows:

2.3.1 Quality Control (QC)

Quality control (process control) is generally defined as the actions and considerations necessary to assess production and construction processes, so as to control the level of quality being produced in the end product. This concept of quality control (QC) includes sampling and testing to monitor the process, but usually does not include acceptance sampling and testing.

2.3.2 Quality Assurance (QA)

Quality assurance is generally defined as all those planned and systematic activities necessary to provide adequate confidence that a product or service satisfies the owner's requirements for quality.

2.3.3 Independent Third-Party Quality Verification

Independent third-party verification (referee testing) is generally completed by an independent laboratory, selected by the owner and acceptable to the contractor in order to resolve differences behind QC and QA testing results.

2.4 Statistical Process Control

Statistical process control is based on the use of quality control charts and process adjustments based on trends in the process control test data.

2.4.1 Control Charts

A quality control chart is a graph of all the test values plotted in the order of sampling and testing that allows the viewing of the process in a glance. By showing the process test data and variability for consecutive test results, the charts draw attention to changes or trends in the process which may require corrective action before non-compliances occur. Charts are usually constructed using an electronic spreadsheet.

2.4.2 Types of Control Charts

There are three main types of quality control charts: process condition, moving averages, and moving range charts. These are described in detail in the Appendix D Guidelines for Quality Control Charts.

2.4.3 Management and Administration of Quality Data

Project specifications typically define the procedures for evaluating compliance with the specifications and the use of a continuous lot for the evaluation process has proven successful. Under this concept, the producer and the owner will know at all times if the material is acceptable.

Adjustments are made to the process based on process control test data, to ensure compliance with the specifications. The quality control technician is responsible for making the appropriate adjustment at the proper time. The process control charts form the basis for when to change the process and for the changes to be made. Analysis of the process control data will typically indicate several options to change the process as necessary to meet the specification requirements.

2.5 Quality Management for Small Projects

The quality achieved for a small flexible pavement construction project is just as important as for a large project. However, the scope and cost of QA must be commensurate with the risk of poor quality and its cost impact to the owner.

For small projects, it may be possible to minimize sampling and testing by relying on results from larger projects using the same materials and underway at the same time. For materials such as asphalt cement and tack coat, reliance on supplier QC reports is usually adequate. The project specifications could also require the supplier to sample and test a specific load(s) delivered to the project for QC, with a split sample retained for QA testing if necessary.

For small projects, it is typical to have a contract administrator (agency or consultant on behalf of owner) taking responsibility for QA inspection (subgrade preparation for example) and some QA representative sampling (testing) of materials (granular subbase/base and hot-mix asphalt) and compaction testing to check conformance with the specifications (e.g. am and pm samples). It is also possible to have a two or three year warranty for small projects, rather than the typical one year involved with large projects.

3 REVIEW OF QUALITY MANAGEMENT PRACTICES FOR FLEXIBLE PAVEMENT MATERIALS AND CONSTRUCTION

3.1 Summary of Canadian Survey

The survey of quality management practices consisted of 25 questions with full responses received from all provinces, one territory and five municipalities. The April 2005 survey questionnaire and detailed responses in matrix format are given in Appendix C. The responses are summarized and discussed in the following sections.

3.1.1 Types of Specifications

Eighty percent of the respondents indicated that they use their own agency specifications for pavements construction, either exclusively, or in combination with provincial standard specifications and others such as federal specifications. For hot-mix asphalt, 60 percent of the respondents indicated that they still use method specifications, either exclusively (35 percent) or in combination with other types including end result and performance. For granular materials, 65 percent of the respondents indicated that they use method specifications, either exclusively (50 percent) or in combination with other types including end result and performance. Federal agencies generally use the National Master Specifications (NMS) which are managed by Public Works and Government Services Canada.

Fifty percent of the respondents indicated that they use end result specifications for HMA, either exclusively (25 percent) or in combination with other types including method and performance. For granular materials, 40 percent of the respondents (eight agencies) indicated that they use end result specifications, either exclusively (20 percent) or in combination with other types including method and performance. Sixty percent of the respondents indicated some specific problems that have been encountered with end result specifications, including differences between QC, QA and referee testing for hot-mix asphalt, segregation assessment, acceptable limits of asphalt cement content, specifications interpretation, contract administration and procedures to be followed with rejectable materials.

Twenty-five percent of the respondents indicated that they use performance specifications for HMA, either exclusively (one agency) or in combination with other types including method and performance. For granular materials, 15 percent of the respondents indicated that they use performance specifications, either exclusively (one agency) or in combination with other types including method and performance.

In a January 2006 follow-up survey, only two provincial agencies (Ontario and New Brunswick) indicated that their Superpave implementation is complete. Province of Quebec indicated that their Superpave (modified for enhanced durability) implementation is in progress. Alberta indicated that no further Superpave mix projects have been completed since 2002 and that the mix performance is still under evaluation. In general, implementation of Superpave by the municipalities appears to be progressing at a slower pace, with only the City of Ottawa planning full implementation in the near future. Province of New Brunswick anticipates that the local municipalities will follow the province's lead in Superpave adoption. Most agencies now incorporate performance graded asphalt binders (cement) in their HMA.

Eight agencies (40 percent of the respondents) indicated that they have a third-party audit process in-place to check the QC and QA. This independent third-party (referee) verification is mainly used when QA/QC results differ or if QA results are appealed. In general, the testing is conducted by an independent private sector laboratory selected by the agency that is also accepted by the contractor.

Sixty percent of the respondents indicated that they use short-term warranties for HMA with duration of one or two years. For granular materials, 45 percent of the respondents (nine agencies) indicated that they use warranties with duration of one or two years. The MTQ indicated that they use warranties with duration of one to three years for both materials.

As indicated in Table 4, asphalt concrete density (compaction) and rutting resistance are the factors that are generally considered to be the most important measures of quality for HMA production and placement, with stability, flow and voids in mineral aggregate (VMA) the least important measures. It is also important to note that asphalt cement content, gradation and recompacted air voids are also considered by most agencies to be important measures of quality for hot-mix asphalt. Most agencies consider binder properties to be an important measure of quality for asphalt cements.

Table 4 – Rating of HMA Attributes
Number of Responses

Attribute \ Importance	1	2	3	4	5	NR
Aggregate Gradation	7	9	1	1	1	1
Density (compaction)	15	3	0	0	1	1
Asphalt Cement Content	7	7	3	1	0	2
Stability and Flow	5	3	5	2	3	2
Voids in Mineral Aggregate (VMA)	5	5	7	1	1	1
Smoothness	9	4	3	1	3	0
Aggregate Physical properties	6	6	5	0	1	2
Asphalt Binder Selection	7	8	1	1	2	1
Asphalt Binder Properties	5	9	1	2	1	2
Percent Air Voids	9	5	3	0	2	1
Surface Texture/Segregation	8	6	2	1	2	1
Rutting Resistance	14	0	2	0	3	1

Note: 1= most important, 5 = not important, NR = No Response.

Most of the respondents (85 percent) indicated satisfaction with the overall quality of asphalt pavements delivered by their current specifications. Some agencies are evaluating their current specifications to incorporate stricter guidelines for HMA segregation (City of Edmonton), to transfer responsibility to contractors and incorporate performance testing (MTQ), and to improve the overall quality of projects (Manitoba).

Twenty-five percent of the respondents indicated plans to adopt new end result specifications or performance specifications in the near future. City of Calgary is currently using end result specifications and is evaluating the use of performance specifications, the City of Ottawa is planning to increase the implementation of end result specifications for large projects in 2006, and province of Manitoba is considering the incorporation of some end result specification requirements into its method specification to produce a hybrid.

Sixty-five percent of the respondents indicated that their specifications have been ‘controversial’. For example, segregation specifications appear to be quite controversial due to the subjective nature of the assessment and the large percentage of premature asphalt pavement failures attributed to segregation. Another issue that leads to disputes is the determination of HMA recompacted air voids and VMA, including their impact on the acceptability of asphalt concrete. Compaction, smoothness, differences between QC/QA, and longitudinal joints were also identified as controversial issues.

The survey indicated that the criteria for acceptance, rejection, and payment adjustment factors are determined from a review of other agency specifications, cost-benefit analysis, previous experience (consideration of what is achievable), judgment, discussion with stakeholders, historical construction data and testing variability (repeatability and reproducibility).

Only 25 percent of the respondents indicated that the contractor’s QC testing is relied upon for acceptance, rejection, and payment adjustment factors. Agencies generally rely on QA testing for acceptance.

It is of interest to contrast the Canadian survey findings with a broader North American NCHRP survey, *State Construction Quality Assurance Programs* (NCHRP, 2005), that included five Canadian Provinces (Manitoba, Newfoundland, Nova Scotia, Ontario and Québec). The attributes and quality measures for granular base and subbase, and HMA, used by states and provinces are summarized in Tables 5 and 6, respectively. As anticipated with the NCHRP broader survey and Canadian component, the NCHRP survey responses are generally similar to the Synthesis survey responses. It is also important to note that the NCHRP survey information for granular base and subbase provides important complementary and current information for this Synthesis. It is also of interest that ten years ago, AASHTO indicated very similar findings for HMA testing and inspection properties as shown in Table 7. Recommended testing frequencies were also given by AASHTO that can be used for QC and QA guidance.

3.1.2 Quality Management Practices

Forty percent of the respondents indicated that they require both laboratory and technician certification for QC and QA testing. One agency indicated that they require laboratory certification, but have no certification requirements for technicians.

Only 30 percent of the respondents indicated that they require that QA and/or QC testing laboratories to participate in correlation programs, or annual laboratory inspections, including the CCIL, CAMP, MTO, and AMRL (AASHTO) programs.

Out of the twenty, only MTQ indicated that it requires construction materials suppliers and paving contractor to have an ISO registered quality management system. In general, respondents indicated that, in their opinion, ISO registration is costly and does not guarantee a better competence or ability.

Table 5 – Attributes and Quality Measures for Granular Base and Subbase Used by States and Provinces
(Adapted from *State Construction Quality Assurance Programs* (NCHRP, 2005))

ATTRIBUTES USED FOR QC AND ACCEPTANCE OF AGGREGATE BASE AND SUBBASE[a]		
Attribute	QC	Acceptance
Gradation	27	42
Aggregate fractured faces	9	21
Moisture content	14	24
Compaction	20	45
Atterberg limits	1	6
LA abrasion	0	4
Thickness	0	4
Sand equivalence	0	3
R-value	0	3

QUALITY MEASURES USED FOR ACCEPTANCE OF AGGREGATE BASE AND SUBBASE[a]	
Quality Measure	Number of Agencies
Individual values	25
Percent within limits	13
Range	13
Average	7
Standard deviation	3
Average absolute deviation	1
Conformal index	1

A – 45 responses including Manitoba, Newfoundland, Nova Scotia, Ontario and Québec.

Table 6 – Attributes and Quality Measures for HMA used by States and Provinces
(Adapted from *State Construction Quality Assurance Programs* (NCHRP, 2005))

ATTRIBUTES USED FOR QC AND ACCEPTANCE OF HMA[a]		
Attribute	QC	Acceptance
Asphalt cement content	40	40
Gradation	43	33
Compaction	28	44
Ride quality	16	39
Voids total mix	20	26
Voids in mineral aggregate	26	23
Aggregate fractured faces	25	23
Thickness	13	22
Voids filled with asphalt	19	13

a – 45 responses including Manitoba, Newfoundland, Nova Scotia, Ontario and Québec.

QUALITY MEASURES USED FOR HMA[b]	
Quality Measure	Number of Agencies
Percent within limits	26
Range	15
Average	13
Individual values	4
Average absolute deviation	4
Standard deviation	3
Percent defective	1
Moving average	1

b – 45 responses including five Provinces.

Table 7 – Testing and Inspection of HMA Construction Process
(Adapted from AASHTO Quality Assurance Guide Specification (AASHTO, 1996a))

	Testing and Inspection Property	AASHTO Recommended Frequency: Quality Control	AASHTO Recommended Frequency: Acceptance
Materials	Aggregate Gradation	1 per 1000 tons and 1 per 500 tons (Plant Setup)	--
	Aggregate Properties	1 per 1000 tons or C	--
↓	Asphalt Cement Properties	--	--
Plant Mixing	Aggregate Gradation	1 per 100 tons	A
	Asphalt Cement Content	1 per 500 tons	A
↓	Volumetric Properties	1 per 1000 tons	A
Mix Transportation and Laydown	Temperature of Mix	1 per hour	--
	Temperature of Base or Air	As Needed	--
	Tack/Prime	Load or Half Day	--
↓	Pavement Application Rate	As Needed	--
Compaction	Density	1 per 500 tons	A
	Temperature of Mat	1 per hour	--
	Thickness	C	--
↓	Smoothness (Ride)	C	0.1 Lane –Mile (Sublot) Project (Lot)
Constructed Pavement	Agency Acceptance	--	--

C = As needed to control operations.
A = To be determined by agency.

Thirty percent of the respondents, including the federal government, four provinces (including MTQ with ISO required) and one municipality, require construction materials suppliers and paving contractors to have quality plans or quality manuals. As of 2006, contractors intending to bid on MTO contracts are required to provide an ISO 9001 registered quality management system, or one meeting MTO's comprehensive minimum requirements. Contractors are required to submit an annual declaration stating that the company has a quality management system that is intended to meet the quality related requirements of MTO specifications, and includes the company: quality policy document, organizational structure, management review of system effectiveness and improvement, and product quality improvement program and review. Alternatively, contractors are required to submit an annual declaration stating that the company has ISO 9001:2000 registration. In response to this new requirement, the Ontario Hot-Mix Producers Association has developed approved quality management system templates *Asphalt Plant Quality Manual* and *Asphalt Paving Quality Manual* (OHMPA, 2005a; OHMPA, 2005b).

Eight agencies (40 percent of respondents) indicated that they are using, or planning to use, information technology systems for the management of quality data, including centralized databases, web-based databases, engineering materials management systems and materials analysis systems.

Quality Control (Process Control)

In general, the sampling and testing for quality control (QC) is carried out by suppliers and contractors. Overall, 50 percent of the respondents indicated that QC activities are carried out by the suppliers and contractors, 30 percent by the agency and 20 percent by consultants on behalf of the agency. It should be noted that agency QC activities are not considered the norm in the QC/QA quality assurance approach based on end result specifications with some method inspection (see Table 2).

Quality Assurance

In general, for quality assurance (QA), the sampling and testing is mostly carried out by the agency or agency designated consultants. Thirty percent of the respondents indicated that suppliers and contractors are not responsible for the sampling.

3.1.3 Agencies Assessment of Quality Management Approaches and Practices

Eighty percent of the respondents indicated that they are satisfied with the quality management approach currently used by their agency for flexible pavement materials and construction.

Sixty-five percent of the respondents indicated that the quality inspection and testing has not been an issue between the agency, contractors and consultants. The agencies that indicated that this has been an issue provided the following reasons: some agencies do not require QC laboratories to be certified (equipment is not calibrated properly); subjectivity of visual assessment of deficiencies; disputes over ignition oven asphalt cement content and California profilograph smoothness results; and lack of consistency between laboratories.

The majority of the respondents (85 percent) consider the effort and expenditures allocated with inspection to be appropriate for the type of construction involved. Similarly, 80 percent consider the effort and expenditures allocated to field and laboratory testing to be appropriate.

3.2 State-of-the-Art

The state-of-the-art for quality management of flexible paving materials, based on the survey and supplementary information such as NCHRP reports, can be summarized as follows:

- Use of contractor QC in combination with a limited amount of agency QA for acceptance, rejection and payment adjustment factors after an acceptable correlation between QC and QA has been established.
- Widespread use of end result specifications, with limited use of warranty and performance specifications, mostly for major projects in the provinces of Ontario, British Columbia and Alberta. Performance criteria for these projects include parameters such as distress condition, smoothness, strength (pavement deflection) and frictional characteristics which are monitored throughout the concession period.

- Requirements for participation in recognized laboratory and technician certification programs such as the CCIL programs.

3.3 Trends in Quality Management Practices

From the review of quality management practices for flexible pavement materials and construction, it is possible to note trends in specifications, testing and inspection.

3.3.1 Specifications

- The development and use of end result specifications should be viewed as evolutionary and enroute to the implementation of performance specifications (rutting resistance, fatigue endurance, thermal cracking resistance and smoothness).
- Warranty contracts are starting to be used to place more responsibility on the contractor – not only to guarantee higher quality construction and maintenance, but also to expedite work schedules.
- Public-private partnering (P3) for projects is steadily increasing, particularly in the provinces of Alberta and British Columbia. Agencies have indicated that if the process works well for P3 projects currently under construction, the same model will be used to advance completion of the other high profile projects.
- Provincial and state agencies are increasingly using Superpave mixes for new construction and rehabilitation projects. Adoption of Superpave has been much slower for most municipalities, but the rate is expected to increase significantly in the near future.

In the past, with method specifications, agencies have been responsible for both quality control and quality assurance testing. However, the trend with end result specification use (statistical quality assurance) during the last ten years has been for contractors to assume a much larger role in the checking (QC) of material and pavement quality and this trend is expected to continue. Contractors are frequently required to submit QC plans and agencies will sometimes integrate all, or a portion of the contractor QC results in their QA based acceptance procedures. Initially, contractors generally engaged private testing laboratories to carry out QC activities. However this has quickly evolved to contractors establishing their own laboratories with qualified technicians.

Current HMA testing indicates some monitoring of physical and volumetric properties based on field samples (cores) and laboratory compacted samples (Marshall or Superpave gyratory compactor). In recent years, new equipment and test methods have been developed to measure performance-related mix properties including engineering properties such as pavement deformation resistance and shear strength as well as performance tests such as loaded wheel-tracking (asphalt pavement analyzer for instance), rutting resistance, fatigue endurance and moisture susceptibility testing. Some of these procedures are in use today by MTQ, MTO and the City of Edmonton for mix design verification and asphalt concrete quality assurance. In addition, pavement performance testing to measure smoothness, strength (deflection) and frictional characteristics have been specified for several large design-build-operate contracts in Alberta and British Columbia.

Under warranty contracts that incorporate performance specifications, material suppliers and contractors will play a much greater role in testing and inspection and also on performance monitoring throughout the warranty period. Contractors will be expected to ‘warrant’ the performance of pavements for a longer period of time (20 to 30 years). This new approach will encourage the use of innovative designs, materials and methods for enhanced life-cycle performance and cost, which is typically not used with standard contracts.

3.3.2 Inspection and Testing

- The use of representative truck box HMA sampling, which is generally more representative (proper, safe, sampling 'platform' adjacent to truck box required), with no mat disturbance or coring.
- The use of calibrated nuclear gauge densities, which are faster, more economical and require considerably less coring (calibration coring only, see Appendix B) is becoming more common.
- Most agencies are taking a firmer stance on the elimination of segregation and decisioning of segregation severity has been incrementally upwards. Previously rated moderate segregation is often severe now. A 'sand patch' test (ASTM designation: E 965-96 (2001) *Standard Test Method for Measuring Pavement Macrotexture Depth Using a Volumetric Technique) (ASTM, 2006)* can be used for resolving segregation severity disputes (MTO, 2004).
- The use of laser profilometers is rapidly becoming an accepted method of measuring pavement smoothness, resulting in a much faster, less expensive and safer way to measure quality.

The benefits of web-based reporting systems for all pavement related materials are now recognized by most agencies and these systems are being developed and implemented. These systems facilitate the real time transmission of critical QC/QA and referee data within projects and from projects to central locations which will have the capability to monitor many job sites. This information technology approach allows immediate analysis and decision making as well as communication within the project, and back to the project, reducing delays and improving quality.

Construction of quality flexible pavements depends on many factors – but primarily on the competence of the construction workers throughout the process of aggregates production, subgrade preparation, granular subbase placement, granular base placement, and HMA production, placement and compaction. It is therefore critical that each person involved in these processes be trained to accomplish their assigned task. There is lack of experienced workers to meet the current demand and more transportation industry attention is required to address this growing problem. The following are some of the groups that regularly provide education and training in the fields of pavement and asphalt technology:

- Asphalt Institute (AI)
- National Center for Asphalt Technology (NCAT)
- National Asphalt Pavement Association (NAPA)
- Ontario Good Roads Association (OGRA)
- Transportation Association of Canada (TAC)

In some provinces, partnerships have been formed between agencies, road builder associations and consultants to hire students for consecutive work terms. The objective is to provide employment opportunities to attract technology and engineering students to the infrastructure construction industry.

There is also a trend for agencies to require contractors to develop a quality management system (QMS) instead of simply quality control plans. A QMS incorporates a quality manual which includes a quality policy, organizational structure and internal audit procedures, as well as a quality plan. The quality plan focuses specifically (in terms of methods of sampling, testing, inspection, etc.) on how the contractor will meet the agency's specification requirements for a specific project. The outline for a typical QMS compliant with ISO 9001:2000 is given in Table 8. The contents of a typical specification for a contractor quality control plan in Table 8 will be of assistance to those agencies considering a staged approach to quality management starting with contractor quality control plans for projects.

Table8. Contents of a Typical Specification (ERS) Requirements Section for a Contractor Quality Control Plan and Commentary for a Flexible Pavement Project

SPECIFICATION REQUIREMENTS FOR CONTRACTOR QUALITY CONTROL PLANS
Submission of the Plan Acceptance of the Plan Inspection Records, Test Results and Quality Review Reports Access and Audit of the Plan Compensation for the Plan
COMMENTARY ON QUALITY CONTROL PLAN REQUIREMENTS (SUGGESTED OUTLINE OF A CONTRACTOR QUALITY CONTROL PLAN)
Quality Control Plan General Requirements Elements of the materials and methods which affect the quality of HMA Processes and criteria to assure the quality of materials and work Functional Responsibilities Quality Control Laboratory Sampling and Testing Aggregates Asphalt Binders HMA Placement of HMA Compaction of HMA Records and Process Control Charts

(Note: The full specification and commentary are given in Appendix F)

4 QUALITY MANAGEMENT FOR FLEXIBLE PAVEMENT MATERIALS AND CONSTRUCTION

The key components in the design of a flexible pavement, performance criteria and main material requirements (prepared subgrade, granular subbase, granular base and hot-mix asphalt) are shown in Figure 5.

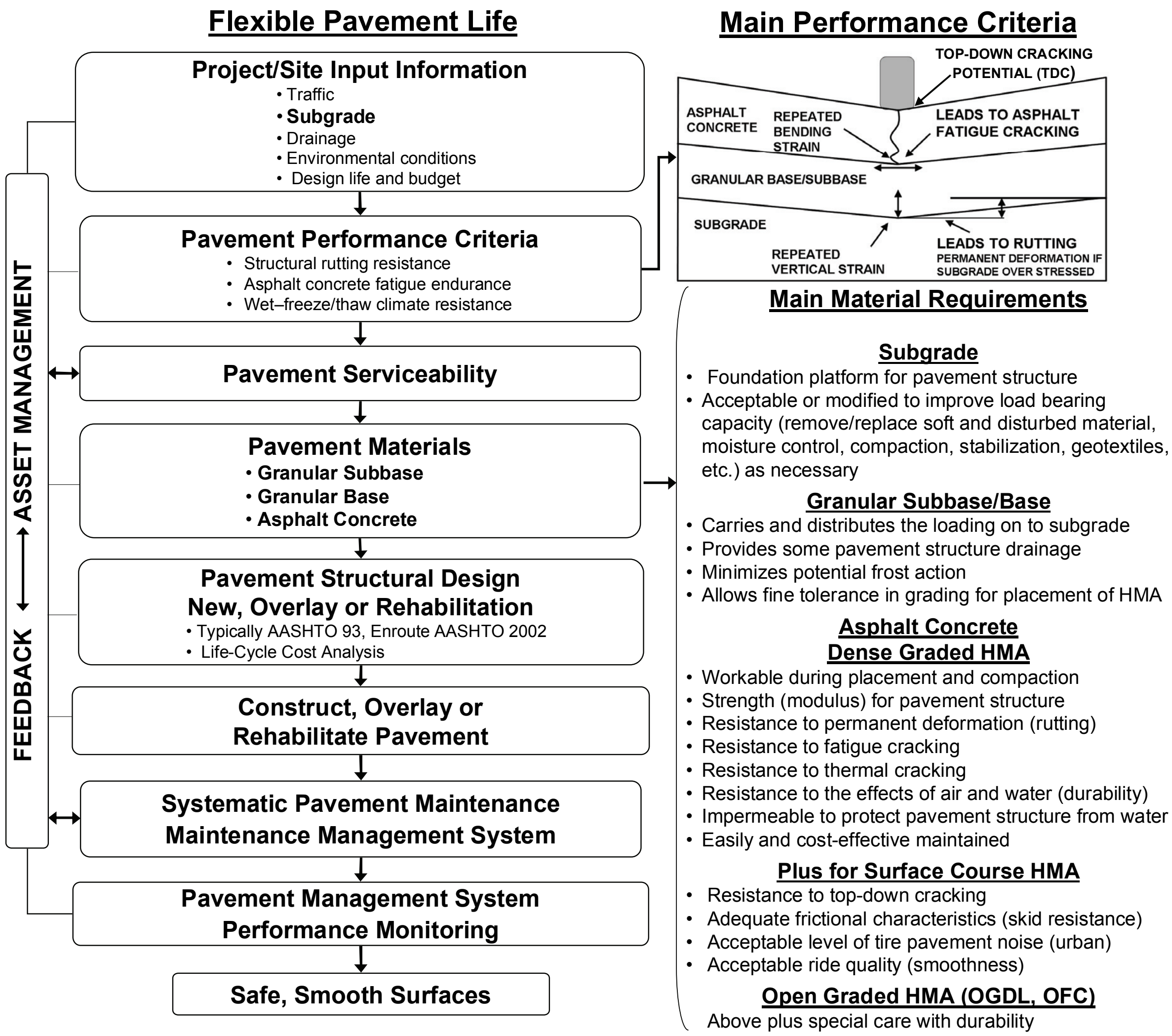

Figure 5 – Flowchart of Flexible Pavement Life with Main Performance Criteria and Material Requirements - Prepared Subgrade, Granular Subbase/Base and Hot-Mix Asphalt (adapted from Infraguide, 2003)

4.1 Design Considerations

The preparation of the site for a new flexible pavement can include land clearing, grading (cuts and fills), compaction, ground water control, subsurface drainage and surface drainage systems installation. A properly prepared pavement foundation normally includes adequate internal (subsurface) and external (surface) drainage and a uniform subgrade that has adequate load bearing capacity as shown in Figure 5. Water removal and drainage systems are imperative to pavement structural and functional serviceability. The pavement structure is then made up of the granular subbase, granular base and asphalt concrete (HMA) components based on a pavement structural design such as AASHTO 93 (enroute to AASHTO 2002, now called Mechanistic-Empirical Pavement Design Guide) as indicated in Figure 5. There are many references available on the design, materials and construction of asphalt pavements (Lavin, 2003 for instance). It should also be noted that while the flexible pavement focus here is on granular subbase, granular base and hot-mix asphalt, other flexible pavement materials and construction such as chip seals, in-place asphalt recycling, hot and cold, and pavement preservation (microsurfacing) can be incorporated from appropriate quality checklists (i.e.FHWA, 2001-2005)

The asphalt concrete (HMA) component of a flexible pavement (new construction, overlay or rehabilitation) tends to be the quality focus from a functional performance viewpoint (rutting resistance, smoothness and frictional characteristics). The materials and construction quality of all the pavement structure components (see Figure 1), from the prepared subgrade to the surface carrying the loadings (granular subbase, granular base and hot-mix asphalt), are important to overall structural performance, again noting the key role of drainage. It should also be noted that with the North American adoption of long-life asphalt pavements (Figure 1), more emphasis is being placed on the rutting resistance and fatigue endurance of the HMA binder courses, with HMA surface course durability and serviceability requiring more attention, as noted in Figure 5.

4.2 Flexible Pavement Materials

The granular base/subbase (GB/GSB) and hot-mix asphalt (HMA) attributes typically used for quality monitoring (QC/QA) are summarized in Table 5, and Tables 4 and 6, respectively. The quality measures for GB/GSB and HMA are summarized in Table 5, and Tables 6 and 7, respectively.

4.2.1 Granular Base and Subbase

The aggregate material attributes typically used for GB/GSB quality control and quality assurance are some, or all, of: gradation, passing 75µm, plasticity index or sand equivalence and Los Angeles abrasion or Micro-Deval abrasion. For GB/GSB construction (placement, moisture content control and compaction), the construction attributes typically used are: moisture content, lift thickness and compaction. It is also quite common to ‘proof’ roll the GB/GSB prior to fine grading. The Aggregate Handbook (NSA, 1991) provides a wealth of information on aggregates production, quality and use, including flexible pavements.

The quality measures associated with the GB/GSB material and construction attributes are either on an individual test basis or lot/sublot basis (mean, mean/range, mean/standard deviation, percent within limits or conformal index). Process control charts (Appendix D) form a key component of QC during aggregates production for GB/GSB and HMA. More details on aggregates production and quality measures are given in the next section.

4.2.2 Hot-Mix Asphalt

The production, placement and compaction of hot-mix asphalt (HMA) and recycled hot-mix asphalt (RHM) (NAPA, 1996a) involves a number of process steps with material and construction components, and inspection and sampling (testing) points, as shown schematically in Figure 6 adapted from NAPA 1993. While HMA contains only two principal ingredients, asphalt binder (cement) and aggregates, the production, placement and compaction of HMA requires a great deal of technical knowledge on a wide variety of topics. The NCAT *Hot Mix Asphalt Materials, Mixture Design, and Construction* (Roberts, 1996) and *Construction of Hot Mix Asphalt Pavements* (AI, 2002) provide extensive overall information on the production, placement and compaction of HMA. An international overview and guide to asphalt surfacing and treatments has been released by the UK Transport Research Laboratory (Nicholls, 1998). NAPA has developed a series of technical and educational guides for:

- HMA materials (NAPA, 1993; NAPA, 1996a; NAPA, 1999; NAPA, 2001; NAPA, 2002b; NAPA, 2002c; NAPA, 2004),
- production (NAPA, 1973; NAPA, 1996b; NAPA, 1997a; NAPA, 2003b; NCHRP, 2001b; TRB, 2005b), emissions control (NAPA, 1987; NAPA, 2000);
- placement (NAPA, 1997b; NAPA, 1998a; NAPA, 1998b; NAPA, 2003a; NCHRP, 1998a; NCHRP, 1998b; NCHRP 2000) and
- compaction (NAPA, 2002a), noting that several of these cover the overall processes.

AI provides full, regularly updated, Superpave method materials selection and design guides (AI, 2001; AI, 2003) and associated technology such as polymer modified asphalt cements (AI, 1999).

Full current and provisional, widely adopted, HMA materials, mix designs and construction specifications, methods of sampling and testing, and provisional standards are provided by AASHTO, noting that many Canadian agencies are involved in AASHTO activities (AASHTO, 2005a; AASHTO, 2005b).

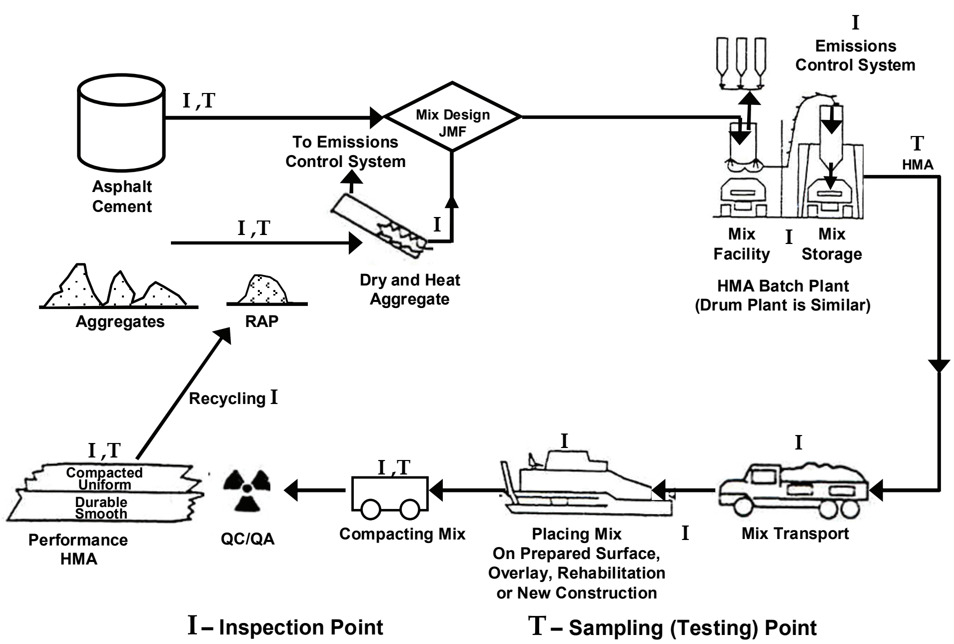

Figure 6 – Schematic of HMA Production, Placement and Compaction Process Showing Typical Inspection and Sampling (Testing) Points (NAPA, 1993a)

The processes involved in the production, transportation, placement and compaction of HMA include:

- Crushing, screening (grading) and stockpiling of aggregates.
- Proportioning asphalt binder (cement) and aggregates (and RAP if incorporated in RHM) for a mix design (Marshall or Superpave) based Job Mix Formula (JMF) for each mix type.
- Verification of the JMF at the HMA plant.
- Storage and handling of aggregate stockpiles at the HMA plant.
- Storage and handling of asphalt binder at the HMA plant.
- Processing, storage and handling of reclaimed asphalt pavement (RAP) at the HMA plant.
- Safety and environmental stewardship of the HMA plant.
- Drying and heating the aggregates (and RAP, if incorporated).
- Mixing the hot aggregates (and RAP, if incorporated) with hot asphalt cement.
- Storage of HMA prior to shipping.
- Transporting HMA to jobsite.
- Placing HMA on prepared surface.
- Rolling HMA to adequate density.
- Ensuring proper asphalt pavement properties achieved.

It is very important that the Job Mix Formula (JMF) for the HMA (including Stone Mastic Asphalt, SMA) or RHM is based on an appropriate mix design (Marshall, or increasingly Superpave) meeting the agency requirements for the specific project site and traffic conditions. A mix design checklist for paving projects with Superpave method HMA or RHM is given in Table 9 with a summary of the Superpave mix design method in Figure 7. The use of Superpave HMA and RHM (and SMA based on the Superpave gyratory compactor, SGC) is increasing across Canada, with some provincial and municipal agencies now 'fully Superpave'. The Superpave method of hot-mix asphalt materials selection and mix design is still evolving (no longer have a restricted zone) and this should be reflected in agency specifications (TRB, 2006). It should also be noted that the LC method of hot-mix asphalt materials selection and mix design, based on the French Laboratoire des chausseés (LC) mix design methodology and Superpave method, has been adopted in Québec (MTQ, 2006). The overall technology of HMA, SMA and RHM materials selection, mix designs and use is beyond the scope of this Synthesis, but readily available to the asphalt technologist as indicated at the beginning of this section.

Canadian agencies may adopt AASHTO current HMA materials, mix design and construction specifications, methods of sampling and testing, and provisional standards (AASHTO, 2005a; AASHTO, 2005b) during the development of their specifications, which should also reflect local experience and special conditions (very cold climate areas for example).

The mitigation of a significant Canadian asphalt pavement performance problem, rutting of heavy duty areas such as at intersections, can be used to illustrate effective HMA and SMA materials selection, mix designs and construction practices at work, and the importance of quality materials, quality mix designs and quality construction (Infraguide 2003):

- For heavy duty performance, incorporate 100 percent crushed, cubical, clean coarse and fine aggregates. Experience has shown that a limited amount (≤ 10 percent) of natural fine aggregate assists in achieving surface course compaction and mat quality (NAPA, 2002 c).
- For heavy duty performance, increase the high temperature asphalt cement performance grade and use an engineered performance graded asphalt cement such as polymer modified (typically SBS) (AI, 1999; AI 2003).
- For Superpave mix designs, build on practical Marshall design experience. Consider fines generation during HMA production. Check potential HMA performance with rutting resistance, fatigue endurance and water susceptibility tests (AI, 2001).
- For construction, adopt proper techniques with contractor quality control and agency quality assurance. Prepare substrate properly (clean and tack), avoid segregation, place uniform and smooth mat, construct joints properly and meet compaction requirements (AI, 2002).

Table 9 – Design Checklist for Paving Project with Superpave Hot-Mix Asphalt

STEP	TECHNICAL ACTIVITY
1	Determine the level of traffic forecasted for the next 20 years (AADT, percentage of heavy vehicles and growth)
2	Determine pavement section design, overlay or rehabilitation strategy
3	Determine the regional climate conditions (LTTPBind)
4	Compute the anticipated 20 year ESALs
5	Identify any special conditions that impact the pavement (heavy trucks, slow traffic, durability, urban or rural, reconstruction, overlay or rehabilitation)
6	Select the Superpave mix criteria for each pavement layer (PG Binder grade, nominal maximum aggregate size, mix design level (gyratory compaction), and aggregate requirements)
7	Check for non-standard mix design criteria and extra costs (life-cycle cost analysis to justify decisions)
8	Place the mix criteria in the project plans (traffic and ESAL projections, asphalt binder grade PGXX-YY, mixture size and mixture properties)

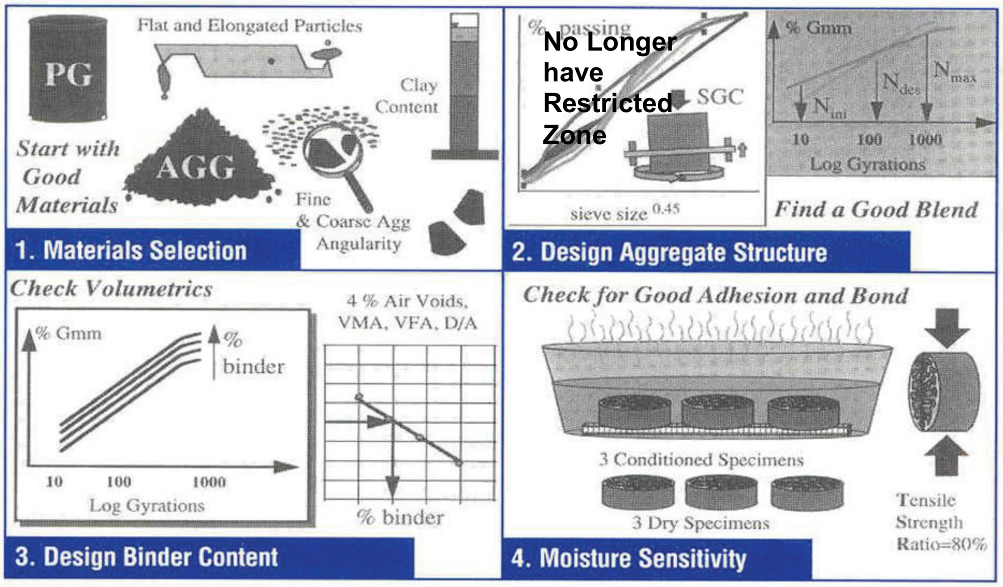

Figure 7 – Summary of Superpave Method of Materials Selection and Mix Designs (AI, 1999)

4.2.2.1 Aggregates

The general aggregate properties considered for HMA are: maximum size and gradation; cleanliness; toughness; soundness; particle shape; surface texture; absorptive capacity; affinity for asphalt binder (moisture susceptibility); and frictional characteristics (surface course mixes) (AI, 2002). The specific aggregate requirements for a project should reflect the agency's aggregate specifications that now include Superpave aggregate consensus properties (fine aggregate angularity, fine aggregate clay content, coarse aggregate angularity and coarse aggregate flat or elongated particles). For Superpave mixes, the consensus property requirements are a function of the 20 year ESALs and pavement structure as indicated in Table 9 (AI, 2001).

a. ***Production of Aggregates***

The aggregate physical properties and gradations should be checked during the processing of all construction aggregates (NSA, 1991). QC tests are conducted to ensure that the crushing and screening plant is producing consistent and acceptable quality aggregates. Sufficient QC samples (typically stratified random samples at 500 tonne intervals until control is established and then at 1000 tonne or higher intervals) should generally be taken from the aggregate stockpiles. Control charts (Appendix D) are useful to both assist in achieving consistent quality and determine when the process is under control at which time the frequency of sampling may be reduced. The overall QC goal should be to detect and correct 'small problems' before they become big ones.

b. ***Stockpiling and Handling***

Proper stockpiling techniques are required to ensure that the aggregates will be of uniform, consistent gradation when fed to the hot-mix plant or placed as granular subbase or granular base. Large stockpiles are very sensitive to single aggregate blends. When using conveyor systems to construct a stockpile, there is always a tendency for the larger particles to 'roll' to the outside of the pile thereby segregating the material; this segregated material can subsequently be fed to the asphalt plant resulting in HMA production variability (NAPA, 1997b).

Generally, different sized aggregates are stockpiled separately since more evenly sized material is less likely to segregate. However, segregation can still occur with finer aggregates (nominal minus 4.75 mm) if there is variability or a wide gradation range in the fine aggregate. The following stockpiling techniques should be checked and monitored to assure uniformity and to minimize segregation:

- Monitor any dozer operations to ensure degradation is not occurring (especially critical when dealing with soft or very brittle aggregates);
- Construct stockpiles in progressive horizontal layers; and
- Construct progressive layers on a slope (not greater than 3:1) and not by dumping down slopes;

The *Aggregate Handbook* (NSA, 1991) provides comprehensive guidelines for all aspects of aggregates production including proper stockpiling techniques. When sampling from stockpiles to set up cold feed bin ratios, it is important to take several samples from each pile and use the median test results for overall gradation blends. A checklist for construction aggregates production is given in Appendix E1 and forms part of the typical construction quality plan given in Appendix H. The production and quality comments given in this section are generally applicable to all construction aggregates.

c. ***Reclaimed Asphalt Pavement***

The use of processed reclaimed asphalt pavement (RAP) in the production of recycled hot-mix asphalt (RHM) in a central asphalt plant (batch, drum or combined batch-drum plants) is well-established and continues to grow across Canada. Recycled hot mix (RHM) is included in most Canadian agencies' specifications for use in binder course mixes, and with some use in surface course mixes, which should also be fostered with the positive materials recovery (particularly asphalt cement) and economics. Processed RAP grindings, millings and/or pieces can be blended with conventional aggregates (sand and gravel or crushed rock) or reclaimed concrete material (RCM) for use as granular subbase, granular base and shouldering material, but this does not recover the aged asphalt cement that is increasing in value, particularly with escalating asphalt cement prices. The ARRA *Basic Asphalt Recycling Manual* (ARRA, 2001) is a recommended reference for additional information on the full range of asphalt pavement recycling technologies.

It is important that the RAP is properly processed to ensure that the physical and gradation properties of the RAP are 'equivalent' to new aggregates. Proper RAP blending and crushing is required to produce a consistent gradation and aged asphalt cement content. This RAP management minimizes variations in the properties of the RAP from different sources, resulting in a relatively homogeneous RAP in the stockpiles. The RAP is processed (crushed and screened) using a portable plant or integrated processing operation at the asphalt plant. The contractor should check, as part of the QC program, to ensure that all processed RAP meets the maximum size required (typically 37.5 mm) when entering the asphalt plant. The processed RAP should be stored in an open-sided shed or building to minimize the moisture content and variability within the stockpile; covering RAP stockpiles with tarpaulins is not recommended as this practice can trap moisture within stockpiles (NAPA, 1996a). There is a growing trend to split (fractionate) the processed RAP into two or three sizes in order to optimize its incorporation in RHM. The contractor should sample and test the combined aggregates (RAP plus new aggregate) to ensure that the specified aggregate properties of the resulting blend comply with project specifications.

For asphalt batch plants, the amount of processed RAP incorporated in RHM is typically limited to 30 percent (by mass of total mix) to ensure adequate drying and heat transfer in the pugmill from superheated aggregate, and to limit 'blue smoke' emissions. It is important for the contractor (as part of an overall QC program) to monitor the amount of RAP going in the RHM to ensure the job mix formula (JMF) is being consistently met. For drum mix asphalt plants, the amount of RAP incorporated in RHM is typically 20 to 50 percent, again with due consideration of consistent RHM quality.

Recycled hot-mix asphalt (RHM) that contains 20 percent or less RAP normally incorporates the same grades of asphalt cement as specified for HMA (some agencies adopt 15 percent or lower of RAP). For RHM that contains between 20 and 30 percent RAP, the low temperature grade of the asphalt cement is typically reduced by one low temperature grading (PG 58-28 would be replaced by PG 58-34 for instance, noting this is agency specific). In addition, for RHMs that contain 20 to 30 percent RAP, the compaction and recompaction (for QC/QA air voids) temperatures will generally be increased (typically about 3°C), depending upon the RHM asphalt cement temperature-viscosity and agency practices. A check to ensure that the appropriate grades of asphalt cement and compaction temperatures are being used for RHMs should be included in the contractor's QC inspection and testing program and reflected in the agency's QA.

4.2.2.2 Asphalt Cements

Asphalt cements (binders) are a key, and the most costly, component of HMA contributing to: overall durability; up to one-third of the rutting resistance; over one-half the fatigue and top-down cracking resistance; and most of the thermal (transverse) cracking resistance of asphalt pavements. The selection of the correct grade and quality of the asphalt cement is critical to HMA quality and asphalt pavement performance (AI, 1999; AI, 2002).

a. ***Penetration and Viscosity Grade Asphalt Cements (Binders)***

The Canadian General Standards Board (CGSB) Specification *Asphalt Cements for Road Purposes* (CAN/CGSB-16.3-M90) is no longer available. Requirements for penetration and viscosity graded asphalt cements can be incorporated in the agency's specification or simply referenced to the appropriate AASHTO specifications (AASHTO 2005a), which also cross-reference ASTM specifications (AASHTO Designation: M 20-70 *Standard Specification for Penetration-Graded Asphalt Cement* for instance).

b. ***Performance Graded Asphalt Cements (Binders)***

Performance graded asphalt cements (PGACs) for a project are selected on the basis of predicted asphalt pavement temperature conditions (at surface and with depth below the surface), anticipated traffic loadings (heavy traffic volumes and speeds) and percent processed RAP, if any, used in the HMA (RHM) (AI, 2003). The PGAC performance criteria are essentially resistance to permanent deformation (rutting) at high asphalt pavement temperatures and resistance to thermal cracking at low asphalt pavement temperatures, both generally of concern for most of Canada with hot summers and cold winters. PGAC specifications are defined by these asphalt pavement temperature extremes – the first number in the PG designation specifies the average seven-day maximum design temperature and the second number specifies the minimum design temperature. For example, a PGAC 58-28 corresponds to a maximum design temperature of 58°C and a minimum design temperature of -28°C. Specifications for PGACs are generally in increments of six degrees (AI, 2003).

Many agencies have divided their area into zones and designated the appropriate PGACs based on long-term climate normals for the area and SHRP/CSHRP long-term pavement performance studies (LTPP), as readily available on-line (FHWA LTPPBind, www.fhwa.dot.gov). As asphalt pavement temperatures tend to moderate with depth in the asphalt pavement, this can be used to advantage for deep-strength and long-life asphalt pavements. PGAC selection and specification also takes into consideration traffic loadings (heavy traffic volumes and speeds) in terms of rutting potential and the use of processed RAP in RHM. For roads and highways with slow moving traffic, or a high number of commercial (heavy) vehicles (trucks and buses), the maximum design temperature is typically increased by one grade for improved rutting resistance (Table 9). For a high percentage of slow moving (or frequent stops and starts) commercial vehicles (curb lanes of heavy traffic intersections for instance) an increase by two grades should be considered (Table 9) (Infraguide, 2003). The selection and specification of PGACs for RHMs was discussed in Section 4.2.2.1a. The appropriate selection, specification requirements, sampling and testing of PGACs is provided through AASHTO activities that involve many Canadian agencies, for example AASHTO Designation: M 320-02 *Standard Specification for Performance-Graded Asphalt Binder* (AASHTO, 2005a; AASHTO, 2005b).

c. ***Polymer-Modified Asphalt Binders***

Polymers are 'engineered' to obtain a broad range of physical properties and are divided into two general categories: elastomers ('rubbers') and plastomers ('plastics'). Elastomers used as asphalt cement modifiers include natural rubber, styrene-butadiene rubber (SBR) latexes, styrene-butadiene-styrene (SBS) block copolymers, styrene-isoprene-styrene (SIS) block copolymers, polychloroprene latexes and crumb rubber (ground tires) modifiers. Elastomers resist deformation from applied stresses by compressing and then recovering their shape quickly when the stress is removed. Plastomers used as asphalt cement modifiers include polyethylene, polypropylene, ethylvinyl acetate (EVA), polyvinyl chloride (PVC), ethylene polypropylene (EPDM) and polyolefin. The results of polymer modification with both elastomers and plastomers are highly dependent on the concentration, chemical composition, and molecular weight of the specific polymer, with most asphalt technology incorporating SBR, SBS, EVA and CRM (AI, 1999). The most common, and widely used, polymer modified asphalt cements (PMAs and PMPGACs) in Canada incorporate SBS at the three to six percent level (Infraguide, 2003). These PMAs and PMPGACs usually have an elastic recovery (ductility) specified (see AASHTO Designation: R 15-00 *Standard Recommended Practice for Asphalt Additives and Modifiers*, and AASHTO Designation: T 301-99 *Standard Method of Test for Elastic Recovery of Bituminous Materials, by Means of a Ductilometer* for instance) (AASHTO, 2005a) to essentially 'verify' the presence of the polymer and potential performance improvements (typically an elastic recovery of 60 percent or greater for a PMPGAC 70-28). It should be noted that there is a PGAC 'rule-of-thumb' that if the absolute value sum of the high and low design temperatures is 92 or greater, then an engineered PGAC will be required (straight refinery-run asphalt cements not suitable). In addition to commonly specified polymer modification (typically SBS), other technologies are available such as oxidation, chemical additives (e.g. polyphosphoric acid) and sulphur addition, the use of which should be subject to technical requirements such as AASHTO Designation: R 15-00 and agency specifications based on demonstrated satisfactory performance.

4.2.2.3 Miscellaneous Materials

a. ***Antistripping Additives***

Moisture damage to asphalt pavements is a serious durability problem throughout Canada and the subject of the report on *Moisture Damage of Asphalt Pavements and Antistripping Additives: Courses, Identification, Testing and Mitigation* (TAC, 1997). It is important that stripping resistance (moisture susceptibility) testing for specific aggregate-asphalt cement combinations (siliceous aggregates and mixed siliceous/carbonate aggregates tend to be the problem) be completed for all HMA mix designs, as is required in the Superpave method (tensile strength ratio, TSR, AASHTO Designation: T 283-02 *Standard Method of Test for Resistance of Compacted Asphalt Mixtures to Moisture-Induced Damage*) (AI, 2001; AASHTO, 2005a). The use of antistripping additives (liquid hydrated lime), when required, significantly improves the stripping resistance of HMAs. Antistripping additives should be subject to technical requirements such as AASHTO Designation: R 15-00, specifications such as AASHTO Designation: M 303-89 (1998) *Standard Specification for Lime for Asphalt Mixtures* (AASHTO, 2005a) and demonstrated satisfactory performance. It is important that effectiveness of antistripping use is checked during HMA characteristics QC and QA TSR compliance testing (TAC, 1997).

Many studies have recommended the use of hydrated lime as an antistripping additive to improve the stripping resistance and stability of HMA, and to reduce the age hardening of asphalt cements (TAC, 1997). The overall mechanism of hydrated lime action is complex – essentially the hydrated lime provides a favourable physical-chemical surface condition for enhanced asphalt cement adhesion to the aggregates – and is effective and compatible with siliceous, siliceous/carbonate and carbonate aggregates (TAC, 1997). There are several ways of adding hydrated lime to aggregates (typically 0.5 to 1.0 percent by mass of aggregates, depending on the TSR requirements) with minimal dust and loss to emission control systems, achieving a uniform coating and meeting a safe work action plan for handling hydrated lime (TAC, 1997):

- During aggregates production and stockpiling operations at a pit or quarry, usually with moist (three to five percent) aggregates and a mixing unit (hydrated lime or quicklime slurry, not commonly used).
- Premixing with moist aggregates as part of stockpiling at the asphalt plant site.
- Addition to moist aggregates on the asphalt plant cold feed (least effective moist aggregates method).
- Addition to moist aggregate through a mixing unit as part of the asphalt plant cold feed.
- Addition to dry aggregate in the pugmill mixing unit of a batch asphalt plant (generally compensate for some 'loss' of hydrated lime to emission mix control system, depending on fines return, and some 'loss' to asphalt cement).
- Addition to dry aggregate in the drum mixing unit of a drum asphalt plant equipped for hydrated lime and filler addition (generally compensate for some 'loss' of hydrated lime to emission control system, depending on fines return ,and some 'loss' to asphalt cement).

Regardless of the method of hydrated lime addition adopted, its effectiveness should be confirmed by contractor TSR compliance testing for typical asphalt mixes incorporating hydrated lime (TAC, 1997).

b. ***Fillers***

Filler for asphalt mixes (e.g. SMA with its high minus 75 µm content), such as fly ash and crusher 'dust' (e.g. limestone dust mineral filler), should meet the requirements of AASHTO Designation: M 17-95 *Standard Specification for Mineral Filler for Bituminous Paving Mixtures* (AASHTO, 2005a) which is based on ASTM Designation: D 242-04 (ASTM, 2006). Care must be taken with the uniform addition of fillers to asphalt mixes, particularly SMA (AASHTO Designation: MP 8-03 *Standard Specification for Designing Stone Matrix Asphalt (SMA)* (AASHTO, 2005b).

c. ***Fibres***

Fibres, typically cellulose or mineral fibre, are added to some asphalt mixes (OGFC and particularly SMA for instance) as a stabilizing additive. Typically about 0.3% of cellulose fibre or 0.4% of mineral fibre or more by mix mass is sufficient to prevent draindown, and that should meet the requirements of AASHTO Designation: MP 8-03 (AASHTO, 2005b). Care must be taken with the uniform addition of fibres to asphalt mixes.

d. ***Tack Coat***

Tack coat used during HMA paving activities is generally SS-1 emulsified asphalt (AASHTO Designations: M 140-88 and RS-89) diluted with an equal volume of potable water. There is an increasing use of polymer-modified tack coats (CRS-2P, AASHTO Designation: M316-99). The diluted SS-1 tack coat is applied uniformly at the specified rate for the surface involved (typically about 0.35 to 0.5 litres/metre^2 for old asphalt pavement surfaces). The use of cutback asphalt for tack coating and granular base sealing is not recommended from a technical (must be fully cured to avoid solvent action) and environmental viewpoint (volatiles emission).

e. ***New Materials***

The use of innovative and/or proprietary new materials and methods (manufactured shingle modifier (MSM), warm asphalt mixes (WAM), and sulphur extended asphalt materials (SEAM) for instance) in flexible pavement construction is important to enhanced life-cycle performance and cost of pavements. However, these materials and methods must be subject to full technical evaluations (AASHTO Designation: R 15-00) and demonstrated satisfactory performance (monitored field trials), with agency product evaluation and management activities playing an important role through qualified product lists (NCHRP, 2004b).

4.3 Subgrade Preparation

The first stage of a new flexible pavement construction project is preparation of the subgrade (earthwork) which generally involves: clearing -close cutting and grubbing, stripping, earth cut construction and earth embankment construction; and drainage-ditching, culverts, catch basins, ditch inlets, subdrains, storm drains and geotextile installation (Monahan, 1994). A properly designed and constructed, uniform, high-quality, well-drained, stable subgrade (roadbed foundation) is essential to a high-quality, durable flexible pavement structure for the site conditions and anticipated heavy traffic. Drainage is the most important aspect of road and highway design. Poor drainage conditions, frost susceptible soils and poor subgrade support conditions are major contributing factors to poor pavement performance and failures (Eaton, R.A., R.H. Joubert and E.A. Wright, 1981). Problems with drainage are generally associated with: standing water in ditches; soils with poor drainage; cracks in the road surfacing; high water table and seepage; frost penetration; freeze-thaw deterioration; and 'pumping' under traffic.

The subgrade soil must be properly graded and uniformly compacted to the required density, typically 95 to 98 percent of standard Proctor density and within two percent of optimum moisture content (AASHTO Designation: T 99-01, with modified Proctors often used for major, heavy duty flexible pavements, AASHTO Designation: T 180-01). All utilities and storm drainage are usually installed prior to final compaction and grading of the soil subgrade. Subgrade soils are compacted to the required depth with a wide range of equipment suitable for the specific soils involved (cohesive, fine or coarse grained) such as static and vibratory padfoot, rubber-tired and steel-drum rollers. The soil density achieved is monitored using a nuclear density gauge, typically each 500 to 1000 metre^2 (AASHTO Designation: T 310-02). Proof rolling with a rubber-tired roller or loaded dump truck is often completed to check the condition of the subgrade and identify any soft spots (high deflections and rutting). Areas which fail the proof rolling are recompacted, subexcavated, replaced with suitable soil and compacted and/or provided with improved drainage, and then retested for suitability.

An action list for subgrade preparation (grading and drainage) inspection and testing can be used as the basis for developing this component of a typical flexible pavement construction quality plan, as outlined in Appendix H (matrix of items, quality requirements and quality responsibilities). The key items to be checked from a flexible pavement construction viewpoint are:

- Have the drainage systems been properly installed and the ditching and side sloping completed to project requirements?
- Have the subgrade compaction requirements been met (compaction testing with nuclear density gauge)?
- Has the subgrade been proof rolled and any soft spots treated as necessary to provide a uniform, well-drained, stable subgrade for the pavement structure?
- Have the prepared subgrade grades and crossfalls been verified prior to the placement of any granular subbase?

It should be noted that there are some subgrade soils that may require special treatment (wet fine-grained soils and expansive clays for instance), such as lime stabilization, in order to provide an acceptable subgrade for the flexible pavement structure. Also, most areas of Canada have a short construction season, with cool, wet springs (poor drying conditions) and the potential for soft subgrades (e.g. silty clays) to deform and rut under construction equipment with granular subbase-subgrade intrusion/pumping and loss of strength. This wet, soft, disturbed subgrade condition must be dealt with through drying, stabilizing, incorporating a separation geotextile, reducing truck loads and/or 'rafting' the granular material, keeping at least 150 mm of granular subbase between equipment treads, tires and rollers by dumping and pushing the granular material ahead to protect the subgrade (Monahan, 1994). In severe cases of strength loss, a separation geotextile and strengthening geogrid may be required.

4.4 Placement and Compaction of Granular Subbase and Base

Once the sufficiently uniform, well-drained, compacted, stable subgrade is ready, and granular subbase and base aggregates processed and stockpiled (or sourced) meeting contract requirements, the placement and compaction of the granular subbase can proceed to the required thickness, crossfall, smoothness and compaction, which is critical to subbase strength in the pavement structure. Granular base and subbase production/placement checklists are given in Appendices E.1 and E.2, and form part of the typical construction quality plan given in Appendix H. Once the granular subbase is placed, compacted and checked (inspected and tested, particularly compaction), the granular base can be placed, compacted and checked prior to asphalt paving operations.

Crushed stone or sand/gravel subbases or bases are normally placed to the required thickness (usually in lifts less than 200 mm) using graders and then compacted using steel drum vibratory rollers. Care should be taken when spreading granular materials to avoid segregation, especially when using larger sizes and/or coarsely graded material. Specifications typically require the surface of the completed subbase or base to have a final smooth, tight surface with no deviations in excess 15 mm (subbase) or 10 mm (base) when checked with a 3 metre straightedge.

Since crushed stone usually dries out faster than sand/gravel, crushed stone is usually placed at a moisture content somewhat higher (1 or 2 percent) than its optimum moisture content. It is important to apply any water necessary for compaction prior to rolling to ensure that the water is thoroughly mixed with the granular material from top to bottom of the lift. Granular subbase and base layers are typically compacted to 100 percent of standard Proctor density (AASHTO Designation: T 99-01, with modified Proctor often used for major heavy duty flexible pavements, AASHTO Designation: T 180-01) and are checked for adequate compaction using a nuclear density gauge typically each 500 to 1000 metre^2 (AASHTO Designation: T 310-02).

A few agencies still specify the addition of a prime coat or granular seal to the completed, smooth, tight granular base surface, prior to the placement of hot-mix asphalt, to help stabilize the base and to improve the bond with the asphalt concrete. (While a medium 'curing' cutback asphalt may be specified, for this purpose an emulsion should be used to avoid curing problems and volatiles emission as discussed in Section 4.2.2.3.d.)

4.5 Hot-mix Asphalt Production and Transportation

The Asphalt Institute MS-22 *Construction of Hot Mix Asphalt Pavements* (AI, 2002) provides comprehensive information on HMA materials, mix designs, production, transportation, placement, compaction, inspection, testing and quality control, with particular focus on the practical aspects of production (Plant Operations, Chapter 4), placement (Placing Hot Mix Asphalt, Chapter 5) and compaction (Compaction, Chapter 6). These practical aspects are covered by the checklists given in Appendix E.1 and E.3, and form part of the typical quality plan for flexible pavement construction given in Appendix H.

With end-result and performance-related specifications, the overall HMA production, transportation, placement and compaction equipment, operations and quality control are the responsibility of the contractor, with the required quality of the resulting HMA and asphalt pavement specified and subject to agency quality assurance (QA). The following HMA production operations should be monitored and controlled by plant operators and quality control staff:

- Materials storage and handling.
- Asphalt plant operations – batch and drum plants.
- Storage silos and truck loading.
- Transportation of HMA.

Communications between the paving site, haul trucks and the asphalt plant are critical to ensure a smooth, uninterrupted paving operation as well as proper mix temperatures for compaction and a smooth, uniform mat texture.

4.6 Environmental Control Systems

The control of emissions is required during all stages of HMA production, transportation, placement and compaction and is increasingly the focus of regulatory action. At the asphalt plant, sources of air emissions can be divided into ducted sources and fugitive sources. Ducted sources are located within the plant itself and handled by the emissions control system. The emissions control system typically consists of a primary collector (cyclone) and a secondary collector (baghouse which is the main type or wet scrubber). The emissions from ducted sources encompass particulate matter, mainly particles less than 10 µm (PM-10), with some PM 7 and PM 2.5, as well as gaseous emissions from combustion (carbon dioxide, water, sulphur oxides and nitrogen oxide are normal products of complete combustion, with carbon monoxide and total organic compounds products of incomplete combustion). Particulate emissions from ducted sources are generated mainly by aggregate heating and drying, plus those scavenged from various discharge points in the plant. Gaseous emissions are generated by the plant burners, hot-oil heaters and diesel generator sets. Odours can also be a significant, but mainly aesthetic, concern (nuisance) and are generated mainly during the transfer of hot asphalt cement from delivery vehicles to storage tanks, during heating as a product of incomplete combustion, and during HMA transportation, placement and compaction. Emissions for fugitive and open dust sources encompass mainly particulate matter (dust) generated in traffic areas (storage yards and plant haul roads), stockpiles, bins and conveyors. Noise emissions associated with the plant and yard operations can also be a significant concern to nearby neighbours.

The control of emissions varies somewhat depending on the specific plant type (batch, drum or combined drum-batch plant) and regulatory agency specific requirements. Regardless, emissions can be effectively controlled by implementation of sound environmental management practices. For instance, the *Alberta Code of Practice for Asphalt Paving Plants* is incorporated in Provincial Legislation (Alberta Environment, 1996), and describes the duties and responsibilities, regulatory requirements and minimum operating requirements for plants.

The Ontario Hot Mix Producers Association has developed an *Environmental Practices Guide* (OHMPA, 2002). This *Environmental Practices Guide* was developed with input from the Ontario Ministry of Environment and provides detailed information on asphalt plant emissions and checklists to ensure that all environmental aspects of HMA production are addressed. *The Fundamentals of the Operation and Maintenance of the Exhaust Gas System in a Hot Mix Asphalt Facility*, (NAPA, 1987), as well as emissions control operation manuals provided by plant manufacturers' also provide detailed information for efficient and environmentally optimal asphalt plant operations.

The control of emissions during HMA transportation and laydown are relatively straightforward. These controls should be included in contractor quality control plans and undergo periodic self-audits for compliance. The HMA should be transported from the plant to the paving site in covered (tarpaulins), insulated trucks. The HMA should not be overheated. The HMA paving operations should be continuous to avoid queuing of haul vehicles and paving and compaction equipment, with associated increases in fumes due to idling.

4.7 Hot-Mix Asphalt Paving

The contractor should prepare a laydown plan, as part of the paving project overall construction quality plan, for the transport, placement and compaction of the HMA to assist in achieving a continuous flow of HMA to the paver, preferably through a material transfer device (uniform paver speed, with least stops-starts and truck bumping that can result in mechanical/thermal segregation and roughness) and to minimize the number of cold joints. This laydown plan should include the sequence of laydown by traffic control, stations, width of mats, lift thicknesses, laydown temperatures, temporary ramping and timing for each part of the work (mobilizing traffic control, milling, cleaning, tacking, paving, compacting, cooling, demobilizing traffic control, etc.). The FHWA has provided *Richard Petty's Ten Tips for Smoother Pavement* that are particularly relevant:

1. **Plan Before You Start.**
   The entire crew should have an organizational meeting long before any work begins.
2. **Keep that Focus on Communication After the Job Starts.**
   Just because the job's underway is no reason to stop communicating.
3. **Go Slow, if Necessary, But Go Steady.**
   The entire paving job should be a continuous, coordinated process.
4. **Try Out Some Skis.**
   Check out alternative ski setups for best control.
5. **Watch What You're Reading.**
   Take sensor readings off the smoothest surface possible.
6. **Consistency Starts at the Hot-Mix Plant.**
   Make sure temperatures of the hot mix are kept as consistent as possible.
7. **No Bumping!**
   Minimize the contact between paver and hauling units.
8. **Keep the Rollers Moving.**
   If you have to stop to take a break, don't park on the new mat.
9. **Stay on the Mat.**
   Keep the rollers on the mat when pinching a joint.
10. **Evaluate.**
    Once the project is complete, review the successes as well as the areas where you could have improved (C-SHRP, 1999; FHWA, 2002; Wolters, 2002).

These tips are incorporated in the Appendix E.3 checklist for hot-mix asphalt production and placement inspection, which are covered in detail in the Asphalt Institute MS-22 Chapter 5-Placing Hot Mix Asphalt and Chapter 6-Compaction (AI, 2002), and will not be repeated here beyond supplemental comments on trial sections, surface preparation, tacking between lifts, material transfer devices, joint construction and working with polymer modified asphalt cements.

4.7.1 Trial Section

A trial section should be completed, prior to placing any surface course HMA, to provide the contractor and agency an opportunity to check the performance of the paving and compaction equipment, and the overall mat quality achieved in terms of mat density, joint density, thickness, smoothness, texture and grade. This trial section can be placed as part of a lower course and can be evaluated for conformance with contract requirements as a pay item.

4.7.2 Preparation of the Underlying Surface

Proper preparation of the underlying surface is very important to the quality of the completed asphalt pavement. For HMA overlay paving (e.g. 'milling/filling') this will generally involve the removal of deteriorated asphalt pavement by cold milling and transverse joint preparation, followed by cleaning of all existing and milled horizontal and vertical surfaces (power brooming, washing and vacuuming as necessary), inspection of the prepared surface, and application of tack coat (typically SS-1 diluted with an equal volume of water, at the rate of 0.35 to 0.5 litres/metre^2), that is allowed to properly cure ('tacky' to the touch). For new HMA paving, the granular base is typically fine-graded as necessary, granular sealed (emulsion preferred) if specified, and then granular base grade finish rolling completed (typically with vibratory steel-drum roller) to ensure a compacted smooth and float-free surface for the asphalt paving.

4.7.3 Tack Coating between Lifts

It is very important to ensure a good bond between the compacted asphalt concrete lifts (layers) of each course. The presence of dirt and dust, and/or moisture, between asphalt concrete lifts has contributed to many asphalt pavement failures (Photograph 4 of Appendix B). Most agencies require the cleaning and tack coating of all existing and milled surfaces (preparation of the underlying surface) and any compacted asphalt concrete lift surfaces that have been left over the winter and/or subjected to construction traffic such as dust and dirt tracking. An increasing number of agencies are requiring the tack coating of all compacted asphalt concrete lift surfaces, unless the lift is being placed on a previous 'fresh', clean, untrafficked lift surface. This tack coating between lifts is particularly critical for the HMA surfacing that must be 'bonded' to the substrate for satisfactory durability and performance. There are typically two specified application rates for tack coating: 0.35 to 0.50 litre/metre^2 for existing and milled asphalt pavement surfaces (preparation of the underlying surface); and 0.1 to 0.2 litres/metre^2 for new asphalt pavement surfaces. The specific tack coat application rate should be monitored and adjusted as necessary, at the time of application to provide just enough tack coat for a uniform 'tacky' surface with no excess.

4.7.4 Material Transfer Devices

The use of material transfer devices (Photograph 6 of Appendix B) is increasing through recognition of their importance to achieving smooth, segregation-'free' asphalt pavement surfaces, with some agencies requiring their use (either directly specified or indirectly 'specified' through smoothness and surface texture quality incentives) (AI, 2002; NAPA, 1997b; NAPA, 2003a; NAPA, 2003b). A material transfer device: allows a continuous paving operation; reduces the occurrence of segregation (mechanical and thermal) during the asphalt paving process; and reduces the occurrence of haul trucks bumping the paver which tends to cause roughness ('bumps') in the compacted asphalt pavement surface. The use of material transfer devices is strongly encouraged based on practical, positive demonstrated experience with enhanced smoothness and reduced segregation asphalt paving projects.

4.7.5 Joint Construction

The proper overlap (approximately 13 mm and straight) between the 'cold' adjacent mat and the hot mat is important to the construction of longitudinal joints. The density of the outer 300 mm of the mat can be increased through vibration, screed end gates and/or joint maker/joint compactor to reduce/eliminate the taper. The joint quality can also be enhanced by tacking with emulsified asphalt and/or by use of an infrared joint heater. New infrared heaters are now available that have been demonstrated to properly heat cold joints for a width of about 200 mm to between 100°C and 120°C, thereby facilitating improved compaction of the outer edge of the previously laid (cold) mat. When practical, echelon paving (two pavers spaced closely to each other) is recommended, noting that traffic control considerations may preclude this practice on rehabilitation projects.

4.7.6 Working with Polymer Modified Asphalt Cements

The incorporation of polymer modified asphalt cements (PMAs and PMPGACs) in hot-mix asphalt (mix designs, production, transportation, placement and compaction) is generally straight forward provided their special features are noted ('sticky' and generally higher mixing and compaction temperatures for instance) (AI, 1999). Guidance on the appropriate polymer modified asphalt cement hauling procedures, and storage, mixing and compaction temperatures, is available from PMA/PMPGAC suppliers and is typically attached to the Marshall or Superpave mix design report (e.g. HMA, Superpave HMA, SMA and OGFC temperature-viscosity charts). For HMAs incorporating PMAs and PMPGACs, it is generally necessary to heat or use a 'soap' solution on rubber tires and a 'soap' solution on steel rollers of compaction equipment in order to prevent adhesion of the mix.

5 TESTING AND INSPECTION OF FLEXIBLE PAVEMENT MATERIALS AND CONSTRUCTION

The importance of proper quality control (QC), quality assurance (QA), and referee if involved, sampling, testing and inspection of flexible pavement materials (prepared subgrade, granular subbase, granular base and HMA) and construction (aggregates production, subgrade preparation, granular subbase and base placement and compaction, and HMA production, transportation, placement and compaction) by qualified technical staff, with calibrated field equipment (e.g. nuclear density gauges for compaction) and calibrated laboratory equipment (dynamic shear and bending beam rheometer for PGAC), in accordance with standard procedures (AASHTO typically) cannot be overemphasized. Production process control (QC) and compliant aggregates and asphalt cements (QC and QA), compliant HMA mix design JMFs (QC and QA) and acceptance of HMAs and asphalt pavements (QC and QA) all require proper sampling, testing and inspection by qualified technical staff using appropriate equipment.

It is important that the specific QC and QA sampling, testing and inspection requirements form a component of the overall flexible pavement construction quality plan (Appendix H), typically through incorporation of the contractor's quality control (QC) plan for the project (Appendix F) and agency (or consultant) quality management system with the specific quality assurance technical services requirements for the project (Table 3 and Appendix G, ISO compliant). The contractor, agency or consultant quality plans must include a laboratory quality system manual or component (Section 7, Product and/or Service Realization of Appendix G, ISO compliant or specifically for testing services meeting ISO/IEC 17025 requirements).

5.1 Sampling for Process Control and Acceptance

The most complete measure of the properties of a material or method requires the inspection and/or testing of the entire production (population), but since this is not generally possible, the material or method is sampled on a statistically representative basis (lots and sub-lots) with small portions inspected and/or tested (AASHTO Designation: R 4-97 *Standard Recommended Practice for Statistical Procedures* and AASHTO Designation: R 9-97 *Standard Recommended Practice for Acceptance Sampling Plans for Highway Construction*) (AASHTO, 2005a). Proper sampling is required to obtain reliable, objective information about the production or process.

- Samples must be representative of the production being evaluated.
- Samples must be taken at the appropriate point in the process (stockpile, plant, roadway, etc.)
- Samples must be clearly identified (information tag or barcode with project, location, item, date, time, lot, sub-lot, observations and sampler).
- Sampling must be completed using standard procedures (AASHTO Designation: T 2-91 *Standard Method of Test for Sampling of Aggregates*, AASHTO Designation: T 40-02 *Standard Method of Test for Sampling Bituminous Materials*, AASHTO Designation: T 168-99 *Standard Method of Test for Sampling Bituminous Paving Mixture* for instance) (AASHTO, 2005a).
- Samples must be taken randomly and without bias, typically using a stratified random sampling plan (ASTM Designation: D 3665-06 *Standard Practice for Random Sampling of Construction Materials*) (ASTM, 2006) with lot and sub-lot sizes determined by the

contractor for QC (process control and specification compliance) and agency for QA (5000 tonne lots with ten 500 tonne sublots for HMA for instance).

5.2 Testing for Quality Control and Quality Assurance

It is very important that all sampling, testing and inspection of flexible pavement materials be completed by qualified contractor, agency and consultant technicians (preferably certified) using appropriate calibrated equipment for the specific inspection and testing involved (preferable through a laboratory certification program). There is currently no Canada-wide highway construction materials technician or laboratory certification program(s) and a range of certification programs are being used to maintain technical standards:

- The Canadian Council of Independent Laboratories (CCIL) provides comprehensive, independent, agency-monitored, industry-wide asphalt technician and laboratory certification programs for aggregates testing, Marshall and Superpave mix design testing and HMA testing ('required' in Ontario and also used by a few contractors, agencies and consultants in other provinces, noting that Québec has a similar system). The CCIL Certification Program *Standards Manual* (CCIL, 2001) with the specific agency testing procedures, AASHTO and ASTM referenced standards and laboratory certification documents, provided to all participants, is an important feature of the Program. The CCIL is currently developing an asphalt cement component to the certification program that will probably include participation in the AASHTO Materials Reference Laboratory (AMRL) program for asphalt cements (already required by MTO). It should also be noted that proficiency testing is an important factor in evaluating the on-going technical performance of technicians and laboratories, as adopted in the CCIL programs.
- The AASHTO Accreditation Program (AAP) is a comprehensive program based on AMRL laboratory assessment and proficiency sample services, that bases accreditation on technical and laboratory compliance with the requirements of AASHTO Designation: R 18-97 *Standard Recommended Practice for Establishing and Implementing a Quality System for Construction Materials Testing Laboratories* (AASHTO, 2005a). While the AAP is required by most US agencies, it has only been used by a few Canadian agencies, asphalt cement suppliers and consultants.
- The Canadian Asphalt and Mix Exchange Program (CAMP), operated under the umbrella of the Canadian User Producer Group for Asphalt (CUPGA) is the most common laboratory proficiency program (not intended as a certification program) for asphalt cement testing, emulsion testing, cutback testing, Marshall mix designs, Superpave mix designs (SHRP gyratory compaction) and asphalt ignition oven. Over 50 agencies, contractor, supplier and consultant laboratories participate in the annual CAMP, with full details provided in the CTAA annual proceedings.
- Many agencies complete HMA inter-laboratory correlations and proficiency programs during the construction season to maintain the necessary quality of technical services for asphalt paving projects.

It is important that all contractor, agency or consultant quality plans include a laboratory quality system manual or component (e.g. ISO 9001 or ISO/IEC 17025) that requires participation in the appropriate (provincial and agency) CCIL, AASHTO, CAMP and/or agency inter-laboratory correlation and proficiency programs, meeting the general intent of AASHTO Designation: R 18-97 (AASHTO, 2005a). The technical staff and testing equipment requirements should be clearly stated in the quality system manual.

It should be noted that there is a growing concern with the documented potential 'health impacts' of asphalt testing laboratory solvent use for extractions. Strict health hygiene should be observed with solvent use, or preferably the AASHTO Designation: T 308-01 *Standard Method of Test for Determining the Asphalt Binder Content of Hot-Mix Asphalt (HMA) by the Ignition Method* (AASHTO, 2005a) should be required. Some agencies, such as Newfoundland now ban such solvent use.

Each agency will develop its own attributes and testing requirements for flexible pavement materials and construction methods based on both generally accepted quality assurance requirements (guidance is provided in Section 3, particularly Tables 4 to 8) and local experience, which is a very important aspect of the evaluation of any specification approach for quality flexible pavements.

5.3 Inspection for Quality Control and Quality Assurance

It is important to recognize that the flexible pavement materials and construction quality achieved for a project is largely a function of the quality focus of the contractor, subcontractor and supplier actually completing the work within a construction quality plan – one which involves everyone from top level management and field supervisors to workers, inspectors and testers. Even when a paving project does not require a contractor construction quality plan, QC inspection will 'pay off' through improved quality with reduced errors and repeat work. Also, as described in Section 4, there are many aspects of flexible pavement materials and construction quality not monitored through attributes testing (QC and QA) that require on-going inspection and action (e.g. subgrade soft spots, granular base placement segregation, HMA thermal segregation), particularly for process and quality control. The contractor, agency or consultant inspectors should be certified technicians or have equivalent training with practical experience in the sampling, testing and record keeping required for construction materials and methods (e.g. the qualification requirements of QC and QA inspectors should be the same).

The contractor's QC inspection activities, with focus on corrective actions before quality becomes a specification compliance issue such as payment and repeat work, will generally be more detailed than the agency's QA inspection which tends to be an overview for specific project specification compliance and acceptance attributes/items (e.g. compacted asphalt pavement segregation), and may incorporate the contractor's QC inspection records. For example, the contractors QC inspectors should complete a detailed inspection (with a team approach to prompt corrective action) of subgrade support (proof rolling), aggregate stockpiles, segregation of granular subbase and base, grade compliance for each component of the pavement structure, condition of HMA transport truck boxes, temperature of HMA, condition and operation of asphalt paver and rollers, HMA mechanical/thermal segregation, placed HMA mat thickness, appearance and straightedge deviation, and joint construction. Detailed checklists for the QC inspection of flexible pavement materials and construction methods are given in Appendix D.

The agency should have a documented QA inspection plan independent of the contractor's QC inspection, noting the agency's overall QA may incorporate the contractor's QC reports. This QA inspection plan should contain a checklist of all attributes/items that require inspection, and be consistent with the project specification requirements. The QA inspection results form part of the basis of the agency's acceptance and disposition of the contractor's work (accept, bonus, payment reduction, repair, reject – remove/replace, etc.) and must be clearly documented in formal inspection reports issued to the contractor. Follow-up QA inspections of all repair and remove/replace activities must also be documented. For some agencies, referee inspection is available to resolve any disputes between the QC and QA inspections.

6 RECOMMENDATIONS FOR A FLEXIBLE PAVEMENT MATERIALS AND CONSTRUCTION QUALITY MANAGEMENT SYSTEM TEMPLATE

A flexible pavement materials and construction quality management system (QMS) must establish the optimum (see Figure 4) general requirements and activities for the quality and process control (contractor's QC), and quality assurance (agency's QA), related to the overall production (materials) and placement (construction) activities for flexible pavement projects. These QMS requirements and activities will include a listing of the QC and QA sampling, testing and inspection requirements and responsibilities for the specific project. These QMS components have been outlined in Section 2.2 and summarized in Table 3 (Contents of a Typical Generic Quality Management System Manual) that is ISO 9001:2000 compliant, with elements and more details given in the appendices:

- Appendix E Example Checklists for Granular Subbase, Base, Aggregates and HMA Production, Transportation, Placement and Compaction.
- Appendix F Typical Specification (ERS) Requirements for a Contractor Quality Control Plan for a Paving Project and Commentary on the Requirements
- Appendix G Table of Contents for a Generic Quality Management System that is ISO Compliant
- Appendix H Outline of a Typical Construction Quality Plan

The contractor should have a properly designed QC plan and the agency should also have a properly designed QA plan, which may incorporate the contractor's QC reporting. The development, design and particularly use of these QC and QA plans is a critical step towards higher quality flexible pavement materials and construction with enhanced life-cycle cost and performance.

It is recommended that the quality management system (QMS) template incorporates the following minimum requirements for QC and QA plans which allow for customization to accommodate the optimum needs (requirements) of individual contractors and agencies for specific flexible pavement projects.

6.1 Contractor Quality Control Plan

The following section describes the quality control plan, including general requirements as well as QC plan for the aggregate production and supply of asphalt materials.

6.1.1 General Requirements

A comprehensive quality control plan should be developed by the contractor specific to operations underway at any given time. The contractor's quality control plan establishes the overall process by which the contractor will achieve the required quality of the work – confirming that quality control is the responsibility of the contractor. The agency (owner) may specify minimum information required for the QC plan such as: personnel, plant operations, transportation of products and roadway operations (see Appendix F).

The quality control plan (QCP) should be contract specific and state how the contractor proposes to control the materials, equipment and operations for the project. The QCP should include the provision of sufficient records of testing, inspection and compliance monitoring to satisfy the agency that the obligations of the contract have been met and the required quality has been achieved. It should clearly detail the policy and methods for identifying and dealing with work that does not meet the specifications, unless the agency details these in the contract documents. The QCP should include a policy and procedure for making revisions to the QCP, as part of the contractor's continuous improvement program for quality control (QC). The following is a suggested outline for the QCP content:

A. Quality control (process control) testing, monitoring and reporting. List the materials to be sampled, tests to be conducted, and location of sampling, lot and sublot size (typically 5 or 10 sublots comprise a lot), frequency of testing, the process control chart system to be used and the reporting of testing results. The relevant AASHTO (or ASTM) standards for sampling, testing, inspection and reporting have been discussed in Section 4 and 5.

B. Inspection/control procedures. Address each of the following items for each phase of the construction:

   1. Preparatory phase

      a. Review all contract requirements.
      b. Ensure compliance of component materials to the contract requirements.
      c. Coordinate all submittals, including certifications of materials and facilities.
      d. Ensure the capability of equipment and personnel to comply with contract requirements.
      e. Ensure preliminary testing is completed.
      f. Coordinate survey and staking of the work, including locates.

   2. Start-Up phase

      a. Review the contract requirements with personnel who will perform the work.
      b. Inspect start-up of work.
      c. Establish standards of workmanship.
      d. Provide training as necessary.
      e. Establish detailed testing schedule based on the production schedule.

   3. Production phase

      a. Conduct intermittent or continuous inspection during construction to identify and correct deficiencies.
      b. Inspect completed phases before scheduled agency acceptance.
      c. Provide feedback and system changes to prevent repeated deficiencies.

C. Description of records. List the records to be maintained.

D. Personnel qualifications.

   1. Document the name, authority, relevant experience and qualifications of person with overall responsibility for the QCP implementation and management.
   2. Document the names, authority and relevant experience of all personnel directly responsible for inspection and testing.

E. Subcontractors and suppliers. Include the work of all subcontractors and products of all suppliers. Detail how the subcontractors and suppliers will interface with the contractor and/or other subcontractors and suppliers. Include the quality control plan of each subcontractor and supplier.

6.1.2 Quality Control Plan for Aggregates Production

A contractor's quality control plan should include as a minimum, discussion on the proposed processing, transportation, stockpiling and plant supply operations and the following elements:

1. The provision of a qualified aggregate technician (preferably certified) that will perform the appropriate duties during critical activities and comply with the specific requirements of the QCP.

2. Provision and maintenance of a laboratory (preferably certified by an accredited agency) for process control testing and requirements for the necessary space, equipment and supplies to facilitate the required QC testing, noting that the laboratory equipment must meet the requirements outlined in the test procedures (AASHTO, ASTM, and other), including proper calibration.

3. Sampling and testing of all materials that require control for aggregate gradation, washed loss, abrasion resistance, deleterious materials and fractured faces count must be in conformance with project requirements. The sampling process, such as uniform tonnage increments in an unbiased manner (e.g. stratified random sampling) and the specified test method, should be documented. The testing should be completed in such time as to assure that the process control is adequately maintained.

4. Maintenance of control charts is performed by the aggregate producer at the QC laboratory. The timeframe for recording all QC test results on the control charts is typically on the same day that the testing is completed. As a minimum, charts should be maintained until 30 test data points have been plotted and the points continuously displayed.

5. Critical sieves (e.g. 4.75 mm, 0.075 mm) for each aggregate size should be included in quality control charts.

6. Minimum period for maintenance of QC test results is defined, typically 3 to 5 years.

6.1.3 Quality Control Plan for Supply of Asphalt Materials

The contractor's QCP should include as a minimum, discussion on the proposed source, manufacture, storage, shipping and handling of all asphalt materials (asphalt cement, tack coat, etc.) and the following elements:

1. Requirements for the supplier laboratory such as need for and type of certification and participation in proficiency programs (AMRL for instance).

2. Frequency of sampling and testing each grade of asphalt cement and the test methods (AASHTO, ASTM and others) to be followed and project specification requirements to be met.

3. Supplier requirements for asphalt transport (e.g. temperatures and tank cleanliness), furnishing instructions (for each grade of asphalt cement) on the proper storage and handling of the asphalt cement, and temperature-viscosity chart showing compaction and recompaction temperatures for each asphalt cement grade for the project.

4. Requirements for providing certificates of compliance for each grade of asphalt cement that the asphalt cement has been manufactured by AASHTO Designation: M 320-02.

5. Timeframe for maintenance of detailed records including QC test results and shipments.

It should be noted that the above suggested outline of the contractor quality control plan (QCP) content may not completely cover the requirements (details) for a specific contract or prescribed work. It is the responsibility of the contractor to ensure that the submitted quality control plan complies with all the contract and work requirements.

6.2 Quality Assurance Plan

The agency quality assurance plan (QAP) must include the requirements for the agency's assessment and acceptance of a flexible pavement construction project. This QAP typically combined with the contractor's quality control plan, provides for the necessary QA for verification and acceptance of the work.

The following sections suggest outline for QAP content:

6.2.1 Quality Assurance Plan for Aggregate Production

The agency's QAP should include as a minimum, discussion on the QA sampling, testing, inspection and acceptance of aggregates for granular subbase and base, and hot-mix asphalt and the following elements:

1. The provision of a qualified QA aggregate technician (preferably certified) who will perform the appropriate duties during critical activities and comply with the specific requirements of the QA plan.

2. Provision and maintenance of a laboratory (preferably certified) for acceptance testing and requirements for the necessary space, equipment and supplies to facilitate the required QA testing, noting that the laboratory equipment must meet the requirements outlined in the applicable test procedures (AASHTO, ASTM, and other), including proper calibration.

3. Evaluation of the aggregate producer's (or supplier's) QC laboratory and testing personnel.

4. Review of contractor submittals (results of physical property testing for instance).

5. Sampling and testing of all aggregates that require acceptance for the contract.

6. The method of acceptance, which should be statistically-based.

7. Minimum period for maintenance of QA test results.

6.2.2 Quality Assurance Plan for Supply of Asphalt Materials

The agency's QAP should include as a minimum, discussion on the QA sampling, testing, inspection and acceptance of asphalt materials (asphalt cements, tack coat, etc.) and the following elements:

1. Requirements for QA laboratory such as need for and type of certification and participation in proficiency programs.
2. Evaluation of the supplier's qualified laboratory and testing personnel.
3. Frequency of sampling and testing each grade of asphalt cement, test methods to be followed and specification requirements.
4. Requirements for review of submittals (QC test results, certificates of compliance, etc).
5. Timeframe for maintenance of detailed records including QA test results.

6.2.3 Quality Assurance Plan for Granular Subbase/Base Roadway Operations

The agency's QAP should include as a minimum, discussion on the QA sampling, testing, inspection and acceptance for the placement and compaction of granular base and subbase and the following elements:

1. The provision of a qualified QA aggregates/compaction technician (preferably certified) and an outline of duties such as QA testing for compaction and grade.
2. Evaluation of the contractor's QC field testing personnel.
3. Review of contractor submittals.
4. Designating the test methods, testing frequencies and locations necessary for QA compaction, grade checks, etc.
5. The method of acceptance, which should be statistically-based.
6. Documentation of all QA sampling, testing and inspection. The plan should indicate what is included in the records (test results, inspection reports, nonconformance reports, nature of corrective and preventative actions, etc), who should have access to them, and how long the records should be kept on file after completion of the work.

6.2.4 Quality Assurance Plan for Hot-Mix Asphalt Production

The agency's QAP should include as a minimum, discussion on the QA sampling, testing, inspection and acceptance of HMA and the following elements:

1. The provision of a qualified QA asphalt technician (preferably certified) who will inspect, sample and test HMA. The duties of the technician such as supervision of all other inspection, sampling and testing of materials and distribution of all test reports.

2. Provision and maintenance of a QA laboratory and requirements such as the necessary space, equipment and supplies for the required testing, noting that the laboratory equipment must meet the requirements outlined in the test procedures (AASHTO, ASTM, or other) including proper calibration.

3. Evaluation of the contractor's qualified QC laboratory and testing personnel.

4. Designating the sampling and splitting procedures, test methods, sampling frequencies, locations, number, and size of samples necessary for QA. A suitable timeframe for testing of the samples should be included (typically within four days after sampling for HMA compliance testing).

5. The method of acceptance, which should be statistically-based.

6. Minimum period for maintenance of QA records.

6.2.5 Quality Assurance Plan for HMA Roadway Operations

The agency's QA plan should include as a minimum, discussion on the QA sampling, testing, inspection and acceptance for the placement and compaction of HMA to ensure compliance with the project specifications and the following:

1. The provision of a qualified QA asphalt technician (preferably certified) and an outline of his/her duties such as QA testing for compaction, segregation and smoothness and the monitoring of paving operations.

2. Evaluation of the contractor's QC field testing personnel.

3. Review of contractor submittals.

4. Designating the test methods, testing frequencies and locations necessary for QA compaction, segregation and smoothness measurements, etc.

5. The method of acceptance, which is commonly statistically-based (for example, percent-within-limits (PWL) using standard deviation, PWL using conformal index, or mean and range).

6. Documentation of all QA testing/inspection, and equipment used in the granular placement operations. The plan should indicate what is included in the records (test results, inspection reports, nonconformance reports, nature of corrective and preventative actions, etc), who should have access to them and how long the records should be kept on file after completion of the work.

6.3 Concluding Comments

These recommendations for the contractor QC and agency QA components of the quality management system (QMS) are generic and incorporate typical processes in use by most contracting agencies; some contracting agencies will have processes or conditions which require additional elements to be addressed in the QCPs and QAPs. It should be also stated in the QMS that if any inconsistencies or conflicts exist between the contract documents and the QCP or QAP, that the contract documents will govern.

Overall, the development of any quality management system template for flexible pavement materials and construction must recognize that quality cannot be tested or inspected into a flexible pavement – it must be built in with the assistance of the QMS contractor's QC and agency's QA plans.

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APPENDIX A DEFINITIONS, ACRONYMS AND ABBREVIATIONS

A.1. DEFINITION OF TERMS FOR PAVEMENT SPECIFICATIONS, QUALITY, MATERIALS AND CONSTRUCTION

The definitions are mainly based on AASHTO and TRB standards and practices that provide a fuller range of terms and notes on use (TRB, 2005a).

acceptable quality level (AQL) – that minimum level of actual quality that is considered fully acceptable as a process average for a single acceptance quality characteristic – for example, when quality is based on percent within limits (PWL), the AQL is that actual (not estimated) PWL at which the quality characteristic can just be considered fully acceptable.

acceptance constant (k) – the minimum allowable quality index (Q) for a variable acceptance procedure.

acceptance number (c) – in attributes acceptance plans, the maximum number of defective units in the sample that will permit acceptance of the inspected lot or batch.

acceptance plan – an agreed-upon method of taking samples and making measurements or observations on these samples for the purpose of evaluating the acceptability of a lot of material or construction.

acceptance sampling and testing – sampling, testing, and the assessment of test results done to determine whether or not the quality of produced material or construction is acceptable in terms of the specifications.

accuracy – the degree to which a measurement, or the mean of a distribution of measurements, tends to coincide with the true population mean.

asphalt binder – an asphalt-based cement that is produced from petroleum residue either with or without the addition of organic modifiers.

asphalt modifier – any organic material of suitable manufacture, used in either new or recycled condition, which is dissolved, dispersed or reacted in asphalt cement to enhance its performance.

assignable cause – a relatively large source of variation, usually due to error or process change, which can be detected by statistical methods and corrected within economic limits.

attribute acceptance plan – a statistical acceptance procedure where the acceptability of a lot of material or construction is evaluated by noting the presence (absence) of some characteristic or attribute in each of the units or samples in the group under consideration, and counting how many units do (do not) possess this characteristic.

base – the layer or layers of material placed on a subbase or subgrade to support a surface course.

bias – an error, constant in direction, common to each of a set of values, which cannot be eliminated by any process of averaging – an error, constant in direction, that causes a measurement, or the mean of a distribution of measurements, to be offset from the true population mean.

buyer's risk (β) – also called type II error or β error – the probability that an acceptance plan will erroneously fully accept (at 100 percent pay or greater) RQL material or construction with respect to a single acceptance quality characteristic.

chance cause – a source of variation that is inherent in any production process and cannot be eliminated as it is due to random, expected causes.

cold recycling (cold asphalt pavement recycling) – full or partial depth reuse of old asphalt concrete pavement (can be used for surface treatment, and can include treated and untreated base) that is either processed in-place (by cold in-place recycling train or full-depth in-place asphalt pavement reprocessing method, CIR) or at a central plant, typically with the addition of emulsified asphalt (or other additive such as cutback asphalt, lime or cement) and sometimes new aggregate to achieve desired cold mix quality, followed by placement and compaction.

control chart (also called statistical control chart) – a graphical method of process control which detects when assignable causes are acting on a continuous production line process and when normal, expected variation is occurring.

control limits (upper, lower) (also called action limits) – boundaries established by statistical analysis for material production control using the control chart technique. When values of the material characteristics fall within these limits, the process is "under control." When values fall outside the limits, there is an indication that some assignable cause is present causing the process to be "out of control".

controlled process (also called process under statistical control) – a production process in which the mean and variability of a series of tests on the product remain stable, with the variability due to chance only.

crown control – a device which shapes the screed to form a mat with the desired crown.

deleterious materials – undesirable contaminants, such as soft shale, coal, wood, or mica, which are found in a blended aggregate.

end result specifications (ERS) – specifications that require the contractor to take the entire responsibility for supplying a product or an item of construction – the highway agency's responsibility is to either accept or reject the final product or apply a price adjustment that is commensurate with the degree of compliance with the specifications.

equivalent single axle loads (ESALs) – summation of 80 kN single axle load applications used to combine mixed vehicle (trucks) and bus traffic to determine design traffic during the pavement design analysis period.

expected pay (EP) curve – a graphic representation of an acceptance plan that shows the relationship between the actual quality of a lot and its expected pay.

foamed asphalt – a mixture of undried, cold RAP and/or aggregate that is bound together by mixing it with a foamed asphalt binder formed by injecting a metered amount of cold water into a stream of hot asphalt binder in a mixing unit.

full depth reclamation (FDR) – full thickness of existing asphalt concrete is processed and recycled, usually by mixing/blending with underlying granular base/subbase or subgrade – full depth reclamation may also include stabilization using foamed asphalt, cement or lime.

hot in-place recycling (HIR) – hot reworking of the surface of an aged asphalt pavement (typically 50 – 75 mm) using preheaters and a heat reforming machine, typically with the addition of a rejuvenator, aggregate or new hot mix (HMA) to restore the condition of the scarified old asphalt pavement, and sometimes with an integral surface course overlay, all suitably placed and compacted in a single or multi-pass process.

incentive/disincentive provision (for quality) – a pay adjustment schedule which functions to motivate the contractor to provide a high level of quality.

independent assurance – a management tool that requires a third party, not directly responsible for process control or acceptance, to provide an independent assessment of the product and/or the reliability of test results obtained from process control and acceptance testing.

independent assurance program – a program conducted by independent, certified staff to ensure all testing is performed correctly – includes elements to train and certify testers, evaluate laboratories and calibrate equipment.

lift – when placing and compacting soils, aggregates and hot-mix asphalt, a lift is any single, continuous layer of material that receives the same compactive effort throughout during a single work operation.

liquidated damages provisions (for quality) – a pay adjustment schedule whose primary function is to recover costs associated with the contractor’s failure to provide the desired level of quality.

long-life asphalt – an asphalt pavement designed and constructed to last longer than 50 years without requiring rehabilitation, and needing only periodic surface renewal (termed “perpetual pavement” by the APA).

material – any substances specified or necessary to satisfactorily complete the contract work.

material and construction (M and C) variable – a characteristic of materials and/or construction that can be directly or indirectly controlled. Thickness is an example of an M and C variable that is controlled directly; compressive strength is an example of one controlled indirectly.

materials and methods specifications (also called method specifications, recipe specifications, or prescriptive specifications) – specifications that direct the contractor to use specified materials in definite proportions and specific types of equipment and methods to place the material.

maximum (aggregate) size – a sieve size which is one size larger than the nominal maximum size.

milling – removing the surface of an asphalt concrete pavement, using a traveling machine equipped with a transverse rotating cutter drum (milling head with tips), typically 25 to 75 mm in depth.

nominal (aggregate) size – a sieve size which is one size larger than the first sieve to retain more than 10 percent of the aggregate.

operating characteristic curve (OC Curve) – a graphic representation of an acceptance plan that shows the relationship between the actual quality of a lot and either (a) the probability of its acceptance or (b) the probability of its acceptance at various payment levels.

pavement condition index (PCI) – numerical rating of the pavement condition that ranges from 0 to 100, with 0 being the worst possible condition (failed) and 100 being the best possible condition (excellent) – it is determined through a systematic pavement condition survey (e.g., ASTM D6433) in terms of the type, severity, and extent of the pavement distresses.

pavement condition indicator (also called pavement distress indicator) – a measure of the condition of an existing pavement section at a particular point in time, such as cracking measured in ft/mi or in m/km or wheelpath faulting measured in in./mi or mm/km – when considered collectively, pavement condition indicators provide an estimate of the overall adequacy of a particular roadway.

pavement distress – external indicators of pavement deterioration caused by loading, environmental factors, construction deficiencies, or a combination thereof – typical distresses are cracks, rutting, and weathering of the pavement surface.

pavement performance – the history of pavement condition indicators over time or with increasing axle load applications.

pavement structure – the combination of subbase, base, paving geotextiles, and surface courses placed on a subgrade to support and distribute the traffic load to the roadbed.

pay adjustment schedule (for quality) (also called price adjustment schedule or adjusted pay schedule) – a pre-established schedule, in either tabular or equation form, for assigning pay factors associated with estimated quality levels of a given quality characteristic – the pay factors are usually expressed as percentages of the original contract bid price.

pay adjustment system (for quality) (also called price adjustment system or adjusted pay system) – all pay adjustment schedules along with the equation or algorithm that is used to determine the overall pay factor for a submitted lot of material or construction.

percent defective (PD) (also called percent nonconforming) – the percentage of the lot falling outside specification limits – it may refer to either the population value or the sample estimate of the population value.

percent within limits (PWL) (also called percent conforming) – the percentage of the lot falling above a lower specification limit, beneath an upper specification limit, or between upper and lower specification limits – it may refer to either the population value or the sample estimate of the population value. PWL = 100 – PD.

performance graded asphalt cement (asphalt binder) (PG or PGAC) – an asphalt cement for which the physical properties can be directly related to field performance by engineering principles – performance graded binders are defined by a term such as PG xx-yy – the first number, xx, is the high temperature grade and indicates the asphalt cement possesses adequate physical properties up to at least xx°C – the second number, -yy, is the low temperature grade and indicates the asphalt cement possesses adequate physical properties in pavements down to at least -yy°C.

performance specifications – specifications that describe how the finished product should perform over time – for highways, performance is typically described in terms of changes in physical condition of the surface and its response to load, or in terms of the cumulative traffic required to bring the pavement to a condition defined as 'failure' – specifications containing warranty/guarantee clauses are a form of performance specifications.

performance-based specifications – specifications that describe the desired levels of fundamental engineering properties that are predictors of performance and appear in primary prediction relationships.

performance-related M and C variable – a characteristic of materials and/or construction that has an influence on pavement performance, either by itself or interactively when in combination with other M and C variables – any M and C variable that is a primary or secondary predictor is a performance-related variable.

performance-related specifications – specifications that describe the desired levels of key materials and construction quality characteristics that have been found to correlate with fundamental engineering properties that predict performance – these characteristics (for example, air voids in asphaltic pavements, and strength of concrete cores) are amenable to acceptance testing at the time of construction – true performance-related specifications not only describe the desired levels of these quality characteristics, but also employ the quantified relationships containing the characteristics to predict subsequent pavement performance.

polymer modified binder (PMB) – polymer modified asphalt (PMA) – asphalt cement that has had its physical and chemical properties modified/enhanced by the addition of a polymer – PMA provides enhanced durability, improved rutting resistance at high temperatures, and increased resistance to low temperature cracking.

precision – (1) the degree of agreement among a randomly selected series of measurements; and (2) the degree to which tests or measurements on identical samples tend to produce the same results.

primary relationship – an equation that can be used to predict pavement stress, distress, or performance from particular combinations of predictor variables that represent traffic, environmental, roadbed, and structural conditions – some examples of predictor variables are annual rate of equivalent single axle load accumulation, annual precipitation, roadbed soil modulus, and concrete flexural strength.

production facility audit – on-site inspection of production facilities to determine the capacity to produce material that will consistently meet specifications.

process control materials and construction variable – a characteristic of materials and/or construction, the specification for which enhances the control of another M and C variable – an example of a process control M and C variable is soil moisture content to control density and compaction.

qualified manufacturers list – list of manufacturers that have been prequalified to perform work in accordance with specifications – usually involves a formalized review of manufacturer's QC program, equipment capabilities and personnel certifications.

qualified products list – list of products that have been prequalified as meeting specifications – usually coupled with an acceptance test to assure the material used is identical to the material prequalified.

quality – (1) the degree or grade of excellence of a product or service; (2) The degree to which a product or service satisfies the needs of a specific customer; and (3) The degree to which a product or service conforms with a given requirement.

quality assurance (QA) – all those planned and systematic actions necessary to provide confidence that a product or facility will perform satisfactorily in service – quality assurance addresses the overall problem of obtaining the quality of a service, product, or facility in the most efficient, economical, and satisfactory manner possible – within this broad context, quality assurance involves continued evaluation of the activities of planning, design, development of plans and specifications, advertising and awarding of contracts, construction, and maintenance, and the interactions of these activities.

quality assurance specifications (also called QA/QC specifications or QC/QA specifications) – a combination of end result specifications and materials and methods specifications. The contractor is responsible for quality control (process control), and the highway agency is responsible for acceptance of the product.

quality characteristic – that characteristic of a unit or product that is actually measured to determine conformance with a given requirement.

quality control (QC) (also called process control) – those quality assurance actions and considerations necessary to assess production and construction processes, so as to control the level of quality being produced in the end product – this concept of quality control includes sampling and testing to monitor the process but usually does not include acceptance sampling and testing.

quality control plan – document that demonstrates the capability to produce material that will consistently meet specifications – normally includes QC organization, tester certifications, sampling and testing regimen.

quality index (Q) – a statistic which, when used with appropriate tables, provides an estimate of either percent defective (PD) or percent within limits (PWL) of a lot – it is typically computed from the mean and standard deviation of a set of test results as follows:

$Q_L = \overline{X} - L / S$ Where $\overline{X}$ = sample mean

S = sample standard deviation

or L = lower specification limit

$Q_U = U - \overline{X} / S$ U = upper specification limit

reclaimed asphalt pavement (RAP) – removed and/or processed pavement materials containing asphalt cement and aggregates.

reclaimed concrete material (RCM) – removed and/or processed old Portland cement concrete (PCC).

recycled hot mix (RHM) – removal (surface milling or full depth) of old asphalt concrete (reclaimed asphalt pavement, RAP), processing, heating and mixing in a hot-mix plant (batch, drum or drum/batch) with new aggregates and new asphalt cement (softer grade or with recycling agent), relaying and compacting to meet specifications for conventional hot-mix asphalt concrete (HMA).

rejectable quality level (RQL) – that maximum level of actual quality that is considered unacceptable (rejectable) as a process average for a single acceptance quality characteristic – for example, when quality is based on percent defective (PD), the RQL is that actual (not estimated) PD at which the quality characteristic can just be considered fully rejectable.

reliability – the degree to which a test produces consistent or dependable results – test reliability is increased as both precision and accuracy are improved – reliability can also refer to product reliability, defined as (1) the degree of conformance or failure of the specific product to meet the consumer's quality needs; and (2) the probability of a product performing without failure of a specified function under given conditions for a specified period of time – in (1) and (2), reliability is that aspect of quality assurance which is concerned with the quality of product function over time.

repeatability – degree of variation among the results obtained by the same operator repeating a test on the same material – the term repeatability is therefore used to designate test precision under a single operator.

reproducibility – degree of variation among the results obtained by different operators doing the same test on the same material – in other words, it measures the human influence or human error in the execution of a test – the term reproducibility may be used to designate interlaboratory test precision.

roadbed – the graded portion of a highway prepared as a foundation for the pavement structure and shoulders.

roller pass – one trip of a roller in one direction over any one spot.

secondary relationship – an equation that shows how one or more M and C variables are related to at least one predictor variable – the equation $S_f = \sqrt{Sc}$ (where S_f is concrete flexural strength and S_c is concrete compressive strength) is an example of a secondary relationship.

seller's risk (α) – also called type I error or α error. The probability that an acceptance plan will erroneously reject AQL material or construction with respect to a single acceptance quality characteristic. It is the risk the contractor or producer takes in having AQL material or construction rejected.

specification limit(s) – the limiting value(s) established, preferably by statistical analysis, for evaluating material or construction acceptability within the specification requirements – it may be expressed as either an upper (U) or a lower specification limit (L), called a single specification limit; or both upper and lower specification limits, called a double specification limit.

statistically based specifications – also called statistical specifications or statistically oriented specifications – specifications based on random sampling, and in which properties of the desired product or construction are described by appropriate statistical parameters.

subbase – the layer or layers of material placed on a subgrade to support a base.

subgrade – the top surface of a roadbed upon which the pavement structure, shoulders, and curbs are constructed.

suitable material – rock or earth material that will provide stable foundations, embankments, or roadbeds, and is reasonably free of organic matter, roots, muck, sod, or other detrimental material – suitable material may require drying or adding water, root picking, and other methods of manipulation before use. Suitable material includes the classifications of material for which the project was designed.

surrogate materials and construction variable – a characteristic of materials and/or construction that can be used to substitute for a performance-related M&C variable – for example, concrete compressive strength can be a surrogate for concrete flexural strength.

tolerance limits – limits that define the conformance boundaries for a manufacturing or service operation.

unsuitable material – material not capable of creating stable foundations, embankments, or roadbeds – unsuitable material includes muck, sod, or soils with high organic contents.

variable sampling rates – sampling rates, by either quantity or production time, that can be tightened or relaxed based on the compliance of the material with specification requirements.

variables acceptance plan – a statistical acceptance procedure where quality is evaluated by measuring the numerical magnitude of a quality characteristic for each of the units or samples in the group under consideration, and computing statistics such as the average or the average and standard deviation of the group.

variables assurance program – sampling rates, by either quantity or production time, that can be tightened or relaxed based on the compliance rating of the material provider.

verification – testing or inspection by the consumer or his agent to verify the accuracy and representativeness of material provider QC.

warning limits (upper, lower) – boundaries established on control charts within the upper and lower control limits, to warn the producer of possible problems in the production process that may lead to the process going out of control.

work – the furnishing of all labour, material, equipment, and other incidentals necessary to successfully complete the project according to the contract.

A.2. ACRONYMS FOR AGENCIES AND ASSOCIATIONS

AASHTO – American Association of State Highway and Transportation Officials <*www.transportation.org*>*.*

ACI – American Concrete Institute <*www.concrete.org*>.

ACPA – American Concrete Pavement Association <*www.pavement.com*>.

AI – Asphalt Institute <*www.asphaltinstitute.org*>

AI (OHMPA) – Ontario Hot Mix Producers Association <*www.ohmpa.org*>*.*

APA – Asphalt Pavement Alliance <*www.astm.org*>.

ARRA – Asphalt Reclamation and Recycling Association <*www.arra.org*>*.*

ASTM – American Society for Testing and Materials <*www.astm.org*>.

CAC – Cement Association of Canada <*www.cement.ca*>.

CCIL – Canadian Council of Independent Laboratories <www.ccil.com>

CGSB – Canadian General Standards Board <*www.pwgsc.gc.ca/cgsb*>.

CSA – Canadian Standards Association <*www.csa.ca*>.

C-SHRP – Canadian Strategic Highway Research Program <*www.cshrp.org*>.

CTAA – Canadian Technical Asphalt Association <*www.ctaa.ca*>.

EPA – Environment Protection Agency <*www.epa.gov*>*.*

FCM – Federation of Canadian Municipalities <*www.fcm.ca*>*.*

FHWA – Federal Highway Administration <*www.fhwa.dot.gov*>.

FPP – Foundation for Pavement Preservation <*www.fp2.org*>*.*

ICPI – Interlocking Concrete Pavement Institute <*www.icpi.org*> [ICPI Canada].

MTO – Ontario Ministry of Transportation <*www.mto.gov.on.ca*>*.*

MTQ – Ministère des Transports du Québec <*www.mtq.gouv.qc.ca*>*.*

NAPA – National Asphalt Pavement Association <*www.hotmix.org*>*.*

NCHRP – National Cooperative Highway Research Program <*www4.trb.org/trb/crp.nsf*>*.*

NGSMI – National Guide to Sustainable Municipal Infrastructure <*www.infraguide.ca.*>

NRC – National Research Council <*www.nrc.ca*>*.*

OPS – Ontario Provincial Standards
<*www.raqsb.mto.gov.on.ca/techpubs/ops.nsf/OPSHomepage*>.

PIARC – Permanent International Association of Road Congresses (PIARC/AIPCR)
<*www.piarc.org/en*>*.*

SHRP – Strategic Highway Research Program <*www.cshrp.org*>*.*

TAC – Transportation Association of Canada <*www.tac-atc.ca*>*.*

TRB – Transportation Research Board <www.trb.org>

A.3. TECHNICAL TERMS

AADT	annual average daily traffic
CBR	California bearing ratio
ESALs	equivalent single axle loads
FWD	falling weight deflectometer
GB	granular base
GBE	granular base equivalency
GSB	granular subbase
HDBC	heavy-duty binder course
HMA	hot-mix asphalt
LCB	lean concrete base
LCCA	life cycle cost analysis
LSBC	large stone binder course
MSDS	material safety data sheet
OGDL	open graded drainage layer
OGFC	open graded friction course
PCCP	Portland cement concrete pavement
PCI	pavement condition index
PG	performance graded
PGAC	performance graded asphalt cement (binder, PGAB)
PMA	polymer modified asphalt cement (binder, PMB)
PMPGAC	polymer modified performance graded asphalt cement (binder, PMPGAB)
SMA	stone mastic asphalt (termed stone matrix asphalt in US)
TGB	treated granular base (with cement for instance)
TSR	tensile strength ratio (tensile strength of conditioned subset/tensile strength of dry subset

APPENDIX B PHOTOGRAPHS OF ASPHALT PAVEMENTS

B.1. TYPICAL ASPHALT PAVEMENT QUALITY PROBLEMS THAT WILL RESULT IN POOR LIFE-CYCLE PERFORMANCE

(These asphalt pavements were less than two years old at the time of inspection.)

1. Example of poor transverse joints and open cracking longitudinal joint. There are also areas of low severity segregation and mat texture variability.

2. Example of very severe shoving and slippage on an uphill gradient area, most likely caused by poor bond of the hot-mix asphalt overlay (inadequate tack coating and dirt on the milled surface for instance).

3. Example (close-up) of an open and medium severity cracking longitudinal joint (progressive deterioration) due to poor construction practices (‘cold’ weather paving, poor compaction of joint area and no joint tacking for instance).

4. Example of generally poor overall quality (poor appearance) with poor transverse and longitudinal joints, mat texture variability, raveling and some low severity reflection cracking.

5. Example of generally poor overall quality (poor appearance) with poor transverse and longitudinal joints, texture variability and, particularly, medium to high severity longitudinal reflective cracking.

B.2. PLACING AND COMPACTING STONE MASTIC ASPHALT (SMA) SURFACE COURSE

6. Placing stone mastic asphalt (SMA) surface course as long-life asphalt pavement with two pavers in echelon and a material transfer vehicle (MTV).

7. Compacting the stone mastic asphalt (SMA) with two large vibratory rollers working in the static mode and soap solution on the steel wheels to avoid pick-up of the polymer modified binder (PMB) SMA.

B.3. ASPHALT CONCRETE (SMA) CORING AS PART OF NUCLEAR GAUGE CALIBRATION

8. Using dry ice to cool the stone mastic asphalt (SMA) to permit quick coring offresh mat in order to calibrate the nuclear gauge that has already been used to determine the in-place densities at each coring location.

Photos: John Emery Geotechnical Engineering Limited

APPENDIX C SURVEY/QUESTIONNAIRE AND RESPONSE SUMMARIES

C.1 ELECTRONIC SURVEY/QUESTIONNAIRE

Synthesis of Practices for Quality Management for the Production and Placement of Paving Materials Available in Canada

TRANSPORTATION ASSOCIATION OF CANADA / ASSOCIATION DES TRANSPORTS DU CANADA

APRIL 2005

The purpose of this electronic survey/questionnaire is to obtain direct information on your agency's current practices and procedures for managing the quality of materials used for flexible pavement construction, maintenance and rehabilitation, during both production and placement. If you are not the technical specialist in this area in your agency, please indicate an appropriate technical specialist at a senior level for us to contact, with thanks.

Name	______________	Date Completed	______________
Title	______________	Agency	______________
Address	______________	Telephone	______________
	______________	Facsimile	______________
City	______________	E-Mail	______________
Province	______________		______________

DEFINITIONS

For this Synthesis of Practices, ***Paving Materials*** have been defined as all materials placed above the subgrade layer including all unbound subbase and base layers and the asphalt concrete layer(s), i.e. flexible pavements. Note that concrete base and exposed concrete (rigid) pavements are not included in this Synthesis of Practices.

GENERAL

In this initial section of the survey/questionnaire, we would like to obtain some general information on the size of your agency/municipality, and the types and distribution of roads under your jurisdiction.

1. What is the approximate size (population) of your agency/municipality?

Small (<100,000)	_______	Medium (100,000 to 500,000)	_______
Large (500,000 to 1 million)	_______	Very Large (>1 million)	_______
Provincial	_______		

2. What is the approximate length of your total road network, in lane-km?____________

3. What is the approximate distribution of pavement types in your road network [*Please estimate each type as a percentage of the total*]?

Flexible – Asphalt concrete over granular base/subbase	_________
Rigid – Portland cement concrete	_________
Composite – Asphalt concrete over Portland cement concrete base	_________
Other – Gravel, concrete pavers, etc.	_________
Total	100

TYPES OF SPECIFICATIONS

In this section, we would like to know what types of specifications your agency/municipality has adopted for paving materials production and placement.

4. What type(s) of specifications are you currently using for the production and placement of flexible pavement components (granular subbase, granular base and hot-mix asphalt)?

	Hot-Mix Asphalt		Base		Subbase	
Prescriptive (Method) Specifications	☐ Yes	☐ No	☐ Yes	☐ No	☐ Yes	☐ No
End result Specifications (ERS)	☐ Yes	☐ No	☐ Yes	☐ No	☐ Yes	☐ No
Performance Specifications	☐ Yes	☐ No	☐ Yes	☐ No	☐ Yes	☐ No
Warranties	☐ Yes	☐ No	☐ Yes	☐ No	☐ Yes	☐ No
Combination of Above	☐ Yes	☐ No	☐ Yes	☐ No	☐ Yes	☐ No
Other	____________					

5. What standard specifications are currently used within your agency for pavement materials and construction, maintenance and rehabilitation work?

Own Agency Specifications or Special Provisions	☐ Yes	☐ No
Provincial Standard Specifications	☐ Yes	☐ No
Federal Specifications (such as National Master General Specifications)	☐ Yes	☐ No
Other Specifications (ASTM, AASHTO, etc.)	☐ Yes	☐ No
If Own Agency or Other, please provide details, or a link where specifications can be downloaded	____________________	

6. Please rank in order of importance (1 = most important, 5 = not important), the factors that you consider to be effective measures of the quality of paving materials production and placement:

Aggregate gradation	______	Aggregate physical properties	______
Density (after compaction)	______	Asphalt binder selection	______
Asphalt Cement Content	______	Asphalt binder properties	______
Stability and Flow	______	% Air voids	______
Voids Mineral Aggregate (VMA)	______	Surface Texture/Segregation	______
Smoothness		Rutting Resistance	

7. Is your agency satisfied with the overall quality of pavements delivered by these specifications, and if *No*, are you contemplating any changes to your specifications or contracts at this time? [*Please provide comments below*.]

☐ Yes ☐ No

____

____

____

8. Do you have any plans to adopt new ERS or performance specifications any time in the near future? [If *Yes*, please indicate the specific paving materials and/or pavement construction where ERS or performance specifications are to be implemented, and the approximate timing.]

☐ Yes ☐ No

____

____

____

9. If you are currently using ERS specifications, can you identify any specific problems that have been or are being encountered with ERS specifications? Would you say that the problems experienced are mainly related to interpretation of the specification, payment factors or contract administration?

____

____

____

____

10. Is there any one specification, or part of the specifications, that has been more controversial (leading to disputes or issues requiring resolution) than the others? Are there any specific specifications that have required or are proposed for substantial revisions or rewriting.

____

____

____

____

11. How does your agency determine the criteria for acceptance and rejection, and payment adjustment factors?

____

____

____

____

12. Is the contractor's QC testing relied upon for acceptance or rejection, or allocation of payment reductions or bonuses? How are the QC tests results verified?

____

____

____

____

QUALITY MANAGEMENT

In this section, we would like to know the approach that your agency is taking for total quality management of the production and placement of paving materials.

13. Who is responsible for quality control/process control activities during paving materials production (field sampling and/or laboratory testing)?

Contractor/Supplier	Sampling	☐	Testing	☐
Owner/Agency	Sampling	☐	Testing	☐
Designated Consultant(s)	Sampling	☐	Testing	☐

14. Who is responsible for quality assurance/verification activities during paving materials production (field sampling and laboratory testing)?

Contractor/Supplier	Sampling	☐	Testing	☐
Owner/Agency	Sampling	☐	Testing	☐
Designated Consultant(s)	Sampling	☐	Testing	☐

15. Does your agency have a third-party audit process in-place to check the QC and/or QA? [If *Yes*, please briefly describe what this encompasses, when it is used, and who is involved.]

☐ Yes ☐ No

____

____

____

____

16. Do you require certified laboratories (such as Canadian Council of Independent Laboratories (CCIL) or equivalent) for QC and/or QA testing?

☐ Yes ☐ No If Yes, please specify: ____________________

17. Does your agency require that QC and QA staff involved in paving materials sampling, field testing' laboratory testing and/or inspection be 'certified'. [If *Yes*, please indicate what certifications, qualifications or special training are required and how these are verified and renewed.]

☐ Yes ☐ No

____

____

____

18. Does your agency require that QA and/or QC testing laboratories participate in round-robin or correlation programs, or annual laboratory inspections, in addition to or in lieu of certification? [If *Yes*, please briefly describe the program and how it is administered below]?

☐ Yes ☐ No

____

____

____

19. Are you satisfied with the quality management approach for asphalt pavement materials and construction currently used in your jurisdiction?

☐ Yes ☐ No

____

____

____

20. Has the quality of inspection and testing been an issue between the owner/agency, the contractors and consultants, and if so, how?

☐ Yes ☐ No

21. Would you consider the amount of effort/expenditures allocated to inspection to be appropriate for the type of construction involved, and if so, why?

☐ Yes ☐ No

22. Would you consider the amount of effort/expenditures allocated to field and laboratory testing to be appropriate for the type of construction involved, and if so, why?

☐ Yes ☐ No

QUALITY MANAGEMENT FOR PAVING MATERIALS AND CONSTRUCTION

In this section, we would like to know what additional quality management practices for the production and placement of paving materials, if any, your agency has implemented.

23. Does your agency require that paving contractors and construction materials suppliers involved in construction and maintenance projects to have Quality Plans or Quality Manuals for instance) to control their processes and products? [If *Yes*, please briefly describe below, or attach requirements]?

☐ Yes ☐ No

24. Does your agency require that paving contractors and construction materials suppliers involved in roadway construction and maintenance projects be ISO registered? [If *No*, please indicate why not.]

☐ Yes ☐ No

25. Is your jurisdiction using or planning to use any information technology (centralized or web-based/accessible computer database for monitoring/management of quality data (such as test results for instance)? If so, please provide a description or details.

☐ Yes ☐ No

If you have any questions concerning this electronic survey/questionnaire, or require clarification of any of the questions posed, please contact Jessica Hernandez (jhernandez@jegel.com), Keith Foster (kfoster@jegel.com) or Mike MacKay (mmackay@jegel.com).

Thank You!

C.2 SUMMARY OF TESTS REQUIRED FOR GRANULAR SUBBASE AND GRANULAR BASE AGGREGATES

TEST / AGENCY	BC	AB	MB	ON	NB	NS	NF	SK	FEDERAL
Crushed Content	✓	✓	✓	✓	✓		✓	✓	✓
Flat/Elongated Particles					✓	✓			
LA Abrasion		✓	✓			✓	✓		✓
MicroDeval	✓			✓	✓	✓	✓	✓	
Soundness (MS)	✓								✓
Soundness (SS)									✓
Petrographic	✓			✓			✓		
Freeze Thaw				✓					✓
Friable Particles								✓	
Loss By Washing	✓					✓			✓
Fractured Particles	✓	✓	✓			✓		✓	
Flakiness Index		✓							
Absorption						✓			
Plasticity Index	✓	✓	✓		✓	✓	✓	✓	✓
Other Testing	Rut Resistance	Detrimental Matter							
Maximum Size	50.0	25.0	25.0	26.5	75.0 (rock), 90.0 (gravel)	56.0	50.8	31.5, but18.0 most common	37.5

C.2 SUMMARY OF TESTS REQUIRED FOR GRANULAR SUBBASE AND GRANULAR BASE AGGREGATES (CONTINUED)

AGENCY / TEST	CALGARY	EDMONTON	SASKATOON	WINNIPEG	WINDSOR	HALDIMAND COUNTY	OTTAWA
Crushed Content	✓	✓		✓	✓	✓	✓
Flat/Elongated Particles			✓				
LA Abrasion	✓	✓		✓			
MicroDeval					✓	✓	✓
Soundness (MS)		✓					
Soundness (SS)		✓					
Petrographic					✓	✓	✓
Freeze Thaw					✓	✓	✓
Friable Particles							
Loss By Washing							
Fractured Particles	✓		✓				
Flakiness Index			✓				
Absorption		✓	✓				
Plasticity Index	✓	✓	✓	✓			
Other Testing							CBR
Maximum Size	25.0	25.0	18.0	20.0	26.5	26.5	26.5

C.3 SUMMARY OF TESTS REQUIRED FOR HOT-MIX AGGREGATES

TEST / AGENCY	BC	AB	SK	MB	ON	QC	PEI	NB
Crushed Content		✓	✓	✓	✓	✓	✓	✓
Flat/Elongated Particles			✓		✓	✓	✓	✓
LA Abrasion		✓		✓		✓	✓	
MicroDeval			✓		✓	✓		✓
Soundness (MS)	✓				✓		✓	
Soundness (SS)								✓
Petrographic					✓		✓	✓
Freeze Thaw					✓			✓
Friable Particles	✓		✓			✓		
Loss By Washing	✓				✓		✓	✓
Fractured Particles	✓	✓	✓	✓				
Flakiness Index		✓						
Absorption	✓		✓		✓		✓	✓
Plasticity Index	✓	✓	✓				✓	
Other Testing	Clay Lumps, Sand Equivalent, Degradation Test	Detrimental Matter	Fine aggregate angularity & sand equivalent	Shale Content, Ironstone Content		Coefficient of Flow		
Maximum Size	37.5	25.0	18.0	16.0	26.5	28.0	25.0	25.0

C.3 SUMMARY OF TESTS REQUIRED FOR HOT-MIX AGGREGATES (CONTINUED)

TEST \ AGENCY	NS	NF	FEDERAL	CALGARY	EDMONTON	WINNIPEG	WINDSOR	HALDIMAND COUNTY	OTTAWA
Crushed Content		✓	✓		✓	✓	✓	✓	✓
Flat/Elongated Particles	✓	✓	✓				✓	✓	✓
LA Abrasion	✓	✓	✓	✓	✓	✓			
MicroDeval		✓					✓	✓	✓
Soundness (MS)	✓	✓	✓		✓	✓	✓	✓	✓
Soundness (SS)	✓		✓		✓	✓			
Petrographic	✓	✓					✓	✓	✓
Freeze Thaw		✓		✓			✓	✓	✓
Friable Particles	✓	✓							
Loss By Washing	✓	✓	✓				✓	✓	✓
Fractured Particles	✓			✓					
Flakiness Index	✓								
Absorption	✓	✓	✓		✓	✓	✓	✓	✓
Plasticity Index		✓							
Other Tests	Stripping	Clay Lumps, Sand Equivalent, Degradation	Lightweight particles						
Maximum Size, mm	20.0	19.0	12.5	25.0	25.0	16.0	26.5	26.5	26.5

C.4 SUMMARY OF ASPHALT PAVEMENT CONSTRUCTION QUALITY ASSURANCE PRACTICES

AGENCY / ASPECT	BC	AB	SK	MB
Specification Type	Method, End Result and Performance	End Result	Method	Method
Acceptance Method	Tolerances	Mean (Gradation Range for Bonus	Mean	
Lot Size	1 day	Generally 1 day	200 tonnes	
Sublot Size or Number	3	Variable	None, only lots	
Price Adjustments	Penalty/Bonus for Smoothness	Penalty/Bonus	Penalty/Bonus	Penalty/Bonus for Smoothness
Acceptance Testing	Agency	Agency (Some QC)	Agency	
Acceptance Inspection	✓	Completion (Visible Defects)	✓	
Acceptance Attributes	✓, Tolerances	✓, EPS (ERS)		
Asphalt Cement Content	✓	✓	✓	✓
Aggregate Gradation	✓	✓	✓	✓
Stability and Flow			✓	✓
Voids in Mineral Aggregates			✓	✓
Aggregate Physical Properties			✓	✓
Air Voids	✓	✓	✓	✓
Thickness				
Compaction	✓	✓	✓	✓
Smoothness	✓	✓	✓	✓
Segregation		✓	✓	✓
Attributes Monitored	Aggregate Gradations	Air Voids		
Additional Aspects	Visual Defects	Visual Defects	Visual Defects	
Mix Design (JMF) Responsibility	Contractor	Contractor	Agency	Agency
Field JMF Adjustments	✓	✓	Agency	✓
Performance Graded Binders		Some Applications Only		✓
Superpave Mix Design	Partial Implementation	Not Since 2002 Past Projects Being Monitored		
Contractor Quality Control Plan	✓			
Technician/Laboratory Certification		Laboratory without certified QC/QA staff		
Outsourcing Administration/QA		✓	On some projects	
ISO Registration				

C.4 SUMMARY OF ASPHALT PAVEMENT CONSTRUCTION QUALITY ASSURANCE PRACTICES (CONTINUED)

AGENCY / ASPECT	ON	QC	NB	PEI
Specification Type	Method, End Result and Performance	Performance	Method, End Result and Performance	Method
Acceptance Method		Mean	Tolerances	Tolerances Mean/Standard Deviation for Compaction
Lot Size	5000 tonnes	1500 tonnes	1 day (Method), 2 days (ERS)	1 day for Compaction
Sublot Size or Number	10	5	500 tonnes (Method)	4 for Compaction
Price Adjustments		Penalty/Bonus for Smoothness	Penalty/Bonus	Penalty/Bonus for Compaction and Smoothness
Acceptance Testing	QC/Agency Verification	QC/Agency Verification	Agency	Agency
Acceptance Inspection		✓	✓	✓
Acceptance Attributes			✓, Tolerances	✓, Tolerances
Asphalt Cement Content	✓	✓	✓	✓
Aggregate Gradation	✓	✓	✓	✓
Stability and Flow	✓	✓	✓	✓
Voids in Mineral Aggregates	✓	✓	✓	✓
Aggregate Physical Properties	✓	✓	✓	✓
Air Voids	✓	✓	✓	✓
Thickness			✓	
Compaction	✓	✓	✓	✓
Smoothness	✓	✓	✓	✓
Segregation	✓	✓	✓	✓
Attributes Monitored	Joint Compaction		Air Voids, Moisture Content	
Additional Aspects		Visual Defects	Visual Defects	Visual Defects
Mix Design (JMF) Responsibility	Contractor		Agency	Agency/Contractor
Field JMF Adjustments	✓		✓	✓
Performance Graded Binders	✓	✓	✓	✓
Superpave Mix Design	Full Implementation (2006)	Partial Implementation	Full Implementation (2006)	
Contractor Quality Control Plan		✓ (ISO)	✓ (ITP)	
Technician/Laboratory Certification	✓	✓ (ISO)	✓	
Outsourcing Administration/QA				
ISO Registration	Optional	✓		

C.4 SUMMARY OF ASPHALT PAVEMENT CONSTRUCTION QUALITY ASSURANCE PRACTICES (CONTINUED)

AGENCY / ASPECT	NS	NF	FEDERAL	KAMLOOPS
Specification Type	Method and End Result	Method and End Result	Method and End Result	End Result
Acceptance Method	Tolerances	Tolerances		
Lot Size	2400 tonnes			
Sublot Size or Number	5 (Core Sample) 4 (Loose Sample)			
Price Adjustments	Penalty/Bonus	Penalty		
Acceptance Testing	Agency	Agency		
Acceptance Inspection	✓	✓		
Acceptance Attributes	✓, Tolerances	✓, Tolerances		
Asphalt Cement Content	✓	✓	✓	✓
Aggregate Gradation	✓	✓	✓	✓
Stability and Flow	✓	✓	✓	✓
Voids in Mineral Aggregates	✓	✓	✓	✓
Aggregate Physical Properties	✓	✓	✓	✓
Air Voids	✓	✓	✓	✓
Thickness	✓			✓
Compaction	✓	✓	✓	✓
Smoothness	✓	✓	✓	✓
Segregation	✓	✓	✓	✓
Attributes Monitored	Moisture Content			
Additional Aspects	Visual Defects	Visual Defects		
Mix Design (JMF) Responsibility	Agency	Agency		
Field JMF Adjustments	✓	✓		
Performance Graded Binders	✓	✓	✓	
Superpave Mix Design	Partial Implementation	Lab Trials		
Contractor Quality Control Plan	✓		✓	
Technician/Laboratory Certification	✓			
Outsourcing Administration/QA	QA Testing			
ISO Registration				

C.4 SUMMARY OF ASPHALT PAVEMENT CONSTRUCTION QUALITY ASSURANCE PRACTICES (CONTINUED)

AGENCY / ASPECT	CALGARY	EDMONTON	WINNIPEG	WINDSOR
Specification Type	Method (Smoothness ERS)	End Result and Warranty	Method	Method and Warranty
Acceptance Method	Tolerances	Tolerances		
Lot Size				5000 tonnes
Sublot Size or Number				4
Price Adjustments			Penalty/Bonus for Smoothness	
Acceptance Testing				Agency
Acceptance Inspection				
Acceptance Attributes		✓, Tolerances		
Asphalt Cement Content	✓	✓	✓	✓
Aggregate Gradation	✓	✓	✓	✓
Stability and Flow	✓	✓	✓	✓
Voids in Mineral Aggregates	✓	✓	✓	✓
Aggregate Physical Properties	✓	✓	✓	✓
Air Voids	✓	✓	✓	✓
Thickness	✓	✓		
Compaction	✓	✓	✓	✓
Smoothness	✓	✓	✓	✓
Segregation	✓	✓	✓	✓
Attributes Monitored				
Additional Aspects				
Mix Design (JMF) Responsibility	Agency	Contractor	Contractor	Contractor
Field JMF Adjustments	✓	✓	✓	✓
Performance Graded Binders	✓	✓	✓	✓
Superpave Mix Design	Evaluating Trials	Evaluating Trials	Evaluating Trials	
Contractor Quality Control Plan				✓
Technician/Laboratory Certification				✓
Outsourcing Administration/QA				
ISO Registration				

C.4 SUMMARY OF ASPHALT PAVEMENT CONSTRUCTION QUALITY ASSURANCE PRACTICES (CONTINUED)

AGENCY / ASPECT	BRANTFORD	HALDIMAND COUNTY	OTTAWA	MONTREAL
Specification Type	Method (Performance) for HMA	Method	End Result and Performance	Combination
Acceptance Method				
Lot Size		5000 tonnes	5000 tonnes	
Sublot Size or Number		4	4	
Price Adjustments				
Acceptance Testing		Agency	Agency	
Acceptance Inspection				
Acceptance Attributes				
Asphalt Cement Content	✓	✓		
Aggregate Gradation	✓	✓		✓
Stability and Flow	✓	✓		✓
Voids in Mineral Aggregates	✓	✓	✓	✓
Aggregate Physical Properties	✓	✓		✓
Air Voids	✓	✓		✓
Thickness		✓		
Compaction	✓	✓		✓
Smoothness	✓	✓	✓	✓
Segregation	✓	✓	✓	✓
Attributes Monitored				
Additional Aspects				
Mix Design (JMF) Responsibility	Contractor	Contractor	Contractor	
Field JMF Adjustments		✓	✓	
Performance Graded Binders	✓	✓	✓	✓
Superpave Mix Design			Partial Implementation	
Contractor Quality Control Plan				
Technician/Laboratory Certification	✓	✓	✓	✓
Outsourcing Administration/QA				
ISO Registration				

APPENDIX D GUIDELINES FOR PROCESS CONTROL CHARTS

The wide range of extensively used ASTM statistical procedures is given in the AASHTO Standard Recommended Practice for Statistical Procedures (AASHTO, 2005b).

Process Condition

Process control charts (quality control charts) can be developed for any type of production parameter testing – the percentage passing a critical sieve size (4.75 mm or 75 µm for instance) from a gradation test, asphalt cement content from an extraction test or air voids in a recompacted Marshall or Superpave specimen for instance. Horizontal lines are drawn to represent the job mix formula (JMF) or target value, and upper and lower tolerances applied to each parameter (+/- five percent for the 4.75 mm sieve from specification limits or statistical process control for instance). Tolerances can be used to control individual (sublot) test results and the mean (lot average) of the test results. The horizontal scale is divided into equal segments representing sample or test numbers.

Moving Average Charts

The process average is the mean of the tests for all samples taken over a specific period of time. However, the process itself and the average will most probably not be constant over a long period due to changes in materials or plant screening efficiency for instance. A moving average will show a drift of the process average much quicker than if a series of 20 or more samples are tested before averaging. In addition, a moving average will indicate trends, such as a gradual increase in passing a particular sieve, so that early corrective action can be taken. As an increased number of tests are averaged, much of the variation due to sampling and testing is averaged out, and the variations shown are mostly due to changes in materials, or in mix proportioning. Any moving average may be used, but an average of four or five tests is preferred as shown in Figure D.1. This process control chart shows a trend towards an increasing percentage passing the 2.36 mm sieve; from an examination of this chart, it can determined that corrective action should have been taken after about test number 14.

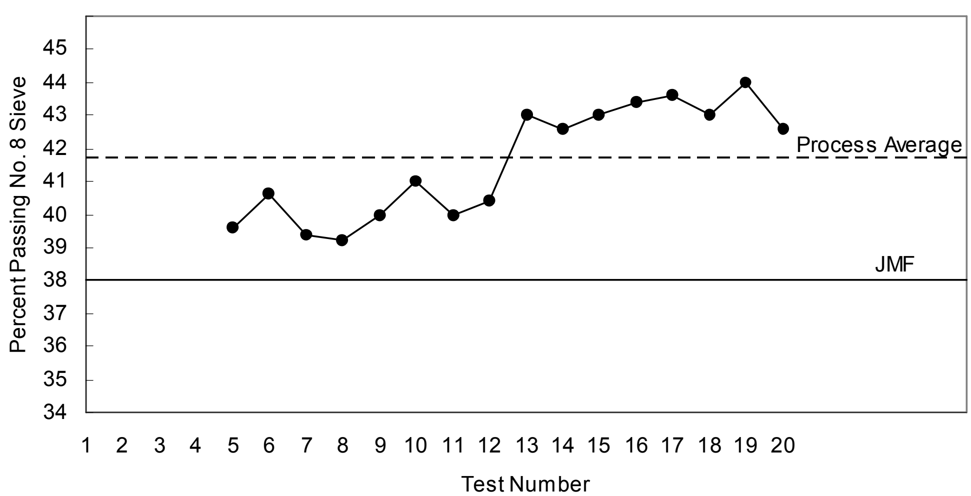

Figure D.1 – Moving Average of Five Measurements – Percent Passing 2.36 mm Sieve Extraction Gradation - Binder Course HMA

Moving Range Charts

The moving range is the difference between the smallest and the largest result in a group of test results with the easiest range to calculate being a moving range of two (the difference between one test result and the previous test result). The range is a measurement of that part of the total spread that is due to batch-to-batch variation and variations due to sampling and testing. A chart of the plotted test results for a moving range of two results is often used in combination with a moving average chart. The moving average shows whether or not the process average is close to the JMF, while the moving range indicates whether or not the process spread is less than the JMF tolerances when the process average is constant and close to the correct value.

In order to calculate the moving range, consecutive test results are arranged in a column and moving ranges are determined by subtracting the test result from the one just above it. Figure D.2 shows charts for a moving range of two test results (it is common practice to plot the point for a particular range directly over the last test result in the range). The location of the line for the average range (R) of the two test results is determined by multiplying the tolerance by 0.564 (from standard statistical process control concepts (AASHTO, 2005b), noting there should be an equal number of plotted points for ranges above and below this line). A trend above to below the line indicates whether batch-to-batch variations or sampling and testing variation (or both) is increasing or decreasing. The upper limit lines for ranges of two test results are determined by multiplying the tolerance by 1.42 (again from standard statistical process control concepts).

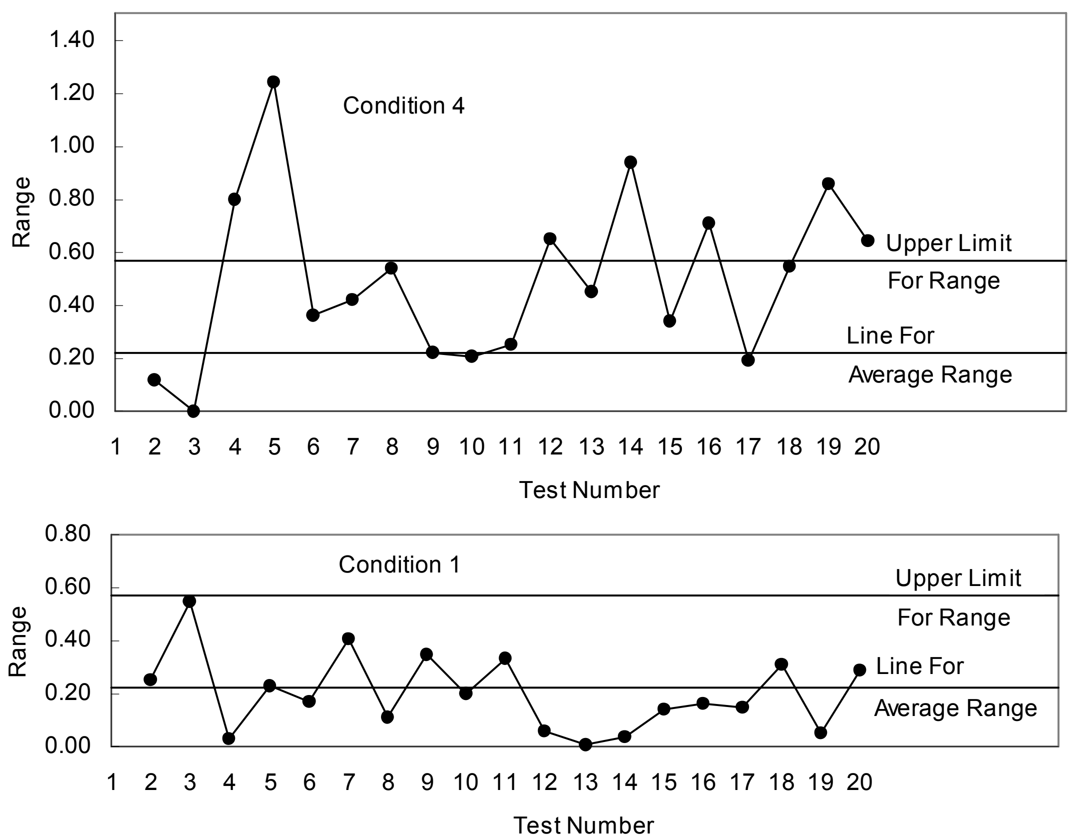

Figure D.2 – Moving Ranges of two Measurements of Asphalt Cement Content in HMA

Analysis of Control Charts

Figures D.3, D.4, D.5 and D.6 are quality control charts for the asphalt cement content of HMA samples and show a process in various control conditions.

Figure D.3 indicates a process that is under control; the mean of the test results is the same as the JMF or target value, and the spread of results is within the tolerances specified for the asphalt cement content by the agency (+0.5 and -0.3% for a sublot or individual result). If an occasional point should fall outside the tolerance limits, this could be considered as an outlier due to some error in proportioning a single batch or to an error in sampling or testing and is tracked in accordance with standard statistical quality assurance concepts (AASHTO, 2005b).

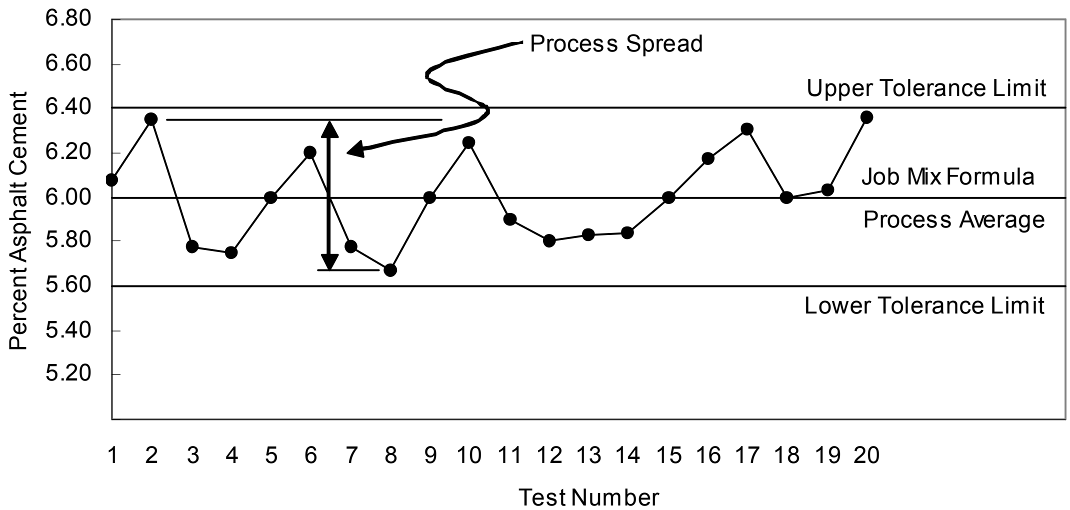

Figure D.3 – Asphalt Cement Content of HMA. (Process Condition 1)

Figure D-4 shows a process where the spread of results is still less than the specified tolerances. However, the mean is no longer the same as the target value, and the resulting drift causes some individual results to fall outside of the tolerances. In some cases, a drift may be due to a bias in the testing procedure which causes test results to be different than the true values. This condition requires that action be taken to bring the process mean in line with the JMF.

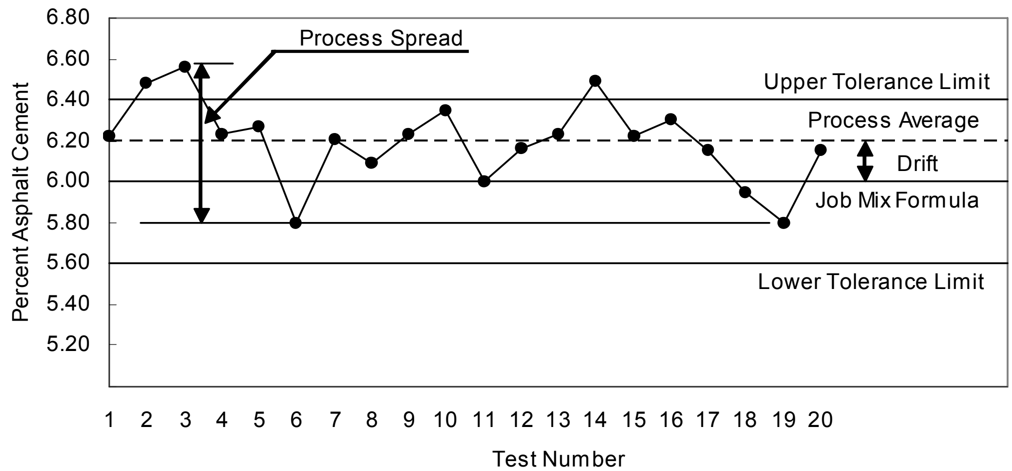

Figure D.4 – Asphalt Cement Content of HMA. (Process Condition 2)

Figure D.5 shows a process where the mean is the same as the JMF; however, the wide spread causes individual results to fall outside the specified tolerance limits.

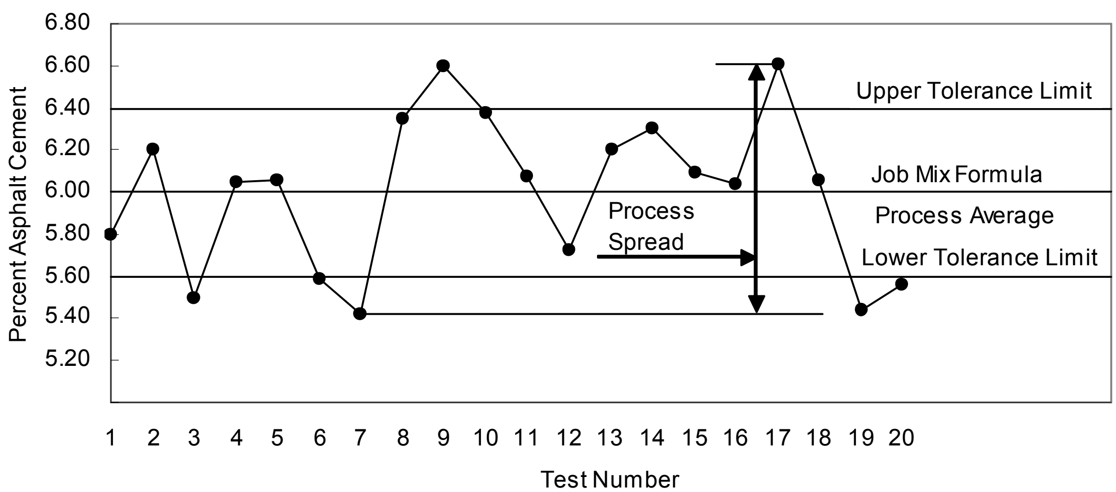

Figure D.5 – Asphalt Cement Content of HMA. (Process Condition 3)

Figure D.6 shows how a wide process spread combined with a drift of the process mean from the JMF may cause a significant number of individual results to fall outside the specified tolerance limits.

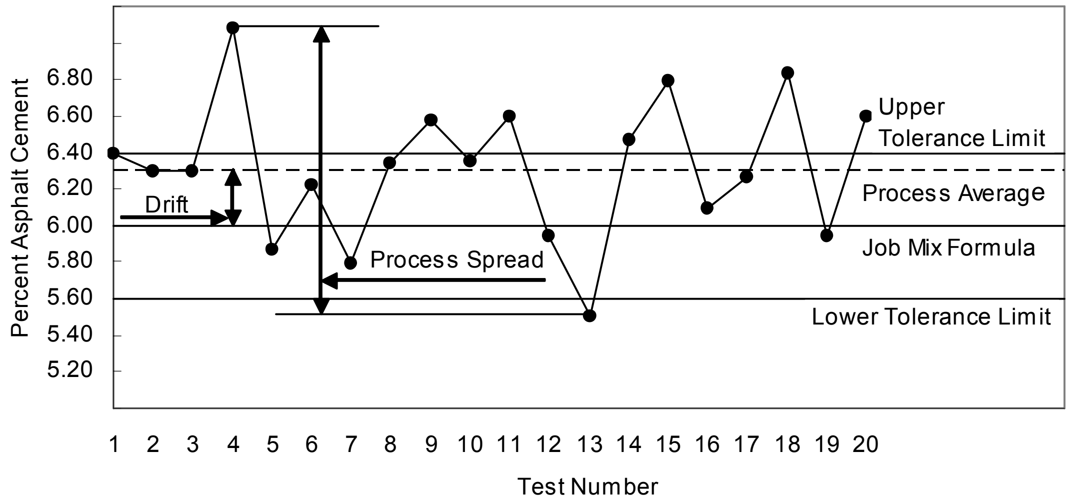

Figure D.6 – Asphalt Cement Content of HMA. (Process Condition 4)

Use of Control Charts in Statistical Process Control

Process control charts present information exactly as it occurs in the test results. Variability in test results could be due to a variety of reasons and therefore some interpretation (are there assignable causes for instance) by the technician may be required in order to decide the appropriate corrective action, if any. The technician may decide that the process is in control even though some test results are outside the specifications or it may be clear (from inspection of stockpiles for instance) that a problem exists which requires immediate attention.

The moving average chart should be used for monitoring HMA properties for which there are price adjustments for non-compliance with specifications (JMF tolerances) for asphalt cement content, gradation or air voids for example. Since the drift of a process away from the target is detected early, corrections can also be made in time to avoid undesirable consequences such as penalties or rejection of the HMA. Timely use of this information can permit the appropriate adjustments to be made to the JMF or to plant operations to ensure the quality of the HMA.

For moving range charts, if more than one point in 20 falls above the limit line, this indicates that the part of the process spread due to variability is probably greater than the total tolerance. This is shown by the plot of individual test results in Figure D.3 (Condition 1) where all of the points are within the tolerance limits. In Figure D.6, all ranges for Condition 1 are below the limit line, while the chart for Condition 4 shows many ranges exceeding the limit line.

The moving range can also be used to determine the process spread due to sampling and testing. Reduction of the spread due to sampling and testing is important simply as a matter of economics since it will be easier to comply with the specification if the spread is small. The process spread due to sampling and testing can be determined as follows:

- Take ten samples by the usual method from a single batch of HMA (it is assumed that this single batch will have consistent properties such as asphalt cement content);
- Prepare a single test portion from each sample by the usual method and complete the test;

- Record the test results in two columns with the odd sample numbers in one column and even sample numbers in the other, as shown in Table D.1;

TABLE D.1 – PROCESS SPREAD EVALUATION

Sample Number	Test Result (1)	Sample Number	Test Result (2)	Range/Difference Between Columns 1 and 2
1	6.15	2	6.54	0.37
3	5.86	4	6.00	0.14
5	5.70	6	6.34	0.64
7	5.38	8	5.80	0.58
9	5.63	10	5.90	0.27
		TOTAL RANGE		2.00
		AVERAGE RANGE		0.40

- Obtain the average difference by adding the differences between the test results on the odd and even numbered samples and dividing by the number of differences.

  Example (illustrated in Figure D.2):

  Asphalt Content Tolerance for JMF = +0.40

  Average Range Line = (0.564) (0.40) = 0.23

  Upper Limit for Single Ranges = (1.420) (0.40) = 0.57

- Multiply the average difference by 3.0 from standard statistical process control, AASHTO 2000, for the average of five among ten samples in a single batch to obtain an estimate of the process spread above and below the process average due to sampling and testing.

  Process Spread = 3.0 times the average range.

  process spread due to sampling and testing would then be

  3.0 (0.40) ± 1.2

- The process spread due to sampling and testing can be reduced by:

  1. Better sampling (using proper sampling devices for instance);
  2. Using a sample splitter to reduce the sample to the required test portion;
  3. Using as large a test portion as possible; and
  4. Strictly following standard test procedures and avoiding short cuts in the process.

APPENDIX E EXAMPLE CHECKLISTS FOR GRANULAR SUBASE, GRANULAR BASE, AGGREGATES AND HMA PRODUCTION, TRANSPORTATION, PLACEMENT AND COMPACTION

E.1 GENERAL AGGREGATES PRODUCTION AND PLACEMENT CHECKLIST

General Requirements

- ☐ Have the Contract specifications, special provisions, supplemental specifications been checked prior to starting aggregate production and/or placement?
- ☐ Are the aggregate materials from an approved source?
- ☐ Have the Inspector and Contractor been advised of any environmental constraints, if applicable?
- ☐ Has the Contractor submitted QC test results prior to delivery of materials demonstrating compliance with the physical property and production requirements specified in the Contract documents?
- ☐ Have quality assurance samples been obtained for testing as specified in the Contract documents?
- ☐ Do the granular subbase and base materials comply with Contract specification requirements?
- ☐ Does visual inspection of the material show any signs of contamination, including clay balls, clay coated particles or other deleterious materials?
- ☐ Has the use of Blast Furnace Slag, Reclaimed Asphalt Pavement (RAP) or other recycled materials been approved for the granular base and subbase?
- ☐ Has the Contractor obtained the required certification for the weigh scale(s) in accordance with the Contract documents?
- ☐ Do the materials control, distribution, weighing and transport systems conform with the Contract documents?

Aggregate Stockpiles

- ☐ Prior to commencing aggregate stockpiling, were the stockpiles checked for:
  - ☐ Clean foundation?
  - ☐ Dry foundation?
  - ☐ Pile separation?
- ☐ Were the aggregates properly separated into stockpiles, and does the stockpiled aggregate have proper:
  - ☐ Consistency?
  - ☐ Particle size/shape?
  - ☐ Moisture content?
  - ☐ Washed aggregates, if applicable?

- ☐ Have the aggregate stockpiles been inspected, and if so, by whom:
  - ☐ Inspector?
  - ☐ Loader operator?
  - ☐ QC testing technician?
- ☐ Is the Agency conducting daily plant inspections?
- ☐ Is the Contractor inspecting the aggregates during load-out, as scheduled or required?
- ☐ Are the Agency and the Contractor visually inspecting the granular subbase and base materials during placement?
  - ☐ Agency?
  - ☐ Contractor?

Equipment

Trucks

- ☐ Are trucks in good working order (i.e. mechanical condition/tarps)?
- ☐ Are the truck beds clean?
- ☐ Are proper approved release agents being used?
- ☐ Is the Contractor using any equipment or carrying any loads that exceed legal load limits?

Compaction Equipment

- ☐ Are the Contractor's compaction equipment and compaction operations being coordinated with the rate of placement so that the required density is consistently achieved?

E.2 GRANULAR SUBBASE AND GRANULAR BASE PRODUCTION/PLACEMENT INSPECTION CHECKLIST

Production Requirements for Granular Subbase and Granular Base Aggregates

- ☐ Have the Granular Subbase and Granular Base aggregates been produced and stockpiled as described in the General Aggregates Production and Placement Checklist?
- ☐ Is there any evidence of contamination from subgrade pumping into subbase and has the Contractor taken appropriate corrective action?
- ☐ Have quality assurance samples been obtained for testing as specified in the Contract documents?
- ☐ Does visual inspection of the material show any signs of contamination, including clay balls, clay coated particles or other deleterious materials, and if so, was appropriate corrective action taken?
- ☐ Do the granular subbase and granular base materials comply with Contract specification requirements?
- ☐ Has the Contractor's compaction been checked to verify that all the work falls within the specified tolerances?
- ☐ Are the horizontal and vertical grades being checked to confirm that they are within acceptable tolerances prior to the placing on the next material/lift or paving?

Remarks (detail any deficiencies / non-compliances)

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Inspector: __________________________ Date: ___________________

E.3 HOT-MIX ASPHALT PRODUCTION /PLACEMENT INSPECTION CHECKLIST

Production Requirements for Hot-Mix Aggregates

- ☐ Have the coarse and fine aggregates for Hot-Mix Asphalt been produced and stockpiled as described in the General Aggregates Production and Placement Checklist?
- ☐ Are the stockpiled aggregates being handled correctly?
- ☐ Is segregation being controlled?

Requirements for Hot-Mix Asphalt Materials and Paving

Document Review

- ☐ Is a copy of the Contract Specifications and Special Provisions on site?
- ☐ Has the Contractor submitted his Construction Schedule for approval?
- ☐ Have the hot-mix asphalt mix designs been submitted and approved?
- ☐ Has the Contractor's Traffic Control Plan been submitted and approved?
- ☐ Does the Contractor have an approved QC Plan?
- ☐ Are copies of Material Safety Data Sheets on site?

Materials Requirements

- ☐ Are the hot-mix asphalt paving materials from approved sources?
  - ☐ Asphalt cement?
  - ☐ Aggregate(s)?
  - ☐ Tack coat?
- ☐ Has the correct asphalt cement grade been selected for the project based on environmental and traffic factors?
- ☐ Do the hot-mix coarse and fine aggregate(s) meet consensus and source properties?
- ☐ Does the surface course coarse aggregate(s) meet specification requirements for polished stone value (skid resistance), if any?
- ☐ Has the hot-mix asphalt plant been approved for the specific mix types?
- ☐ Does the hot-mix asphalt mix design comply with the specified asphalt cement content, target gradation, and air voids requirements.
- ☐ Has the asphalt mix been checked for moisture susceptibility?
- ☐ Is the nominal maximum aggregates size less than one-half the specified compacted lift thickness for dense graded mixes?

Hot-Mix Plant Inspection

Cold Feed Bins and Conveyors

- ☐ Are the hot-mix asphalt coarse and fine aggregate stockpiles clearly marked, separated, and free of contamination?
- ☐ Have the aggregate cold feeds been calibrated?
- ☐ Do the cold feed bins contain the correct aggregates?
- ☐ Have the aggregate cold feeds been calibrated and set correctly?
- ☐ Are all aggregates feeding continuously?

Asphalt Cement Heating and Hot-Mix Asphalt Temperature (PGAC)

- ☐ Is the correct grade of asphalt cement in the tank(s)?
- ☐ Is the asphalt cement uniformly heated to the specified mixing temperature (ideally from temperature-viscosity data)?
- ☐ Is the specified hot-mix asphalt temperature being achieved and maintained uniformly?
- ☐ Is an anti-stripping additive required and if so, being properly incorporated?

Drum Mix Plant

- ☐ Have the aggregate cold feed bins been calibrated?
- ☐ Is the moisture content of the aggregates known?
- ☐ Are the aggregate and asphalt cement feeds interlocked?
- ☐ Are the belt scales calibrated and operating properly?
- ☐ Is the plant micro-processor functioning properly with the desired hot mix proportions entered?

Batch Plant

- ☐ Have the scales been calibrated?
- ☐ Does the asphalt cement bucket tare properly?
- ☐ Is the screen deck of adequate capacity and functioning properly (no holes, reasonable carry-over, overflow chutes free flowing, etc.)?
- ☐ Does the aggregate weigh box hang freely?
- ☐ Are the mixer parts in good condition?
- ☐ Is an appropriate batch size being mixed?
- ☐ Is the asphalt cement distribution uniform along the pugmill?
- ☐ Are the aggregates and asphalt cement at the proper temperatures?
- ☐ Are the dry and wet mixing times adequate?
- ☐ Is the plant micro-processor functioning properly with the desired hot mix proportions entered?

- ☐ Is the aggregate hot bins balance being maintained?
- ☐ Is the access for sampling adequate?

Dryer or Drum

- ☐ Is the aggregate properly dried to the desired temperature?
- ☐ Is the dust collection system functioning properly?
- ☐ Are the collected fines being properly returned or proportioned (dry collector) or wasted (wet collector)?

Surge/Storage Silos (if applicable)

- ☐ Has the maximum mix storage time been established by penetration-viscosity testing?

Lime and Filler Silo (if applicable)

- ☐ Has the lime and/or filler feed system been calibrated?

Haul Trucks

- ☐ Are the truck boxes clean?
- ☐ Are the truck boxes properly coated with non-solvent release agents?
- ☐ Are all haul trucks equipped with suitable tarpaulins to protect the mix from temperature loss and precipitation during transport and to control odours?

Paving Site Inspection

General

- ☐ Has the surface to be paved been prepared properly (patching, leveling course, sealing, tacking, etc.)?
- ☐ Is traffic control adequate?
- ☐ Has the continuity of operations been planned (plant production, number of haul trucks, number of pavers, and number and type of rollers)?

Tack Coat Distributor

- ☐ Has the tack coat distributor been properly calibrated?
- ☐ Have the nozzles been checked to ensure that they are not plugged and are able to apply a uniform tack at the specified rate?
- ☐ Is the distributor spray bar at proper height to provide overlapping coverage from spray nozzles?

Paver(s)

- ☐ Does the paver(s) comply with specifications?
- ☐ Is a pick-up machine being used?
- ☐ Is a material transfer vehicle being used?

- ☐ Is the screed heater working properly?
- ☐ Are the tamping bars in good condition and correctly adjusted?
- ☐ Are the surfaces of the screed true and in good condition?
- ☐ Are the thickness and crown controls in good condition and properly adjusted?
- ☐ Are the screed vibrators in good condition and properly adjusted?
- ☐ Is the automatic screed control functioning properly?
- ☐ When paving in echelon, is the distance between the pavers being checked and maintained in conformance with specifications?

Spreading

- ☐ Is the mat of uniform texture and satisfactory appearance?
- ☐ Does the mat meet surface smoothness tolerances?
- ☐ Is the mat the correct thickness?

Compaction

- ☐ Is the required number of rollers of the proper type on the job?

  What type(s) of rollers will be used for breakdown, intermediate, and finish rolling?

  Breakdown: ____________________

  Intermediate: ____________________

  Finishing: ____________________
- ☐ Are the proper rolling procedures and patterns being followed?
- ☐ Are the joints and edges being properly compacted?
- ☐ Is the necessary overall compaction being achieved?
- ☐ Are the water spray bars, wetting pads, and scraping bars working on all rollers to avoid material buildup?
- ☐ Is an approved asphalt release agent being used on roller drums or tires to reduce pick-up?
- ☐ Are the roller steel drums free of grooves and dents and not warped?
- ☐ Are the rubber tires (if applicable) inflated to within +/- 34.5 kPa (+/-5 psi)?
- ☐ Are vibratory plates or hand tampers available and being used in areas inaccessible to rollers?

Sampling

- ☐ Are all sample locations (plates and cores) being properly reinstated on a daily basis?
- ☐ Are all required samples being taken at correct (random) locations and tonnages, as per specification acceptance requirements?

Remarks (detail any deficiencies / non-compliances)

____

Inspector: __________________________ Date: __________________

APPENDIX F TYPICAL SPECIFICATION (ERS) REQUIREMENTS FOR A CONTRACTOR QUALITY CONTROL PLAN FOR A PAVING PROJECT AND COMMENTARY ON THE REQUIREMENTS

Typical specification (ERS) requirements for a contractor quality control plan for a paving project and commentary on the requirements (developed by JEGEL for use on international projects, based on Canadian experience).

F.1: SPECIFICATION REQUIREMENTS FOR CONTRACTOR QUALITY CONTROL PLANS

1.01 SUBMISSION AND DESIGN REQUIREMENTS

1.01.01 General

Any required submissions shall be in writing to the Contract Administrator. All information and test data forms must be legible. E-mail or faxed copies are acceptable provided the original is submitted to the Contract Administrator within three days following receipt of the e-mail or fax.

1.01.02 Material Safety Data Information

At least five days prior to starting the Work, the Contractor shall submit safety data information for all materials to be incorporated in the Work.

1.01.03 Quality Control Plan

1.01.03.01 Submission of the Plan

At least 15 days prior to starting the Work, the Contractor shall submit three copies of the Contractor's Quality Control Plan (the Plan) for the Work. The Contractor's Quality Control Plan establishes the overall process by which the Contractor shall achieve the required quality of the Work. It confirms that quality control (QC) is the responsibility of the Contractor. A Quality Control Plan shall include the provision of sufficient records of testing, inspection and compliance monitoring to satisfy the Owner that the obligations of the Contract have been met and the required quality has been achieved. It shall detail clearly the policy and methods for identifying and dealing with work that does not meet the Specifications, unless the Owner details these in the Contract Documents. The Quality Control Plan shall include a policy and procedure for making changes to the Quality Control Plan, as part of the Contractor's continuous improvement program for quality control. The Contractor's Quality Control Plan shall form part of the Contract Documents. The Quality Control Plan shall be signed by an Officer of the Contractor. The Quality Control Plan shall name the individual responsible for administering the Quality Control Plan (the Plan Administrator) and describe the qualifications of the Plan Administrator. A commentary for Quality Control Plans is given in Appendix F-2.

1.01.03.02 Acceptance of the Plan

Subject to any other restrictions on starting work on the Contract, the Contractor will not be permitted to start work on the Contract (except for surveying and erecting temporary signs), until the Contract Administrator accepts the Quality Control Plan in writing. The submission will be reviewed by the Contract Administrator, and either accepted or rejected, within five days of receipt of a complete submission. The acceptance or rejection will be based on the adequacy of the Quality Control Plan in documenting the Contractor's continuing good policies and practices to ensure that the Owner will receive quality work meeting the Contract Document requirements. If the Quality Control Plan is rejected, the Contract Administrator will provide to the Contractor, in writing, the reasons for rejection, and the Contractor shall modify the submission and resubmit it within four days. This process will continue until the submission is acceptable to the Contract Administrator. If, for whatever reason, the Contractor cannot produce an acceptable Quality Control Plan within 35 business days of the initial submission, the Contractor will be considered to be in default of the Contract.

The acceptance of the Contractor's Quality Control Plan is specific to the Contract, and a similar, or the same submission, may not be accepted on other contracts. The acceptance of the Contractor's Quality Control Plan is not an assessment of the Contractor's quality control (QC) and does not relieve the Contractor of full responsibility for ensuring that the quality of materials and work specified in the Contract Documents is achieved for the Work. Once the Contractor's Quality Control Plan is accepted, it shall not be revised without the Contract Administrator's written agreement.

1.01.03.03 Inspection Records, Test Results and Quality Review Reports

The Contractor shall complete inspection records not later than the next day after the inspection took place, and record test results on the day on which the tests were performed. The Contractor shall provide all inspection records and test results to be used for acceptance purposes to the Contract Administrator. These inspection records and test results shall be submitted in a format acceptable to the Contract Administrator, under the signature of the Plan Administrator.

The Contractor shall identify deficient materials and work, and notify the Contract Administrator within one day of each occurrence. The Contractor shall determine the cause, extent, and impact of the identified deficiency, and submit a proposal for remedial work to the Contract Administrator for approval, if remedial measures are not specified in the Contract. The Contractor shall submit to the Contract Administrator, for information purposes, a description of preventative measures to be undertaken to prevent reoccurrence of the deficiency.

In addition of the routine inspection, sampling, and testing described in the Quality Control Plan, the Contractor shall inspect, sample, and test any material or work which appears to be deficient or inconsistent.

The Contractor shall carry out additional inspection, sampling, and testing at any time or directed by the Contract Administrator. The Contractor will be compensated for this additional inspection, sampling, and testing, unless the work or material fails to meet the Contract requirements.

The Contractor shall submit a Quality Review Report to the Contract Administrator, under the signature of the Plan Administrator, within five days of month end. This Quality Review Report shall summarize:

a. All quality control activities covered by the quality control plan for the month;
b. Results of quality control inspections for the month, including specified, planned, and actual frequencies, comments on the timeliness of quality control inspections, and actions taken to correct deficiencies in the materials and the work;
c. Quality control test result summaries for the month, specified, planned, and actual frequencies, comments on the timeliness of quality control test results, and actions taken to correct deficiencies in the materials and the work;
d. Results of monitoring the Contractor's compliance with the Quality Control Plan, including monitoring of any Subcontractors and Suppliers, and actions taken for deficiencies; and
e. Differences between the Contractors quality control (QC) results and the Contract Administrator's quality assurance (QA) results for inspection and/or testing, and if resolved, how these were resolved, including Referee testing.

The Plan Administrator shall attend a site meeting with the Contract Administrator to explain the monthly Quality Review Report. Upon the written request of the Contract Administrator, the Plan Administrator shall attend other meetings dealing with Contract quality-related matters.

1.01.03.04 Access and Audit of the Plan

The Contract Administrator shall be given access at any time to all original inspection records and test results, and testing and production facilities, as necessary for the Contract Administrator to monitor and audit the Contractor's adherence to the Quality Control Plan and to the requirements of the Contract. The Contractor shall provide copies of original inspection records, test results, and other quality control documents within one day of receiving a written request from the Contract Administrator.

The Contract Administrator shall be given access for inspection, monitoring, sampling, and testing, as necessary, in order to monitor and audit the Contractor's adherence to the Quality Control Plan and to the requirements of the Contract.

The Contract Administrator will monitor and audit the Contractor's adherence to the Quality Control Plan during the course of the Contract, and identify deviations, if any, in writing to the Contractor. Deviations will result in a warning, instruction, or stoppage of work until the Contractor demonstrates that the Quality Control Plan can be adhered to, or appropriately revised, depending on the seriousness of the deviation.

1.01.03.05 Compensation for the Plan

Full compensation for preparing, submitting and modifying the Quality Control Plan, for carrying out quality control activities (QC) described in the Quality Control Plan, and for meeting the requirements associated with the submission of the Quality Control Plan, shall be included in the Contract price for each of the appropriate Tender Items.

F.2: COMMENTARY ON QUALITY CONTROL PLAN REQUIREMENTS

General

This Appendix provides Contractors with information on a suggested outline of the comprehensive written Contractor Quality Control Plan for the Work to be submitted to the Contract Administrator. Appendices are not a mandatory part of the Specification.

Suggested Outline of a Contractor Quality Control Plan

1. Quality Control Plan General Requirements

The Quality Control Plan should address all elements of the materials and methods which affect the quality of hot mix asphalt (HMA). These elements include, but are not limited to, the following:

a. Aggregate sources (suppliers), types, gradations, transportation, stockpiling, moisture contents, handling, and quality (physical characteristics and supplier quality control);
b. Asphalt binder sources (suppliers), types, grades, transportation, storage, incorporation, and quality (physical characteristics and supplier quality control), including mixing and compaction temperatures, safety data information, and any special handling requirement for polymer modified asphalt binders;
c. Asphalt mixture (HMA) designs (Job Mix Formula, JMF), including mix design laboratory and technician qualifications, and reporting;
d. Antistripping additive source (supplier), type, amount, safety data information, and handling, when applicable;
e. Asphalt mix production, including: overall process control for proper storage and handling of component materials; accurate proportioning and feeding of the aggregate; effective drying and heating of the aggregate to the proper temperature; proper dust and filler control; proper proportioning, addition and mixing of asphalt binder; and proper storage, handling and weighing of the asphalt mix;
f. Asphalt mix transportation, including truck box cleanliness (only non-solvents used) and tarpaulins;
g. Asphalt mix placement, including segregation avoidance (material transfer device or equivalent), thickness, texture, joints and smoothness;
h. Asphalt mix compaction, including rollers selection, roller patterns, and density testing (calibrated nuclear density gauge very effective); and
i. Inspection, sampling and testing for quality control (QC) to meet all specification requirements.

The Quality Control Plan should include processes to assure the quality of materials and work. These processes and criteria include:

a. Types of inspection and testing required;
b. Frequency of inspection, sampling, and testing required;
c. Inspection and testing equipment requirements and calibration procedures;

d. Qualification requirements for laboratories and inspection and testing staff;
e. Documentation and retention of inspection records and test results;
f. Procedures for reporting inspection records, test results, and monthly summaries to the Owner (typically Contract Administrator);
g. Procedures for dealing with non-conformities in materials and work, and
h. Supplementary quality control plans and procedures for any subcontractors and material suppliers.

2. Functional Responsibilities

The Quality Control Plan should describe the functional responsibilities for the quality control (QC) activities related to HMA production, transportation, placement, compaction, and testing. As a minimum, the Quality Control Plan should include the following individuals reporting to the Contractor Quality Control manager (typically also a Contract Plan Administrator):

Process Control Technician. This person uses the laboratory testing results, and other quality control practices, to assure the quality of aggregates and asphalt binder, adjust and control mix proportioning to meet the asphalt mix designs, and determine when and how any corrective actions are to be taken. The Process Control Technician is responsible for periodically inspecting all equipment utilized in proportioning and mixing the HMA, to assure its proper operating conditions and that the proportioning and mixing is in conformance with the asphalt mix design and other requirements. The quality control Plan should describe how these duties and responsibilities will be accomplished and documented. At least one full-time person is generally required to perform this function. The criteria to be used by the Process Control Technician to reject unsatisfactory materials should be described; and

Quality Control Technician. This person periodically inspects all equipment and methods used in transporting, placing and compacting the HMA, to assure proper operating conditions and that the placing, segregation avoidance, joint construction, compaction, and smoothness achieved are in conformance with the project requirements. The Quality Control Plan should describe how these duties and responsibilities will be accomplished and documented. At least one full-time person is generally required to perform this function. The criteria to be used by the Quality Control Technician to reject unsatisfactory materials and work, and to have unsatisfactory construction practices and methods corrected, should be described.

The testing laboratory staff should report to the Process Control and Quality Control Technicians, and are responsible for the testing of aggregates, asphalt binder, and HMA samples in accordance with standard methods. The Quality Control Plan should identify all laboratories and personnel to be involved in the quality control procedure, and the overall quality control management structure.

The Process Control and Quality Control Technicians should have demonstrated proficiency in performing the required inspection and testing functions, and each meet at least one of the following criteria: Engineer with a minimum of one year of highway asphalt paving experience; Technician with a minimum of three years of highway asphalt paving experience; or individual with more than five years of highway asphalt paving experience. (Equivalent to senior technicians.)

3. **Quality Control Laboratory**

The Quality Control Plan should include details on the laboratory, or laboratories, suitably equipped, calibrated, and certified, to carry out the quality control testing to applicable standards and test methods. The laboratory should be located such that test results are available in an expedient manner. The Quality Control Plan should include a description of the type and quality of testing equipment in the laboratory, standard test methods followed, calibration and certification procedures, and test result reporting system, in accordance with specific project requirements. The quality control laboratory should complete a regular correlation program involving the QC, QA and Referee testing laboratories.

4. **Sampling and Testing**

The Quality Control Plan should include a statistically-based procedure(s) of random sampling to ensure that all aggregates, asphalt binders, and HMA produces, have an equal chance of being selected for sampling and testing, in accordance with specific project requirements. Information should be provided on the sampling procedures, particularly how segregation will be avoided.

All testing should be performed in accordance with the quality control and acceptance test methods applicable to specific project requirements. The Quality Control Plan should detail the frequency of each type of test and means for reporting (documentation).

5. **Aggregates**

The Quality Control Plan should address the quality control of aggregates incorporated in each HMA type for the specific project. As a minimum, the quality control testing and process control charts should meet the specific project requirements. Aggregate supplier quality control can form part of the Quality Control Plan.

6. **Asphalt Binders**

The Quality Control Plan should address the quality control of asphalt binders incorporated in each HMA type for the specific project. As a minimum, the quality control testing should meet the specific project requirements. Asphalt binder supplier quality control can form part of the Quality Control Plan. (Miscellaneous materials, such as tack coat emulsions and antistripping additive, can be dealt with in a similar way using supplier quality control.)

7. **Hot Mix Asphalt**

The Quality Control Plan should address the quality control including Process Control Technician duties, related to the production of each HMA type for the specific project. As a minimum, the quality control sampling and testing should include asphalt binder content, aggregate gradation, and Marshall or Superpave properties of the HMA

8. **Placement of Hot Mix Asphalt**

The Quality Control Plan should address the quality control, including Quality Control Technician duties, related to the placement of HMA. As a minimum, the quality control inspection and testing should include mix temperature, mix distribution, mat (lift) thickness, geometry and width, mat texture and uniformity, mat smoothness, joint construction, reinstatement of sampling locations, and visual attributes of particular concern such as segregation and flushing.

9. Compaction of Hot Mix Asphalt

The Quality Control Plan should address the quality control, including Quality Control Technician duties, related to the compaction of HMA. As a minimum, the quality control inspection and testing should include a description of the types and numbers of rollers (compaction procedure) being used, establishment and monitoring of rolling patterns, checking that the required compaction is being achieved (the use of a calibrated nuclear density gauge is quite effective in this regard), and sampling (coring) and density testing to meet the QC and QA requirements for the specific project.

10. Records and Process Control Charts

The Contractor should maintain complete inspection records and testing results, and submit them as required for the specific project. Process control charts should be kept through the course of the project for parameters such as asphalt binder content, percent passing the 4.75 mm sieve size, percent passing the 0.075 mm sieve size, air voids, and percent compaction for each HMA type. These control charts should form part of the Contractor's overall quality control system for identifying and rectifying any material, equipment, production, placement, and compaction problems.

Please note that the above suggested outline of the Contractor Quality Control Plan may not completely cover the Quality Control Plan requirements (details) for a specific Contract or prescribed Work. It is the responsibility of the Contractor to ensure that the submitted Quality Control Plan meets all of the Contract and Work requirements.

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APPENDICES

For Design and Development Company (e.g. Engineering Services)
A – Organization Chart
B – System Level Procedures
C – Quality Procedures
D – Work Instructions

For Design, Development, Production, Installation and Services Company (e.g. Design Build)
A – Contract Requirements
B – Organization Chart
C – System Level Procedures
D – Quality Procedures
E – Quality Plans
F – Work Instructions

APPENDIX H OUTLINE OF A TYPICAL CONSTRUCTION QUALITY PLAN

Matrix Outline of Items, Quality Requirements and Quality Responsibilities During Flexible Pavement Construction

Item Number	Activity	Quality Requirement	Quality Control and Quality Assurance	
			Control	Assurance
1	Excavation	Compaction as specified Subgrade requirements: Subgrades in cuts with no undercutting Requirements… Subgrades in cuts requiring undercutting Requirements…	Contractor Check lift thickness during placement and compaction	Establish rolling pattern Gradation testing of subgrade for suitability Compaction control testing Requirements and testing frequency…
2	Borrow	Materials requirements: Borrow A Requirements… Borrow B Requirements…	Submittal by Contractor if off-site granular borrow source Granular borrow Requirements and testing frequency Bedrock borrow: Requirements and testing frequency…	Granular borrow: Requirements and testing frequency… Bedrock borrow: Requirements and testing frequency…
		Moisture conditioning and compaction as specified Borrow B … Requirements… Borrow A … Requirements…	Contractor	Establish rolling pattern Gradation testing of subgrade for suitability Compaction control testing Requirements and testing frequency…
3	Water	Equipment capable of applying water at a uniform and evenly distributed rate	Contractor	Visual inspection
4	Subbase/ Base Aggregates	Material requirements: Base/Subbase Aggregates: Specifications…	Submittal (Supplier QC) and site inspection by Contractor For each source: Requirements and testing frequency…	For each source: Requirements and testing frequency…
		Processing and production as specified	Contractor	Visual inspection
		Handle wastes in accordance with Specification requirements	Contractor	Visual inspection
	Plant	Water to be used for washing aggregate to be clean and free of injurious substances	Contractor	Visual inspection
	Stockpiles	To contain material of the specified quality and gradation	Contractor	Visual inspection
	Sampling and testing	Monitor crushed product throughout the work Sample materials produced in accordance with Specifications	QC by Supplier Requirements and testing frequency…	QA by Owner/Agency or Independent Laboratory Requirements and testing frequency…
	Placement	Final grade as specified	Contractor	Gradation testing for suitability Requirements and testing frequency…

Item Number	Activity	Quality Requirement	Quality Control and Quality Assurance	
			Control	Assurance
	Segregation	Segregation requirements as specified	Contractor	Gradation testing for suitability Requirements and testing frequency…
	Compaction	Compaction requirements as specified	Contractor	Compaction control testing Requirements and testing frequency…
5	Aggregates - General	Material requirements: Crushed Gravel: Specifications… Crushed Rock: Specifications… Pit-Run Gravel: Specifications…	Submittal (Supplier QC) and site inspection by Contractor For each source: Requirements and testing frequency…	For each source: Gradation testing for suitability Requirements and testing frequency…
6	Fine Grading	Compaction as specified	Contractor	Compaction control testing Requirements and testing frequency…
7	Cold Milling	Construction requirements: Specifications…	Contractor	Visual inspection
8	Tack Coat	Material requirements: Specifications…	Submittal (Supplier QC) and site inspection by Contractor For each source: Requirements and testing frequency…	For each source: Requirements and testing frequency…
9	Hot-Mix Asphalt	Materials requirements: Aggregates: Specifications… Reclaimed Asphalt Pavement (RAP): Specifications… Asphalt cement: Specifications	Submittal (Supplier QC) and site inspection by Contractor For each source: Requirements and testing frequency…	For each hot-mix aggregate source: Gradation testing for suitability Requirements and testing frequency…
		Asphalt Mix Design as specified	Submittal (Supplier QC) and site inspection by Contractor For each hot-mix asphalt mix type: Requirements and testing frequency…	For each hot-mix asphalt type/mixture: Mix properties for suitability Requirements and testing frequency…
	Construction	Construction requirements: Specifications…	Contractor	Establish rolling pattern Gradation and AC content testing of hot-mix asphalt mixtures for suitability Air voids and physical properties testing Compaction control testing Requirements and testing frequency…
	Quality Assurance Testing and Adjustments – Asphalt	Materials requirements: Specifications…	Sampling by Contractor	For each asphalt cement type/grade: Requirements and testing frequency…

Item Number	Activity	Quality Requirement	Quality Control and Quality Assurance	
			Control	Assurance
	Cement			
	Smoothness	Smoothness as specified	Contractor	Smoothness: Requirements and testing frequency…

Note … indicates specific requirements to be inserted for the project involved.