Defining an Advanced Quality System and the Elements that Integrate It

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FOREWORD

This report summarizes the findings of the Advanced Quality Systems Workshop held in Washington D.C in November of 2006. The workshop was sponsored by the FHWA and brought together a number of key quality researchers and practitioners. The objective of the workshop was to generate discussion on what constitutes an Advanced Quality System and how to best advance quality systems. This report will be of interest to those involved in construction specification development, design and construction quality assurance, and design and construction of concrete and asphalt pavements.

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16. Abstract
This report summarizes the findings of the Advanced Quality Systems Workshop held in Washington D.C. in November of 2006. The workshop was sponsored by the FHWA and brought together a number of key quality researchers and practitioners. The objective of the workshop was to generate discussion on what exactly constitutes an Advanced Quality System and how to best advance State highway agency quality systems. During the workshop, a definition of Advanced Quality Systems was created. It is important to note that, for State highway agencies, an Advanced Quality System includes both design quality assurance and construction quality assurance. The two are part of the same system. They must not work independently but should be consistent in communicating to the contractor the quality/performance of construction that the State highway agency wants. Continuous improvement in construction quality can best occur when State highway agency construction personnel have a good understanding of the design, especially the design assumptions regarding construction quality, and when they also provide the necessary construction quality feedback to the designers.

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SI* (MODERN METRIC) CONVERSION FACTORS

APPROXIMATE CONVERSIONS TO SI UNITS

Symbol	When You Know	Multiply By	To Find	Symbol
		LENGTH		
in	inches	25.4	millimeters	mm
ft	feet	0.305	meters	m
yd	yards	0.914	meters	m
mi	miles	1.61	kilometers	km
		AREA		
in^2	square inches	645.2	square millimeters	mm^2
ft^2	square feet	0.093	square meters	m^2
yd^2	square yard	0.836	square meters	m^2
ac	acres	0.405	hectares	ha
mi^2	square miles	2.59	square kilometers	km^2
		VOLUME		
fl oz	fluid ounces	29.57	milliliters	mL
gal	gallons	3.785	liters	L
ft^3	cubic feet	0.028	cubic meters	m^3
yd^3	cubic yards	0.765	cubic meters	m^3
		NOTE: volumes greater than 1000 L shall be shown in m^3		
		MASS		
oz	ounces	28.35	grams	g
lb	pounds	0.454	kilograms	kg
T	short tons (2000 lb)	0.907	megagrams (or "metric ton")	Mg (or "t")
		TEMPERATURE (exact degrees)		
°F	Fahrenheit	5 (F-32)/9 or (F-32)/1.8	Celsius	°C
		ILLUMINATION		
fc	foot-candles	10.76	lux	lx
fl	foot-Lamberts	3.426	candela/m^2	cd/m^2
		FORCE and PRESSURE or STRESS		
lbf	poundforce	4.45	newtons	N
lbf/in^2	poundforce per square inch	6.89	kilopascals	kPa

APPROXIMATE CONVERSIONS FROM SI UNITS

Symbol	When You Know	Multiply By	To Find	Symbol
		LENGTH		
mm	millimeters	0.039	inches	in
m	meters	3.28	feet	ft
m	meters	1.09	yards	yd
km	kilometers	0.621	miles	mi
		AREA		
mm^2	square millimeters	0.0016	square inches	in^2
m^2	square meters	10.764	square feet	ft^2
m^2	square meters	1.195	square yards	yd^2
ha	hectares	2.47	acres	ac
km^2	square kilometers	0.386	square miles	mi^2
		VOLUME		
mL	milliliters	0.034	fluid ounces	fl oz
L	liters	0.264	gallons	gal
m^3	cubic meters	35.314	cubic feet	ft^3
m^3	cubic meters	1.307	cubic yards	yd^3
		MASS		
g	grams	0.035	ounces	oz
kg	kilograms	2.202	pounds	lb
Mg (or "t")	megagrams (or "metric ton")	1.103	short tons (2000 lb)	T
		TEMPERATURE (exact degrees)		
°C	Celsius	1.8C+32	Fahrenheit	°F
		ILLUMINATION		
lx	lux	0.0929	foot-candles	fc
cd/m^2	candela/m^2	0.2919	foot-Lamberts	fl
		FORCE and PRESSURE or STRESS		
N	newtons	0.225	poundforce	lbf
kPa	kilopascals	0.145	poundforce per square inch	lbf/in^2

*SI is the symbol for the International System of Units. Appropriate rounding should be made to comply with Section 4 of ASTM E380.
(Revised March 2003)

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INTRODUCTION

In response to increasing budget constraints and personnel shortages, and the increasing demand for improved pavement performance, highway construction specifications have been evolving from purely prescriptive (method-based) to a less conservative approach where the contractor has more control over the design and construction processes. This shift in responsibility, however, has brought new risks to agencies and contractors, which are often hard to quantify.

New specifications have taken the form of Quality Assurance Specifications (QA), Performance-Related Specifications (PRS), and Warranties. The first two rely on performance estimation to statistically determine pay factors which are assessed most commonly based on a lot-by-lot sampling plan. QA specifications employ quality measures such as percent within limits/percent defective (PWL/PD) to quantify material and product quality characteristics. The agency uses the computed PWL to determine payment based on compliance with specified acceptable/rejectable quality levels (AQL/RQL). While QA specifications hold on to some method requirements, they rely on the sum total of the individual requirements and sampling measurements to provide a product that satisfies the designer's performance goals.

In contrast, PRS, which also contain some method requirements, attempt to use modeling and other analytical tools to assess the impact of certain quality characteristics on pavement performance. PRS directly relate product quality characteristics, expressed as average value and standard deviation, or a combination thereof, to expected performance in order to determine payment.(1)

Many find that the application of modeling is too 'mysterious' and opt to measure the performance of the pavement some time in the future after some time period of actual service. Thus, somewhat similar in concept, warranties look at performance by prescribing minimum thresholds for roadway condition that have to be met over a specified period of time (warranty period) or amount of traffic loading. Warranties make the contractor responsible for the costs associated with repair during the warranty period. Acceptance, with minimal agency involvement during the construction phase, is not final until the warranty expires.[2]

With these scenarios of more contractor influence and responsibility on final product quality, it is imperative that State highway agencies (SHAs) identify the critical project delivery processes and quality characteristics of the product; so that they are better able to influence them by taking proactive and cooperative actions to problem solving. This requires a system that interconnects all those critical processes to meet project requirements, uses tools and methods to assure and measure quality in a timely manner, and bases continuous improvement on objective data.

The Federal Highway Administration (FHWA) has taken the first step to define the direction that the pursuit of quality in the highway industry should take. This first step was accomplished by putting together a workshop entitled "Advanced Quality Systems (AQS)" held in November 2006. Individuals from SHAs, academia, government, and industry participated in sharing knowledge and discussing pertinent issues and potential solutions to the advancement of highway construction specifications and the establishment of an Advanced Quality System.

The AQS workshop included presentations of Quality Assurance Specifications, Performance-Related Specifications, and Warranties. In addition, open discussions were facilitated for identification of research needs to improve existing quality assurance methods and specifications for pavements. These improvements will lead to pavements that have higher quality and performance, as well as project delivery mechanisms that are more cost-effective, than what exists today.

As a result of this workshop, a definition of AQS and its elements was proposed along with recommendations for implementing and Advanced Quality System within a process-based perspective. This AQS will be composed of different integrated elements, some of which already exist in the form of construction specifications, analysis tools, processes, policies, resources, data, and obviously constraints.

This document describes the concepts, discussions, and insights brought forth during the course of the AQS workshop, as well as the view of the authors on what constitutes an Advanced Quality System.

BACKGROUND

The term Advanced Quality Systems was first introduced in the highway arena during the Infrastructure Research and Technology Stakeholder Workshop, and documented in FHWA Report FHWA-RD-03-071.(3) According to the FHWA report, an AQS enables better control of the as-constructed quality of the pavement. In this way, the AQS provides the methodology to help ensure that the quality and performance expectations established during the pavement design are met during construction, and are monitored during pavement performance to provide a closed loop system.

As a result of the Infrastructure Research and Technology Stakeholder Workshop, it was proposed that the AQS topic be divided into three areas: ***as-constructed quality***, ***performance measures***, and ***analysis systems***. The objectives of each of these areas are presented below as outlined in the referenced document.

As-constructed quality

The objectives of this area are structured in such a way as to advance from current prescriptive or method specifications to performance-related specifications to performance-based specifications and warranties. These objectives are:

- To further develop and implement performance-related specifications.
- To develop the foundation for performance-based specifications.
- To develop the application of warranties.
- To develop tools and techniques for the use of warranty contracts to optimize performance, cost, and risk.

Performance measures

In order to apply more advanced types of quality systems and specifications, better measurement and pavement characterization tools are needed. Thus, the proposed objective of performance measures is to develop the next generation of pavement evaluation tools which better estimate the quality and performance measures defined in the specifications.

Analysis systems

In order to enable best application of quality systems and specifications, better systems will be needed to interpret and analyze the construction and performance data collected.

Therefore, under analysis systems, the objectives are:

- To optimize pavement quality standards.
- To further implement and continue to enhance the HIPERPAV® (HIgh-PERformance concrete PAVing) software system for concrete pavements.
- To develop other tools similar to HIPERPAV for analysis of asphalt pavements.

The FHWA Strategic Pavement Technology Program Roadmap* identifies Advanced Quality Systems as one of its five focus areas (along with Optimized Pavement Performance, Enhanced Surface Characteristics, Technical Capability Building, and Environmental Stewardship). This roadmap establishes a series of performance targets, one of which is the adoption of AQS by more than 30 States by 2012.

The FHWA Strategic Pavement Technology Program Roadmap identifies two primary performance objectives for AQS: 1) Utilization of quality assurance procedures and tools that ensure that as-constructed pavements match design requirements, and 2) Development of "next generation" systems. The FHWA Roadmap also identifies strategies that will help to accomplish these objectives, as follows:

- Strategies that will help to accomplish the first performance objective include:
    - Documenting the benefits of AQS.
    - Development and delivery of advanced, statistical reliable, usable QA systems.
    - Review of existing agency QA procedures.
- Strategies for accomplishing the next generation system's objective include:
    - Development of next generation QA concepts, procedures, and tools.
    - Development of rapid test tools for QA systems.
    - Development of performance-related specification guidelines for asphalt and concrete pavements, and development of trial projects.
    - Development of guidelines for warranty projects.

* During the preparation of this report, FHWA was in the process of revising its Strategic Pavement Technology Roadmap. The revised roadmap, known as the Focus Area Leadership and Coordinating Team (FALCON) roadmap, contains six focus areas, one of which is Materials and Construction Quality Assurance and incorporates Advanced Quality Systems.

While some of these strategies are being pursued under existing initiatives, more work is still needed to accomplish these objectives. Additional work is needed, for instance, in documenting pavement performance and identifying the key performance indicators to assure specification reasonableness and reduce risk.

These initiatives should be conducted in an organized manner to avoid duplication of efforts and to maximize the use of limited resources. To do this, the new efforts must consider existing research road maps like the Concrete Pavement (CP) Road Map, and the Performance Specifications (PS) Strategic Roadmap, with which common objectives exist.[(4,5)]

CHAPTER 2. WORKSHOP SYNTHESIS

SUMMARY

The workshop content was meant to be educational and to trigger discussion on issues associated with each of the specifications being presented, including specification advancement opportunities and the role of specifications within an Advanced Quality System.

The workshop was structured in two main sessions. In the first session, power point presentations were delivered on Quality Assurance Specifications, Performance-Related Specifications, and Warranties. Discussion of issues related to each specification was held as the presentations were delivered. The goal here was to determine the strength and weakness of each specification, and what the participants saw as its place in the future.

Some critical questions that needed answer were:

- Do the specifications properly and simply communicate the desired delivered construction?
- Can contractors working under current specifications give us the desired delivered construction?
- Do current specifications create a level playing field for contractors?
- Do current specifications and current analysis tools properly quantify product performance?
- Do the specifications adequately and properly predict future pavement performance?
- Do the specifications assign risk properly?
- Where are specifications going? How are they going to evolve?
- Are current specifications actually cost-effective?
- Are the specifications compatible with reduced State resources?
- Do the specifications encourage innovation?
- What are the associated training needs?

In the second session, the workshop participants crafted a vision of advanced quality systems. With this vision, a series of activities was identified in the areas of research, implementation, marketing and training for FHWA and SHAs to work cooperatively toward the improvement of the specifications and implementation of new and enhanced measurement and analysis tools within the process-based approach of AQS.

WORKSHOP HIGHLIGHTS

- An Advanced Quality System is an integrated quality management system that makes optimum use of available resources and tools to continuously improve the system processes and the quality of the product delivered to the customer.
- Quality must be built-in by creating a culture of quality that is brought about by quality conscious agencies and contractors working under proven quality management principles.
- Process control must be emphasized irrespective of the type of specification that governs the contract (QA, PRS, Warranties).
- Further marketing efforts geared at top management are needed to gain their commitment to advancing quality systems.
- Statistical acceptance plans need to use proper sample sizes to reduce the risks to the agency and contractor of making incorrect payment decisions.
- Rapid testing tools are needed to expedite measurement of quality characteristics within the control of the contractor.
- Data is needed to serve as a feedback mechanism to tie design to construction and to performance for better decision making.
- It was concluded that since the advancement of any type of specification is an evolutionary process, unless sound and widely proven methods and technologies are available to quantify and improve quality as it relates to performance and cost, the industry will continue to rely to some extent on method specifications.

ISSUES RELATED TO QA, PRS, AND WARRANTIES

Below is a brief discussion of some of the most important issues facing the advancement of QA, PRS, and Warranty specifications, as identified during the workshop open discussion and through informal papers submitted by the presenters on each of the three types of specifications.

QA Specifications:

Although many SHAs have QA specifications in place, they may not be very effective for a number of reasons. The most important issues that need to be addressed for improvement of QA specifications are discussed below.

Need for emphasis on contractor process control

There is still confusion between which quality characteristics are used for quality control (QC) and which are used for quality acceptance. According to the Glossary of Highway Quality Assurance Terms, quality control and quality acceptance are two components of quality assurance, with totally different purposes. [6] However, some SHAs still consider any test run by the contractor to be a QC test, even if it is used for acceptance.

Process control and acceptance are two separate functions and should not be mixed. The reasons they are often confused include the presence of quality characteristics in the acceptance plans that can be used for both purposes; for example, thickness, PCC air content, and asphalt content, etc., and the inherent contractors' focus on acceptance since that is what determines their pay adjustments. The issue lies in that contractors should not use acceptance testing as part of their process control because different limits apply to the same quality characteristics depending on the function they serve. Specification limits are used for acceptance, whereas statistical control limits are used for process control purposes. In addition, process control testing needs to be processed in real time to make timely adjustments if needed, which may not be the case for acceptance testing; for example, 28-day strength.

It has also been argued that contractor test results yield more favorable data for use in the acceptance decision.[7] Although further analysis may be needed to determine whether acceptance testing should reside only with the agency, the small sample sizes currently used significantly reduce the power of the statistical tests used to detect actual differences between the sources of data. What is known at this point is that SHAs that use contractor test results for acceptance often use weak verification procedures.

Need for rapid test methods

With the emphasis on process control, there is a need for the development of rapid test methods to determine quality characteristics as early as possible for both process control and acceptance. This is particularly important with the shortage of agency personnel available for inspection and testing. It must be stressed, however, that it is not the amount of testing that improves quality. Rather, rapid testing methods are just a tool to facilitate process-related decision making, by making more samples available and requiring fewer personnel.

Need for more education and training

SHAs need to make sure that contractors understand the importance of process control and its effect on quality and performance. Technicians and engineers need to understand the importance of sample size on variability and vice versa, how variability can be controlled, and how it ultimately affects profit and pavement performance.

Training needs and effectiveness of training must be evaluated to make sure the right people are being trained, and that the material being taught is adequate for the desired purposes of the training.[8] Training is needed for contractor and agency personnel in charge of specification development so that concepts are not misapplied. For example, PWL for thickness is often applied to leveling courses or grade correction where the thickness is already out of contractor's control. Although, there are reasonably good risk assessment tools available, and others in the development process, many SHAs do not know how to use them. Training will help to ensure these tools are utilized.

Measure what really needs to be measured

Acceptance quality characteristics should be those that the product must have, be within the control of the contractor, and be related to performance. However, due to the difficulty of measuring certain quality characteristics that better predict performance, many SHAs still measure volumetric quality characteristics, even though these may not be well related to performance. Moreover, the quality measures used may not be the most effective, but the easiest to calculate. This highlights the need for new test methods to more accurately estimate the quality of work as it relates to expected pavement performance.

Increased risks due to small sample sizes

Sample frequency has a significant effect not only on the discriminating power of the statistical tests used to validate consistency between agency and contractor's results, but also on the confidence of the quality levels achieved. Therefore, there is a significant potential for the statistically estimated lot quality to be incorrect. Unless this is accounted for in the specification, disputes may easily arise.

Many SHAs and contractors still do not seem to understand the relationship that exists between acceptance plan risks and sample size. Consequently, they do not realize the importance of improving the population estimate by using more test results than the minimum specified in most contract documents.

It must be stressed that acceptance plans need to be such that minimum sampling frequencies are used only when a steady production process has been achieved. When the process is out of control, acceptance and verification sampling frequencies should be increased. This needs to be spelled in the acceptance plan. It is also believed that the usual 10% verification sample frequency is ineffective for verification purposes, even under steady process conditions. In addition, the size of the lot must correspond to the amount of product that can be produced under a steady process; thus ensuring that the process creating the lot does not violate fundamental statistical assumptions.

In summary, for a sample size to be effective, it should be based on the risk of making incorrect decisions, the time required to perform the testing procedure, and the size of the lot. Rapid testing methods would enhance the capability of the engineer to estimate quality based on greater but optimum sample sizes

Need for more commitment from top management

In order to support the changes needed and to provide the resources required, commitment is needed from the highest level of every agency. Nonetheless, top management commitment may fall short since the typical top manager's life in office tends to be short. A structure for change embraced by legislators and other decision makers is needed to guarantee that initiatives keep moving in the right direction.

For the most part, the tools and knowledge to achieve the needed changes already exist. What has been lacking is willingness to make the changes. The risks that new specifications pose to the agencies and the industry need to be seen from a broader perspective; one that identifies, quantifies, and addresses them. To effectively address risk, its analysis must be based on performance data to assure the most critical performance-related quality characteristics are emphasized.

Formulation of the specifications

Two premises must be accepted with regard to quality. First, quality must be built-in; it can't be inspected-in. Second, requirements must be achievable, within the contractor's ability to control, and worth controlling. As for the former, inspection can only give an estimate of quality, and can do nothing to change quality of the final product it if it does not meet requirements. In other words, inspection alone does not eliminate the cause of nonconformities to prevent recurrence. Rework is not a solution to poor quality, but the consequence thereof.

With this is mind, quality must be part of the life cycle process of a highway project. This requires that construction variability and variability in performance be addressed at the design stage, so that there is consistency between what is designed and what is specified. However, pavement design practice still relies on empirical procedures based on traffic as an estimator of performance, and does not consider durability issues, nor does it take actual variability of each quality characteristic and performance indicator into account.

The state of the art in QA specifications is the use of life cycle expectancies to determine pay factors. However, even with this method, pay schedules and weighing factors associated with individual quality characteristics are often based on “best guesses.” Therefore, there is a need to rationally determine pay factors through methods employing life cycle cost analysis, and evaluate correlations among the specified quality characteristics. Risk tools currently under development (PWL-Pay, SpecRisk) are expected to improve this aspect of specification analysis and development.

It must be recognized that while incorporation of more acceptance quality characteristics (AQCs) is desirable, more AQCs may mean less emphasis on any one individual quality characteristic. This could possibly cause deficiencies in some areas, and present a greater overall risk to the contractor of having good construction rejected. This risk should be identified before writing a specification. An understanding of this risk can be helpful in mitigating pay factor balancing as well. Operating characteristic (OC) curves and expected pay (EP) curves should be developed to assess risks associated with both individual and combined AQCs .

Need for an effective feedback system

Ideally, SHAs should be able to write the specifications based on the performance they desire, and then be able to determine if the specification is working properly or where it needs improvement. However, data are needed to support this development process. This means, among other things, that material, process, and product variability sources must be accounted for and quantified. Once identified and quantified, variability measures should be stored in a properly referenced database to help in the specification writing process.

The problem SHAs face is that even though the data needed may be available, it is not easily accessible or ready for integration for the kinds of engineering analysis that could be performed. Therefore, integrated database systems must be implemented to not only capture data and allow the engineers to perform analysis, but also to become a knowledge base that builds on the knowledge and lessons learned by others in the agency.[9]

Only valid data will provide the information needed for cost-benefit analysis to gain support from top management.

Need for cultural changes

Contractors are so used to following prescribed methods that some may not want the responsibility and associated liability that are inherent in QA specifications. Further, they may not have the needed staff or experience. SHA efforts at improving quality need to be aimed at establishing the foundations for creating a cultural change in the industry; a culture change that brings about quality conscious contractors that understand the implications of quality on pavement performance and cost, and that take the necessary actions to guarantee good quality.

Quality conscious contractors will be the result of quality conscious agencies that streamline their own processes in order to make quality a top priority as well. Therefore, an agency must lead by example, which means controlling its operational processes as an integrated system that sets achievable expectations, continuously assesses its effectiveness on reaching those expectations, and selects its service providers based on their ability to deliver at or above those expectations. [10] This, in turn, will help the agency create the foundation for transitioning from low-bid to value-added contracting mechanisms. It is clear then, that the need exists to create a business environment that rewards the best contractors. Low-bid contracting frequently results in problems with quality in general, and does nothing to help shift a contractor's attention from acceptance to process control.

Performance-Related Specifications:

PRS are in fact a subset of QA specifications. In PRS, the acceptance quality characteristics to be measured are directly related to pavement performance through mechanistic-empirical (M-E) relationships.

A number of improvements to current Portland cement concrete (PCC) and hot-mix asphalt (HMA) PRS specifications are needed to advance their development and implementation, as explained below.

Specification development

PRS Levels 1, 2 and 3 mainly differ in the AQC sampling and testing methods, and the payment adjustment procedures. Level 2 PRS is an expansion and refinement of the Level 1 PRS. Theoretically, the Level 2 PRS represents the dynamic transition from the proposed Level 1 specification to an ideal PRS.

Level 1 PRS include five AQCs: concrete strength, slab thickness, entrained air content, initial smoothness, and percent consolidation around dowels. As opposed to Levels 2 and 3, Level 1 PRS may be implemented using the SHA's current field sampling and laboratory testing procedures. Therefore, the Level 1 PRS should be readily implementable in any SHA with minimal change to the agency's current acceptance. [11]

Since level 1 PRS generally matches the State's existing requirements, the effort of developing and implementing the specification is not much greater than a conventional specification on a project basis.[12]

Level 1 PRS is the only type of PRS that has been implemented in States like Indiana, Wisconsin, Florida, and Tennessee. However, having a tailored PRS for every project reduces the number of new projects since site specific information is needed to determine applicable pay relationships. Consequently, if Level 1 PRS were to be tailored on a project-by-project basis (as opposed to one PRS for all projects Statewide within a functional pavement classification), more time and effort would be required by the State to develop the PRS.

What would help, therefore, is a substantially streamlined process that minimizes the number of inputs needed during construction. Additionally, extending the application of PRS to other types of pavements such as continuously reinforced concrete pavements (CRCP) and whitetopping, could drive more efforts from States using those types of pavements.

The accuracy and applicability of the performance prediction models to the site conditions is a critical issue. The suitability of national models applied to specific projects is dependent on the accuracy of the models in determining the relative importance and effect of the critical parameters. However, no prediction model can accurately predict the magnitude of distress or performance indicator that applies to all conditions and materials.[12] In addition, calibration and validation tests to local conditions are needed to render greater confidence in the predictions.

As part of the validation testing, sensitivity analysis of the models to PRS inputs is essential to identify the more critical inputs in terms of their impact on performance. The test program for each type of project can then be focused on those properties.

Some researchers feel that additional AQCs related to durability and structural and functional performance are needed to be better able to determine the quality of a pavement. However, it must be recognized that different properties become critical under different conditions. Any new AQC must be able to accurately relate construction quality characteristics to their effect on performance (e.g., CTE, segregation, interface friction between two adjacent HMA layers, etc.). A risk analysis needs to be conducted before including any more AQCs, keeping in mind that risk depends on soundness of sampling and testing and on the accuracy of prediction models. Adding more AQCs without having sufficiently large sample sizes to assess their benefit to the quality level analysis may cause more harm than good.

Designers must take a leading role in developing project level PRS. However, design is still performed based on empirically derived methods, whereas the PRS are based on mechanistic-empirical (M-E) procedures. This tends to create inconsistencies in the specifications. Although the new AASHTO Mechanistic Empirical Pavement Design Guide does not include variability as a design input and reliability is just an overall general input, [13] it has the capability to tie mixture design to structural design, incorporate available and innovative paving materials and determine their effect on performance. This could permit SHAs to better quantify pay factors.

The effect of construction variability on performance also needs to be addressed. When accounting for variability, it is fundamental to consider the suitability of normality assumptions. The current PRS specifications rely on random sample selection assuming normal distribution from sublot to sublot. This overlooks the fact that the sample distribution may not reflect the assumed population distribution, which as a result makes the estimated variability imprecise.

Need for more testing, methods and training

States are finding it hard to commit personnel and resources to development and implementation of Level 1 PRS. Furthermore, some quality characteristics that may be more important due to local conditions may not be properly considered due to the lack of tools to measure them accurately; as for example, curing effectiveness, steel location, and dowel bar alignment for concrete pavements. For asphalt pavements, those examples include moisture susceptibility, segregation, bonding between hot-mix asphalt (HMA) lifts, and texture. (14)

Therefore, more rapid (shorter turnaround periods of 24 to 48 hours or less, if not instantaneous), accurate, precise and nondestructive in-situ testing methods are needed, particularly those related to strength and durability for each of the pavement layers. It must be stressed though, that inaccurate and/or unrepeatable tests not only compound the problem of data variability; they also weaken the confidence in test results which can lead to greater disputes in contractor pay assessments. Any new testing method to be used as a standard procedure must include properly developed precision statements.

Further research is needed to increase the potential capabilities of methods like the adjusted seismic modulus, which could be used in accepting and controlling HMA mixtures, as well as in-situ hand held moduli measuring devices for control of field compaction like the GeoGauge and other similar devices.

The rapid testing methods for field conditions should also be capable of measuring continuously, as opposed to point-specific methods. This includes development of equipment to measure entire lots rather than random points within the lot, which would help overcome sample size issues. Some of this equipment is already readily available. For example, the air-coupled ground penetrating radar (GPR) equipment provides reliable continuous measurements of layer thickness, voids and moisture.

Formal training on test equipment and procedures will also be needed to build confidence in technicians' understanding of the equipment's fundamental properties. Current PRS training plans include developing and conducting a 2 to 3-day National Highway Institute (NHI)-type training course on HMA PRS. This should also be done for PCC PRS. An information hub needs to be developed to provide assistance to agencies, material suppliers, and contractors implementing HMA and PCC PRS.

Need for senior management's commitment

Support for PRS from senior management at the national level is required to make feasible a transition to a PRS-based approach. SHAs will require support in the form of both training and technical assistance. For instance, process training at the engineering level would familiarize technical personnel (e.g., design, materials, and construction engineers) with the PRS concepts and procedures, and instruct them in the use of the PaveSpec or HMASpec software products. It would also provide guidance in developing the many PRS inputs, creating project or network-level PRS, and in administering PRS on actual projects.

Promotional training at the upper-management level would focus on comparing and contrasting PRS and conventional QA specifications, quantifying the many benefits of PRS, and strategizing the transition to or adoption of PRS policies and practices. Buy-in from top management will facilitate the achievement of consensus on performance tests, and smooth out existing and potential policy differences including those regarding incentives.

Warranties:

Lack of analytical tools to estimate risk and develop specifications

To ensure the contracting community and surety companies have confidence in warranties, deployment of existing rational risk allocation and assessment tools and methods needs to be part of project planning activities and be supported by enough and proper data.

A rational risk management process contains six primary steps: Risk identification, assessment, analysis, mitigation, allocation, and tracking and updating.[15] In other words, managing risk means identifying high-risk project responsibilities (e.g., providing traffic data, condition of the road and base, etc), risks associated with those responsibilities (e.g., errors in traffic data), the likelihood of the risk (defining reliability of traffic data), the consequences of the risk, and mitigation measures. Thus, project selection and delivery method determined during the project planning stage becomes fundamental for risk reduction.

Warranty specifications need to address the risk of pavement failure before or soon after the warranty period ends, especially for short-term warranties. However, this need poses another problem: it is difficult for contractors to bid warranty projects with final acceptance criteria that include remaining life or structural capacity requirements, especially given the contractor's limited degree of involvement in design. Remaining life acceptance criteria may be practical where up-to-date, accurate, and reliable measurement tools are employed. In addition, the conditions of the existing pavement structure have to be known, and are such that there is enough confidence in holding the contractor responsible for unforeseen or premature failures.

Performance measures and thresholds need to be consistent with the degree of control the contractor has over the conditions that affect those performance measures. However, as warranty practice has shown, performance thresholds for design build (D-B) contracts, where the contractor is responsible for pavement type selection and design, are similar to those in design-bid-build (D-B-B) contracts, where the contractor has a very limited role in those decisions. This factor of the specifications needs to be reviewed.

The discussion above brings up the issue of warranty length and how it affects risk. Some argue that longer warranties can help the SHA minimize certain risks like that related to remaining life. Nonetheless, surety companies still need to be convinced through objective data to start embracing longer warranty periods while bonding issues that hinder competition need to be resolved.(16) This supports the argument for best value contracting, provided there are ways to ensure the warranty is actually enforceable. This far, SHAs seem to prefer the use of maintenance contracts in lieu of long-term performance warranties in D-B contracts.

Survival analysis has been proposed as a tool for measuring the risk of pavement failure.(17) However, large amounts of pavement performance data are needed, including failures, which may not be practical for short-term warranties. Hence, all the accumulated experience with long-term warranties needs to be evaluated and fed back into the warranty specification development process.

Presence of conflicting requirements

Minimizing risk means holding contractors responsible for those aspects of a project specifically under their control.[18] Therefore, the warranty specifications must be articulated exactly in the contract through clear and understandable performance criteria that are consistent with the level of risk assigned to the contractor. This means that method requirements must be limited to the possible extent and not be in conflict with what else is being required.

While warranty specifications should allow for contractor's innovation, there may be some limitations that may need to be set forth in the specifications. One example is specifying corrective actions, which may be necessary to protect the SHA from "quick fixes," especially on short-term warranties. Nonetheless, the warranty should allow for using innovative repair methods that have proven effective.

Warranty administration and quality assurance

The level of involvement of SHAs in quality assurance during construction and performance monitoring needs to be assessed. It may be true that, in general, contractors may be "paying more attention to detail" on warranty projects than on typical QA contracts.[19] However, from a quality management systems perspective, SHAs still are responsible for providing confidence to the road users and interested parties that the desired product quality level will be delivered. Needless to say, highway agencies need to keep their own records as evidence to justify performance criteria, or if conflicts occur.

Some States claim that warranties reduce their inspection force, but it is actually true that some also lack data on construction operations and oversight to make better decisions or justify penalties. [20] The question that naturally arises is, "How do you know where you need to improve if you don't know where you are wrong?"

To ensure performance, frequent monitoring takes place. Monitoring is conducted mainly by the SHAs as part of their regular PMS data collection process. Although it is reasonable to utilize existing PMS capabilities for warranty administration purposes, there are important differences between monitoring pavement performance for pavement management purposes and monitoring for warranty enforcement purposes. For warranties, the monitoring of project pavement performance is done for quality assurance purposes. For pavement management, however, it is conducted predominantly to aid in the planning and programming of maintenance and repair activities, primarily at a network level.

The acceptance process during performance monitoring may be based on sampling; however, like in other types of specifications, sample size may become an issue, especially if the sampling plans are such that important distresses are left outside the sampling area. Additionally, warranty administration requires a more rapid pavement performance monitoring method since data need to be reported to the contractor rapidly. Consequently, to continue to use agency PMS to monitor warranties, consistency in the techniques used to establish thresholds and conduct PMS measurements must be enforced. Therefore, it would be worth studying the feasibility of having contractors monitor their warranted projects, and use adapted PMS as a quality control tool.

Lack of objective data to demonstrate cost effectiveness

Warranties seem attractive to many SHAs because of the initial low cost to them and other expected benefits like protection against premature pavement failure. However, it is difficult to estimate the cost of administering and enforcing warranties, especially from a LCC perspective.

Often the nominal warranty cost is included as an additional bid item, but the true cost of warranties is difficult to estimate because it depends on factors such as the effect of warranties on other bid items, the cost of administering/enforcing warranties, and the cost of inspection and testing during construction, among others.

Only a few efforts have been made so far to collect and analyze objective data, such as pavement performance, initial quality, and cost on warranty projects.[19, 20] For the most part, the existing data on warranty specifications for highways has been obtained predominantly from agency surveys/interviews, which even though informative, are prone to inaccuracy and subjectivity.

Unless sufficient data are collected to perform objective cost/benefit analyses, little commitment can be expected from top management to actually engage the industry in making the necessary changes for the betterment of this type of specification. Needless to say, these analyses must be conducted by comparing the warranted pavements with similar condition non-warranted ones to determine that cost-benefit ratio.

CHAPTER 3. ELEMENTS OF AN ADVANCED QUALITY SYSTEM

THE ISO 9000 PERSPECTIVE

According to the International Organization for Standardization (ISO) in its 9000 series, *quality* is a *characteristic* that a product or service must have (strength, thickness, air voids, etc).[21] In rather similar terms, the Glossary of Highway Quality Assurance Terms states, "Quality is the degree to which a product or service conforms to a given requirement." [8] Therefore, it is the product requirements as defined in the specifications that should reflect what those characteristics must be. In the highway industry, product requirements should be performance-related (both structural and functional performance).

It must be noted that not all quality characteristics are equal; some are more important than others. It is the most important ones – those that customers desire – which the service provider must focus on. This implies that a set of inherent characteristics of the product has been defined, and that there is some objective or subjective way to measure the quality level achieved and the degree this quality meets customer expectations.[10]

The ISO 9000 series describes the fundamentals of quality management systems. These systems start and end with the customer, who is defined as any party or individual(s) internal or external to the organization that receives the result of a process (a product). Within the context of the highway industry, three kinds of customers can be defined: road users, administrative customers (agency and contractor personnel), and interested parties or stakeholders (legislators, professional organizations, Federal, State governments, etc.). Customers play a vital role in providing the requirements that the product delivered to them must meet.

With such a broad range of customers the quality requirements must be differentiated among road user requirements or product/service requirements, management requirements, and legal or statutory requirements. To make sure these different requirements are understood and properly met, quality must be systematically managed from quality planning, to quality control, to quality assurance, to quality improvement. According to quality management systems practitioners and consultants, the best way to manage quality is through a system that orderly transforms inputs (requirements) into outputs (products and services) through a chain of value-adding interrelated processes.[20]

Due to financial and personnel constraints agencies are faced now, more than ever, with the challenge of becoming operatively more efficient and effective to be able to keep up and do more with less. In doing this, agencies have adopted different types of specifications and contract delivery mechanisms with different requirements in terms of responsibilities and liabilities. The requirements set forth in the specifications have sometimes been considered non-achievable, based on subjective information, and not well-enough specified to guarantee that everyone involved in the process has a firm understanding of what is required by them.

This situation presents the agencies with the opportunity to embrace a systems approach to management that makes quality a top priority. To help in this evolutionary process, the authors believe that the most effective way to do it is by resorting to proven methodologies and concepts that are well suited to all types of organizations, including those dealing with highway delivery processes.

The ISO 9000 series is applicable to:

- Organizations seeking advantage through the implementation of a quality management system.
- Organizations seeking confidence from their suppliers that their product requirements will be satisfied. [8]

A quality management system can provide the framework for continual improvement to increase customer satisfaction. [8]

The ISO 9000 Quality Management Systems principles provide the basis for instilling a culture of quality within the organizations that embrace these principles, and help these organizations raise their customers' confidence in the organization's commitment to consistently achieving quality.[8] Eight principles constitute the basis for a quality management system:

- Customer-focus.
- Leadership.
- Involvement of people.
- Process approach.
- System approach to management.

- Continual improvement.
- Factual approach to decision making.
- Mutually beneficial relationships with suppliers.

Although all principles are important, three of them are worth noting here for their great relevance and potential impact in the achievements of the objectives of the AQS initiative: the process-based approach, the management of processes as a system, and the development of mutually beneficial relations with suppliers.

The International Standard promotes the adoption of a process-based approach, and the management of the interactions between the processes. In an ISO quality management system, customers play a significant role in defining requirements as inputs to the process, and providing feedback about their satisfaction with the product/service received. This helps the organization assess the effectiveness of its quality system.

An organization and its suppliers are interdependent. For this reason, a mutually beneficial relationship increases the capacity of both to create value.

It has been demonstrated elsewhere that when those quality principles have been applied, they facilitate the development of a culture of quality in the organization. (21) In a quality-focused environment, top management is committed by getting involved in establishing the quality objectives and making sure the processes necessary to deliver the product are aligned with customer requirements and the organization's policies. In addition, top management provides the resources the processes need, reviews the effectiveness of the system, and ensures actions are taken to continually improve its performance and effectiveness.

A quality management system established according to these principles helps organizations bring down communication barriers, change paradigms, and make every department in the organization know how the result of its work affects other processes or areas in the organization.

Working under a quality management system implies leadership from the agency to:

- Manage the interfaces between different groups involved in design and development to ensure effective communication and clear assignment of responsibility.

- Establish complete, unambiguous requirements not in conflict with each other.
- Evaluate and select suppliers based on their ability to supply product in accordance with the organization's requirements.
- Identify the product by suitable means throughout product realization.
- Maintain available records of monitoring, measurement and treatment of nonconforming product (documentation).
- Determine, collect, and analyze appropriate data to demonstrate the suitability and effectiveness of its own quality management system in meeting requirements.
- Determine actions to eliminate the causes of potential nonconformities in order to prevent their occurrence.
- Control legible, readily identifiable, and retrievable records and documents to provide evidence of conformity to requirements and of the effective operation of the quality management system.

In the ISO 9000 language, the term “product” applies only to the product or service intended for, or required by, a customer.(10) (See additional definitions in glossary at the end of the document).

The benefit of looking at the agency’s operations from a quality management systems perspective lies in that, the various parts of the organization's current management system may be integrated together with the quality management system into a single management system using common elements. This can facilitate planning, allocation of resources, definition of complementary objectives, and evaluation of the overall effectiveness of the organization. (21)

AN ADVANCED QUALITY SYSTEM IN THE HIGHWAY INDUSTRY

Any new pavement performance improvement initiative needs to come out of an integrated set of activities (system) with a common goal. For this system to be effective, a definition of what the system means needs to be spelled out. As opposed to the current interpretation of quality systems as mere analysis tools or specification types, the AQS definition revolves around an underlying approach (process-based approach), which is based on interconnected processes as discussed in the previous section. These processes use tools (analysis systems) and resources to transform inputs into outputs because some kind of work, activity, or function is performed. [10]

During the AQS workshop a preliminary definition was reached, which has been expanded based on the ISO 9000 principles into the following:

> An ***Advanced Quality System*** is a set of interrelated continuously improved processes to fulfill the customer's expectations of pavement performance by making optimum use of the available tools and resources, and fostering cooperative working relationships among all parties.

In an AQS, quality is dealt with by looking at the processes that intervene in product realization from a system's perspective. Thus, a quality management system is in place for the agency to coordinate its quality improvement initiatives. All levels of government in the highway delivery process work under the same perspective.

The elements of an AQS are shown in figures 1 and 2. Figure 2 is a more detailed version of figure 1.

The main processes of this AQS and what the processes entail are:

- **Top Management Commitment**
    - Identification of customer requirements the product must have.
    - Definition of quality and system objectives, quality policy, and organization's quality plan.
    - Revision of effectiveness of the quality system.
    - Revision of assessment of customer satisfaction.
    - Verification that improvements are made, and actions taken to prevent occurrence of nonconformities.
    - Verification that responsibilities and authorities are defined and communicated throughout the organization.

- **Resource Management**:
    - Provision of resources (personnel, infrastructure, funds).
    - Verification and development of skills and competencies.
    - Training.

- Assignment of personnel.
- Assessment of training effectiveness.

- **Product Realization**:
  - Project planning.
  - Design.
  - Design verification.
  - Adjustments.
  - Construction.
  - Process control.
  - Acceptance.

- **Assessment and Improvement**:
  - Monitoring of performance (system and product).
  - Assessment and analysis of system and product effectiveness.
  - Development of improvement plans.

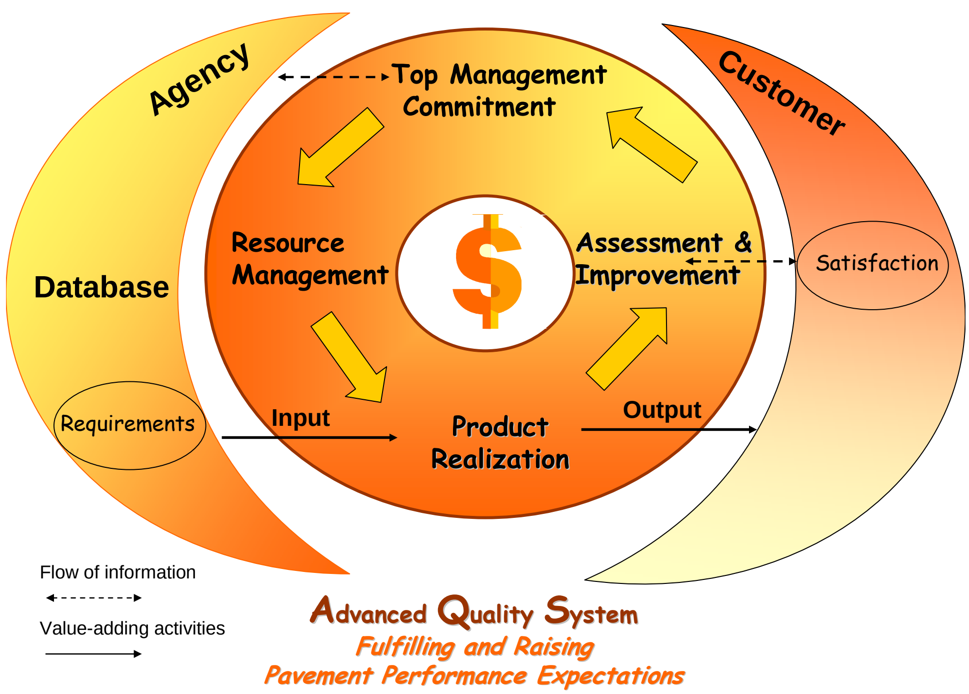

Figure 1. Advanced Quality System, main elements

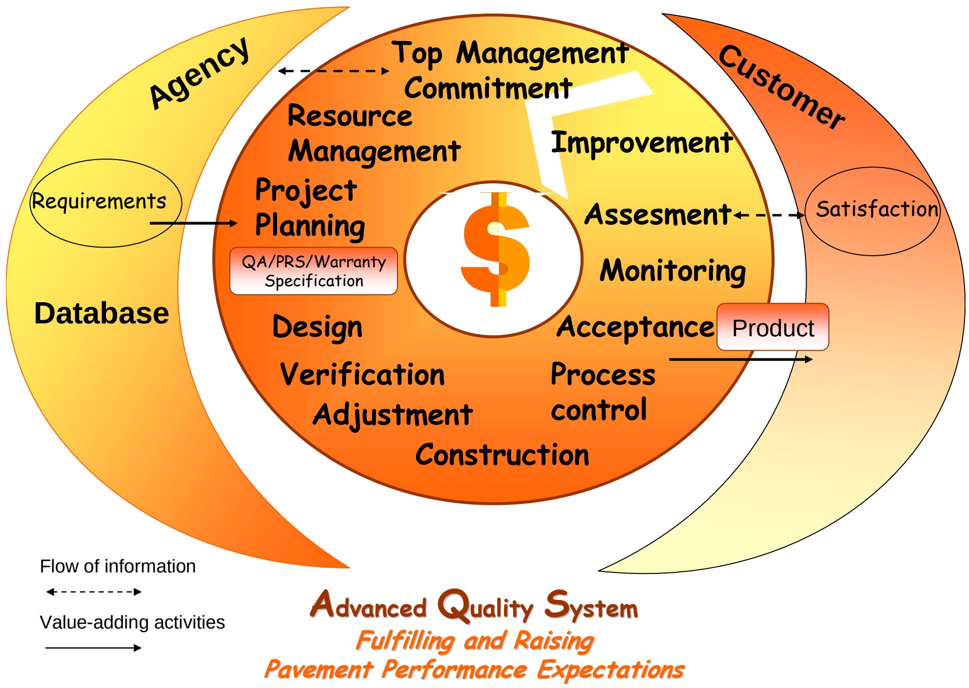

Figure 2. Sub-processes of product realization and assessment in an AQS

DESCRIPTION OF THE ELEMENTS OF AN ADVANCED QUALITY SYSTEM

An Advanced Quality System, like any system, is composed of entities and processes which use resources and tools. However, it is advanced in the sense that it integrates those resources and tools in a systematic way by using a process-based approach. The project life cycle is covered in its entirety by the system in such a way that feedback is provided for continuous improvement.

Note that the system is described herein as it should be under ideal conditions. A description of each element of the system is provided below including ways that would help achieve system development and implementation.

Entities:

Customers

There are different kinds of **customers** to the system: road users who receive the end result of the product realization process, administrative customers who take part of the product realization (agency and contractor personnel), and interested parties or stakeholders (legislators, professional organizations, federal, State governments, etc.). All of these customers have a stake in the end result, and their requirements are stated in the specifications either explicitly or implicitly.

Agency

The agency in an AQS captures the requirements of all customers to the system, and puts those requirements in the form of specifications that tell the contractor the level of quality the product characteristics must have. The agency makes sure those requirements are congruent with the skills of the individuals (personnel) taking part in the product realization process. The agency also periodically evaluates the effectiveness of its quality management system in achieving the product and system's quality objectives, and maintains communication with the customer and interested parties.

The agency makes sure personnel are aware of the relevance and importance of their activities and how they contribute to the achievement of the quality objectives.

Resources and tools:

Database

The database plays a key role in the system as a decision making tool, and the importance of good quality data cannot be overstressed. It is by looking at historic data that trends can be depicted and problems can be investigated to aid in the specification development process, and efficiency of the agency's operations. In other words, it is through data that objective decisions can be made and translated into achievable requirements.

The database is not a standalone tool meant only for specific and isolated purposes, but rather it is made up of integrated databases with common referencing capabilities and wide accessibility levels to facilitate monitoring of specifications for further development and implementation. This central database allows SHAs to determine, for example, the effect of variability on performance, and the effectiveness of the specs (whether the agency is getting what it specifies, and specifying what it wants).

More specifically, by having this integrated database, the targets and standard deviations needed to develop PRS specifications are easily determined from past projects, the costs associated with particular specifications are traced, congruent pay factors and performance prediction equations are calibrated, and risk analyses through survival curves for warranties assessment are conducted. In the field, real time information is available on a lot-by-lot basis for timely process control. Through integration with PMS and other databases, SHAs have the ability to ascertain actual versus predicted costs and performance of past projects, and thus make corresponding adjustments to the performance models in use.

Within this concept of AQS, data becomes available to link all inputs and outputs of the product realization process, and spelled-out procedures are built-in to ensure flow of information and communication. In addition, the information to be collected is identified, and consistency of the information is guaranteed.

Basic guidelines for implementing such databases have been recently released in the form of report FHWA-HRT-07-019, "Advanced Quality Systems: Guidelines for Establishing and Maintaining Construction Quality Databases."[9] These guidelines call for effective databases that not only allow for data storage and retrieval, but also lend themselves to data analyses different than those needed merely for payment purposes.

Funds

Monetary resources are a central element of the AQS since they constrain the scope of the actions the system can take for continuous improvement. In an AQS, it is important to recognize that quality has a cost, and the best decisions are made throughout the project life cycle for the cost effectiveness of the delivered product.

Personnel

Agency and contractor personnel are a key element of the system in that through their skills, abilities, and competencies, they add value to the chain of processes that lead to the final product.

Infrastructure

Infrastructure in an AQS refers to buildings, workspace and associated utilities, process equipment (both hardware and software), and supporting services such as transport or communication. The agency ensures that all parties involved in the product realization exceed minimum infrastructure needs.

Processes:

Top management commitment

In an Advanced Quality System, top management identifies the customer requirements the product must have, defines quality and system objectives and the organization's quality plan, reviews the effectiveness of the quality system, and assesses the level of customer satisfaction. In addition, top managers make sure improvements are made and actions are taken to prevent the occurrence of nonconformities. They also define responsibilities and authorities, and communication required throughout the product realization, monitoring, assessment, and improvement processes.

Resource management

The agency makes sure that all personnel performing work that affects product quality are competent on the basis of appropriate education, training, skills and experience. It does this by evaluating the effectiveness of the actions taken, and ensuring that agency and contractor's personnel are aware of the relevance and importance of their activities and how they contribute to the achievement of quality. Records of education, training, skills, and experience are maintained.

The SHA determines, provides, and ensures that the infrastructure needed to achieve conformity to product requirements is available.

The role of quality managers is revisited and redefined so that they can, like in any manufacturing process, influence the production decisions without being constrained by the hierarchical ladder. Inspectors on the jobsite know what to look for and how to interpret results to make the best decisions on pay adjustments and possible corrective actions.

Product realization

The process of product realization involves all activities, before the project starts up to the final acceptance of the pavement.

Project planning

During this stage, general project requirements are defined by the agency, which reflect its policies and objectives. Requests for Proposals are solicited at this stage if design is included in the proposal. Proposals are evaluated and projects are awarded. SHAs make use of a formal risk management process that starts at this stage of the project development process so that the governing specification is determined (QA, PRS, Warranty) and becomes part of the contract documents. Tools like Washington Department of Transportation's (WSDOT) Cost Estimate Validation Process (CEVP) and Cost Risk Assessment (CRA) are widely used.

Tools such as PWL-Pay, SpecRisk, and Prob.O.Prof (Probabilistic Optimization for Profit) help agencies write rational, fair and objective quality assurance specifications while aiding contractors in evaluating target quality levels and pay factors, both before and after the bid.

The level of trust and partnership between the SHA and the industry is such that public-private partnerships become more attractive and feasible.

Design

This stage of the project life cycle is carried out according to project requirements (either by the SHA or contractor). The different stages of the design process are laid out and responsibilities assigned. In addition, the interfaces between different groups involved in design are coordinated, and communication channels ensured.

Several tools are available for designers to perform their duties. Traditional pavement design software is abundant; however, since performance-related design is the state-of-the-art in an AQS, updated PaveSpec and HMAspec software applications are there to encourage designers to work together with construction personnel to develop optimized job-specific specifications and get both interested enough to provide the construction feedback to design. In the same fashion, COMPASS (Concrete Mixture Performance and Analysis System) allows for truly performance-driven concrete mix design, and new tools are available for asphalt concrete mix design.

Accordingly, in an Advanced Quality System, most States have implemented M-E pavement design procedures on new construction, rehabilitation and maintenance, to the extent that the SHAs can incorporate the actual construction test results into validated performance models to determine payment.

Verification

Irrespective of who is in charge of the design, verification of the design inputs, outputs and underlying assumptions is performed, including compliance with input requirements. Potential problems are identified and solutions are proposed. Validation may be part of this process, in case the methods and assumptions used are new to the design review and verification team and/or have not been proved elsewhere. Records of reviews and verifications are maintained.

Several tools common to other processes can be used for design verification purposes as well. For instance, HIPERPAV (HIgh PERformance concrete PAVing) allows the designer (structural design or mix design) to estimate the effect the design parameters will have on the behavior of the pavement under a set of environmental, construction and materials conditions. The array of conditions becomes “what if?” scenarios that allow for design optimization.

Adjustment

Changes may be recommended as a result of design review and verification. Once the changes are made, they are reviewed, verified and validated as appropriate, and approved before implementation. This review includes evaluation of the effect of the changes on the product already delivered. Records of changes and any necessary actions are maintained.

Construction

During this stage, the actual pavement construction, rehabilitation, and/or maintenance take place. A construction quality assurance system is in place, and the level of detail of its related activities is defined depending on the type of governing specification (QA, PRS, Warranties).

Closer attention to detail in pre-construction planning and deployment of the paving operation is exercised. Better equipment and more skilled labor are deployed. Equipment is mostly automated for most highway construction operations. Faster construction techniques are regularly employed to minimize traffic disruption.

Process control

According to the Glossary of Highway Quality Assurance Terms, process control refers to the set of quality assurance actions and considerations necessary to assess and adjust production and construction processes needed to control the level of quality being produced in the end product. In an AQS, this is a contractor activity since the contractor is the one capable of modifying its own processes, if needed.

Work instructions, the use of suitable equipment, the availability and use of monitoring and measuring devices, the implementation of monitoring and measurement, control of non-conforming product, and the release of conforming product are contained in a quality control plan. As part of its process control, the contractor identifies the product status with respect to monitoring, measurement, and acceptance. The controls and related responsibilities and authorities for dealing with nonconforming product are part of the quality control plan.

The agency aids in process control by defining criteria for review and approval of the processes, approval of equipment and qualification of personnel, use of specific methods and procedures when they apply, record keeping protocols, and verification/validation procedures. In addition, during periodic construction quality audits, the agency ensures that any product which does not conform to product requirements is identified and controlled to prevent its unintended use or delivery.

A number of tools are available to the industry for process control, including what is called pre-process control, which allows contractors to plan their construction operations by simulating possible construction scenarios and their effect on pavement behavior. These tools include enhanced HIPERPAV, COMPASS, Prob.O.Prof, PWL-Pay, etc.

In an Advanced Quality System, high-speed testing devices are widely used to measure quality continuously in the field in a timely fashion through non-destructive techniques, and the results of measurements are reported in real-time.

Acceptance

This quality assurance activity performed by the SHA or independent parties consists of sampling and testing, or inspection, to determine the degree of compliance with contract requirements. In QA and PRS projects, the agency monitors and measures the quality characteristics of the product at appropriate stages of the product realization process to verify that product requirements have been met. Validation of contractor’s acceptance results is conducted, but it reaches the point where it is becomes less necessary.

In warranty projects, this activity is performed periodically to determine payment following monitoring of the in-service pavement and at the end of the warranty period. It consists of measurement of compliance of the pavement condition indicators set in the contract requirements. During construction, the agency performs quality audits of the contractor's process control and quality management system, keeping records of the audits and data generated by the process control in case future disputes arise.

In summary, the level of testing and the degree of involvement of the agency depend on the type of specification governing the contract. However, the agency's purpose is to provide minimal yet sufficient presence and oversight to record evidence of its commitment to quality.

Monitoring

This process extends to monitoring of the agency's quality management system. The agency/contractor applies suitable methods for monitoring the specified characteristics of the product, including PMS data collection efforts, when applicable. SHAs use feedback loops from their PMS to monitor performance.

The monitoring methods are capable of demonstrating the ability of the processes and the product (pavement) to achieve expected performance. When planned results are not achieved, corrective actions are taken to ensure conformity. Evidence of conformity with the acceptance criteria is maintained.

Assessment

The agency determines, collects, and analyzes appropriate data to demonstrate the suitability and effectiveness of its quality management system, and to evaluate where continual improvement of the effectiveness of the quality management system can be made. In the same fashion, the data analysis includes customer satisfaction, evaluation of suppliers, and characteristics and trends of its product realization processes, from where opportunities for preventive action are identified.

On the product side, the agency conducts performance model improvements, and correlations between quality, cost, and performance to improve its construction specifications. Note that this process, as well as the previous one, addresses both the product and the agency's capability to deliver a quality product.

By conducting self-assessments, the agency can systematically review its activities and results, thus identifying areas requiring improvement and determining priorities.

Continuous improvement

The agency continuously improves the effectiveness of the quality management system and its products through the use of corrective and preventive actions and top management review. Actions are taken to eliminate the cause of nonconformities in order to prevent recurrence.

There is a procedure in place to review nonconformities (including customer complaints), determine the causes of nonconformities, evaluate the need for action to ensure that nonconformities do not recur, determine and implement actions needed, and review the corrective actions taken. Furthermore, the causes of potential nonconformities are evaluated and eliminated in order to prevent their occurrence.

With all of the above, the foundation is set for a systematic pavement performance improvement that counts on specifications based on objective information and a commitment to exceeding the customer's expectations.

CHAPTER 4. RESEARCH, IMPLEMENTATION, TRAINING, AND MARKETING ACTIVITIES RECOMMENDED FOR ACHIEVING AN ADVANCED QUALITY SYSTEM

The recommendations presented here constitute a set of actions needed in terms of research, implementation, training, and marketing, as well as measures FHWA and the highway industry can take to provide the leadership for the deployment of an Advanced Quality System in the highway industry. This includes advancement of all related systems and specifications to maximize their cost-effectiveness.

These recommendations are based on the discussions brought about during the AQS workshop described in chapter 1, as well as those deemed necessary by the authors. Since most issues presented in chapter 2 are common to the three types of specifications discussed previously, a distinction between specifications is not made, unless the recommended action is particular to one type of specification.

These recommendations should be looked at in conjunction with existing plans which share common issues or points of interest, such as the CP Roadmap, the PS Strategic Road Map, several States' research roadmaps, and States' efforts to implement the M-E procedures.

FHWA should ensure there is a strong connection between research results and implementation. In addition to serving as a channel for disseminating information on innovations in materials, tools, and methods, FHWA could help ensure adequate and effective training is conducted so that new technologies and techniques are not misapplied.

RECOMMENDATIONS

Research:

- Continue to develop and/or improve new field testing methods; and continue to investigate proprietary technologies that are non-destructive in nature and capable of taking measurements continuously. Full automation is desired, with an emphasis on accuracy, precision and correlation with other/existing testing methods.

- Develop new tools and improve the capabilities of existing ones to help agencies/contractors assure/control quality by ascertaining the best design, materials, and placement conditions that result in high pavement performance and minimal impacts on the traveling public.
- Investigate the applicability of ISO 9000 requirements in the US in public agencies, particularly the highway sector. Based on the results, develop a guideline for implementation that considers the complexities and idiosyncrasies of the State highway agencies.

QA specifications

- Investigate the feasibility of assessing quality characteristics like IRI in terms of lot PWL/PD to be consistent with the rest of AQCs used in QA specifications.
- Identify relationships between construction variability and performance so that rational and objective relationships between the quality measures like PWL/PD and the actual pavement performance can be developed. This would get rid of the guessing approach now used when developing pay factors for QA specifications, while at the same time could aid in the transition to PRS. The limitations to relating these quality measures to performance should be addressed.
- Assess the appropriateness of and level of difficulty in incorporating other AQCs or replacing existing ones in PCC QA specifications so that their application to PRS specs can be facilitated. Some examples of new AQCs to consider are curling and warping, w/c ratio, coefficient of thermal expansion, dowel bar misalignment, tie-bar location, joint formation, texture, and base/subgrade quality.

PRS

- Further assess the appropriateness of and level of difficulty in incorporating other AQCs or replacing existing ones in PCC PRS.
- Develop a prototype PRS for the entire pavement structure.
- Develop a prototype statewide PRS implementation plan based on the project level plan currently used in the pilot projects. In addition, the level of detail of the inputs and a streamlined process between pavement design and specification writing should continue to be addressed.
- Develop PRS for other pavement types like CRCP, whitetopping, and other rehabilitation strategies (e.g., chip seals, microsurfacing, etc.) commonly used by SHAs.

- Refine the existing HMA performance prediction models by more accurately considering the effect of construction and durability defects (e.g., inadequate bond, segregation at the bottom of the HMA lift, permeability, moisture susceptibility, etc).
- Refine the existing PCC performance prediction models by more accurately considering the effect of construction and durability defects (e.g., dowel bar misalignment, tie-bar location, joint formation, freeze-thaw damage, corrosion potential, etc).
- Develop a methodology for identifying sources of variability and incorporating their effect on quality, performance and cost for both PCC and HMA PRS. This, together with the incorporation of updated performance models into PaveSpec and HMASpec would facilitate the integration between structural and mixture design.
- Develop tools for risk analysis of PRS through development of OC and EP curves of the project acceptance plans.

Warranties

- Develop software tools to aid in the development and evaluation of warranty specifications following guidance and model specifications like those to be provided by NCHRP 10-68. Such tools should allow for the quantification of risks (and their consequences) associated with both the short-term and long-term warranties.
- Study the feasibility of having contractors monitor their warranted projects through PMS types of systems.

Implementation:

- Establish a Quality Management System, built on the ISO 9000 principles, within the organization of SHAs and the FHWA to help in the definition of their quality-related policies and objectives, all within a comprehensive quality management plan. This would allow agencies to manage their activities as a system of related processes, measure their effectiveness, and furnish the resources needed within funding constraints. This strategy would help agencies be in a better position to implement the recommendations presented below.
- Set the foundations toward creating a better working environment based on mutually beneficial relationships in order to increase the capacity of the contractors to add value. This will bring about several benefits, such as a smooth

transition from low bid to value-added awarding criteria, and the implementation of alternatives to bonding in warranty projects.

- Continue to specify process control and provide guidelines to carry it out, irrespective of type of specification governing the contract. Contractors familiar with process control are more prone to produce a quality product. In the case of warranties, this would reduce the need for SHA involvement in quality assurance during construction, which may translate into reduced cost of warranty projects.
- Seek mechanisms to ensure that the proper number of samples is obtained during both steady and out of control process conditions. These mechanisms include spelling out in the specifications the minimum actions to take depending on process conditions, as well as encouraging deployment of proven testing techniques.
- Support and promote the development of integrated databases through the implementation of pilot projects that further investigate and demonstrate the effectiveness and usefulness of integrated construction databases. The model database will be that which includes multiple levels of accessibility, data storage and retrieval, and capability to perform engineering analysis. Construction quality, pavement performance and cost data must be linked together. Off-the-shelf packages should be consistent with these needs.
- Establish a pooled fund with resources from the Federal Government, States and industry to support training initiatives and information sharing.

PRS

- Gather enough data from pilot projects for SHAs to be able to perform sensitivity analysis of inputs to the pay factor in PRS, as well as risk analysis to determine the effect of sample size and the effect of maintenance plans on the estimated LCC. This would facilitate the development of a catalog of Statewide PRS.
- Set up pilot projects that seek to implement the results of NCHRP 9-22 HMA PRS and NCHRP 10-65 project for the design and control of HMA mixtures by using nondestructive testing (NDT) technologies.
- Determine the range of adequate incentives that would be appropriate for PRS by focusing on optimum quality and the relationship between a decrease or increase in remaining life to an incentive or disincentive based on the quality level achieved.

- Allow the modification of pay factor for specific mixes after the bid to let potential contractors know before contract award how the pay adjustments are being determined.

Warranties

- Set up pilot projects with alternative warranty enforcement mechanisms such as guarantees and the option to purchase a warranty, if it becomes necessary, once the project construction phase has been completed.
- Continue to conduct case studies that look at actual performance of warranty projects to help SHAs, contractors, and sureties understand the benefits, costs, implementation, and development of warranties. This should include the effect of warranties on the number of bidders and the ability of small contractors to bid on warranty projects, as well as the impact that incorporating incentives into warranties could have on accelerating warranty implementation. This effort should follow currently available guidelines and those resulting from NCHRP 10-68 once they become available.

Training:

- Assess training needs at all levels of each organization (FHWA, SHA, and industry) and evaluate the effectiveness of the training provided. Current training efforts should be reviewed to make sure they include issues pertaining to both agencies and contractors, such as specification development, bid preparation, general statistics, quality assurance elements, and the differentiation between acceptance control and warranted items, as well as guidance on SHAs' role in design-build/warranty quality assurance process.
- Develop training courses (workshops) on the use of HMASpec. Training should address the use of the MEPDG in the design process to develop specifications that are performance related.
- Develop training courses (workshops) on the use of PaveSpec.
- Develop non-technical training courses, intended for top managers and other decision makers, on topics such as quality management systems and their management-wide role in the achievement of agency's results and operational effectiveness and efficiency.

Marketing:

- Set up a centralized source of information on specification development, best practices, latest developments and findings, and analysis tools, etc., with the purpose of making readily available through one sole source of information all the knowledge and tools needed to understand and tackle the underlying AQS complexities. This centralized source of information should include a database of projects built under warranty, PRS, and QA specifications. Such a database might allow for comparative analysis across the three types of specifications.
- Create a team that sets up and delivers non-technical outreach workshops aimed at top management and decision makers, to keep them informed of the needs and developments of the research, implementation and training initiatives.

APPENDIX

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GLOSSARY

Competence: demonstrated ability to apply knowledge and skills.

Conformity: fulfillment of a requirement.

Corrective action: action to eliminate the cause of a detected nonconformity or other undesirable situation.

Correction: action to eliminate a detected nonconformity.

Customer: person or entity that receives a product.

C**ustomer satisfaction:** customer's perception of the degree to which the customer's requirements have been fulfilled.

Design: set of processes that transform requirements into specified characteristics or into the specification of a product, process, or system. Note that the inherent characteristics are the important ones from a quality perspective. Inherent characteristics are related to a requirement.

Effectiveness: extent to which planned activities are realized and planned results achieved.

Efficiency: relationship between the result achieved and the resources used.

Interested party: person or group having an interest in the performance or success of an organization.

ISO 9000: standards established by the International Organization for Standardization to provide a structured approach to developing, maintaining and improving a quality management system.

Inspection: conformity evaluation by observation and judgment accompanied as appropriate by measurement, testing or gauging.

Management system: set of interrelated elements needed to establish policy and objectives and to achieve those objectives.

Nonconformity: non-fulfillment of a requirement.

Organization: group of people and facilities with an arrangement of responsibilities, authorities and relationships.

Preventive action: action to eliminate the cause of a potential nonconformity or other undesirable potential situation.

Product: the result of a process.

Product realization: the set of sequential value-adding processes carried out from planning, design, construction and acceptance of the final product.

Project: unique process consisting of a set of coordinated and controlled activities with start and finish dates, undertaken to achieve an objective conforming to specific requirements including the constraints of time, cost and resources.

Quality Management System: set of interacting elements to direct and control an organization with regard to quality. The portion of an organization's total management system centered around performance to objectives and satisfying the needs of the customer.

Quality management: coordinated activities to direct and control an organization with regard to quality.

Quality objective: something sought, or aimed for, related to quality. Quality objectives are generally based on the organization's quality policy

Quality plan: document specifying which procedures and associated resources shall be applied by whom and when to a specific project, product, process or contract. A quality plan is generally one of the results of quality planning.

Quality planning: part of quality management focused on setting quality objectives and specifying necessary operational processes and related resources to fulfill the quality objectives.

Quality policy: overall intentions and direction of an organization (3.3.1) related to quality as formally expressed by top management. Generally the quality policy is consistent with the overall policy of the organization and provides a framework for the setting of quality objectives

Requirement: need or expectation that is stated, generally implied or obligatory.

Review: activity undertaken to determine the suitability, adequacy and effectiveness of the subject matter to achieve established objectives.

Supplier: person that provides a product.

System: set of interrelated or interacting elements, not necessarily a computer program.

Test: determination of one or more quality characteristics according to a procedure.

Top management: person or group of people who directs and controls an organization at the highest level.

Traceability: ability to trace the history, application, or location of that which is under consideration. When considering product, traceability can relate to the origin of materials and parts, the processing history, and the distribution and location of the product after delivery.

***Verification** confirmation, through the provision of objective evidence, that specified requirements have been fulfilled. This implies performing alternative calculations, comparing a new design specification with a similar proven design specification, undertaking tests and demonstrations, and reviewing documents prior to issue.

***Validation:** confirmation, through the provision of objective evidence, that the requirements for a specific <u>intended use</u> or application have been fulfilled. The use conditions for validation can be real or simulated.

Notes:

*Although similar to the definition presented in the Glossary of Highway Quality Assurance terms, these should be considered complementary to and in line with an Advanced Quality System.

Definitions have been taken from clause 1-3 terms and definitions of the ISO 9000:2005 Quality Management Systems Fundamentals and Vocabulary.

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