APPENDIX B

WARRANTY PERFORMANCE INDICATOR TABLES FOR VARIOUS END PRODUCTS

TABLE B1 Performance indicators for HMAC pavement

State	Performance Indicator	Threshold Level	Requirements for Corrective Action
AL	Alligator cracking	10% of total area in a lane segment	--Level 1: Clean and seal with rubber crack filling material.
			--Level 2&3: Remove and replace for first 5 years. Remove and replace or strip patch (as approved by engineer) for remaining 3 years.
			>Removal area shall be 150% of distressed surface to a depth not to exceed the warranted pavement.
AL	Bleeding	20% of the length of a lane segment	--Remove and replace.
			>Removal area shall be 150% of the distressed area to a depth not to exceed the warranted pavement.
AL	Block cracking	10% of total area in a lane segment	--Level 1: No action. --Level 2&3: Remove and replace for first 5 years. Remove and replace or strip patch (as approved by engineer) for remaining 3 years. --Level 4: Remove and replace.
			>Removal area shall be 150% of the distressed area to a depth not to exceed the warranted pavement.
AL	Disintegrated areas	Existence	--Remove and replace when observed or immediately after being notified by engineer (no more than 4 hours response time).
			>Removal area shall be 150% of distressed area to a depth not to exceed the warranted pavement.
AL	Longitudinal cracking	30% of the length of a lane segment	--Level 1: No action. --Level 2&3: Clean and seal with rubber crack filling material. --Level 4: Remove and replace for first 5 years. Clean and seal with rubber crack filling material for last 3 years.
			>Removal area to be 1 m times the length of the longitudinal crack symmetrical about the crack to a depth not to exceed the warranted pavement.

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TABLE B1 (Continued)

State	Performance Indicator	Threshold Level	Requirements for Corrective Action
AL	Potholes	Existence	--Remove and replace when observed or immediately after being notified by engineer (no more than 4 hours response time).
			>Removal area shall be 150% of distressed area to a depth not to exceed the warranted pavement.
AL	Ride quality	Not defined	Plane and place a minimum overlay of 45 kg/m^2, full lane width.
AL	Raveling	10% of total area of a lane segment	--Level 1: No action. --Level 2&3: Remove and replace for first 5 years. Place thin overlay, not less than 45 kg/m^2 for remaining 3 years. Overlay to be placed full lane width if planed, or full roadway width if not planed.
			>Removal area shall equal 150% of distressed area to a depth not to exceed the warranted pavement.
AL	Rutting	9 mm in depth	--Remove and replace for the first 5 years. Remove and replace or rut fill for the remaining 3 years.
			>Removal area shall be not less than a full lane width to a depth not to exceed the warranted pavement.
AL	Scabbing	Existence	--Remove and replace when observed or immediately after being notified by engineer (no more than 4 hours response time).
			>Removal area shall be 150% of distressed area to a depth not to exceed the warranted pavement.
AL	Skid resistance	Friction Value = 40	--Plane and overlay with skid resistant material, not less than 45 kg/m^2, full lane width. Overlay full roadway width if not planed.
AL	Slippage areas	Existence	--Remove and replace when observed or immediately after being notified by engineer (no more than 4 hours response time).
			>Removal area shall be 150% of distressed area to a depth not to exceed the warranted pavement.

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TABLE B1 (Continued)

State	Performance Indicator	Threshold Level	Requirements for Corrective Action
AL	Transverse cracking	Five cracks within the length of a lane segment	--Level 1: No action. --Level 2: Clean and seal with rubber crack filling material. --Level 3&4: Remove and replace for first 5 years. Spot patch and strip patch for remaining 3 years.
			>Removal area shall be 150% of the distressed area to a depth not to exceed the warranted pavement.
CA	Cracking*	0.25 in. wide	Prepare and fill cracks with crack sealant, provide engineer with a certificate of compliance.
CA	Delamination*	Occurrence	Cold plane AC pavement to a depth not less than the affected depth for the full width of the affected lane or shoulder and replace the removed pavement with Type G rubberized AC.
CA	Flushing*	Coefficient of friction <0.30	Cold plane AC pavement to a depth not less than the affected depth for the full width of the affected lane or shoulder and replace the removed pavement with Type G rubberized AC.
CA	Raveling*	Occurrence	Cold plane AC pavement to a depth not less than the affected depth for the full width of the affected lane or shoulder and replace the removed pavement with Type G rubberized AC.
CA	Rutting*	0.04 in. deep	Cold plane AC pavement to a depth not less than the affected depth for the full width of the affected lane or shoulder and replace the removed pavement with Type G rubberized AC.
CO	Bleeding	Coloring of surface visible	Observe more frequently.
		Asphalt free on surface	Microsurface or stone mastic asphalt.
		Free asphalt, tire marks	Remove and replace.
CO	Delamination	Existence	Remove and replace affected areas.

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TABLE B1 (Continued)

State	Performance Indicator	Threshold Level	Requirements for Corrective Action
CO	Potholes	See Table CO-1	--Low: Seal coats, crack/joint seals, correct before end of 3 years.
			--Moderate: Patching, seal coats, crack/joint seals, correct before end of 3 years.
			--High: Remove and replace 24 in. beyond limits of apparent distress.
CO	Rutting and shoving	-- 0.3–0.5 in.	--Micromill or diamond grind to remove ruts, then seal coat or microsurface; or remove and replace before end of 3 years.
		-- 0.5–1.00 in.	--Micromill or diamond grind to remove ruts, then microsurface; or remove and replace.
		-- >1.00 in.	--Evaluate cause, then remove and replace.
CO	Raveling and weathering	-- Low severity: <0.25 in. (6.35 mm) deep	--Fog seal.
		-- Moderate severity: 0.25 in. (6.35 mm) to 0.375 in. (9.53 mm) deep	--Seal coat.
		-- High severity: >0.375 in. (9.53 mm) deep	--Microsurface.
CO	Transverse cracking	See Table CO-2	--Low: Crack sealing.
			--Moderate: Crack sealing.
			--High: Remove and replace.
FL	Cracking	600 ft (183 m) in length	Remove and replace distressed segment to the full depth and lane width of the warranted pavement.
FL	Disintegrated areas	None	Remove and replace an area equal to 150% of the distressed area as approved by engineer.
FL	Potholes	None	Remove and replace an area equal to 150% of the distressed area as approved by engineer.
FL	Rideability	Pavement condition survey (PCS) <8.0	Correct surface defects to increase the PCS to 8.0 or higher.
FL	Rutting	>0.25 in. deep	Remove and replace distressed segment to the full depth and lane width of the warranted pavement.
FL	Slippage areas	None	Remove and replace an area equal to 150% of the distressed area as approved by engineer.

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TABLE B1 (Continued)

State	Performance Indicator	Threshold Level	Requirements for Corrective Action
IN	IRI	2.1 m/km (133 in./mi)	---
	Alligator cracking		Remove and replace distressed layers, the area to be 150% of distressed area to a depth not to exceed the warranted pavement.
	Block cracking		Remove and replace distressed layers, the area to be 110% of distressed area to a depth not to exceed the warranted pavement.
	Flushing		Remove and replace distressed surface-layer full-lane width, the area to be 150% of distressed area.
	Longitudinal cracking		Rout and seal all cracks with rubber crack-filling material, or agreed upon equal.
	Longitudinal distortion		Remove and replace distressed layer(s), the area to be 110% of the distressed area to a depth not to exceed the warranted pavement.
	Potholes, slippage, raveling, segregation, and disintegrated areas		Remove and replace distressed areas, the area to be 150% of distressed area to a depth not to exceed the warranted pavement.
IN	Transverse cracking**	5.5 m (18 ft) in length	Rout and seal all cracks with rubber crack-filling material or agreed upon equal.
IN	Rutting	9.0 mm (0.35 in.) in depth	Remove and replace distressed layers full lane width.
IN	Skid resistance	Average friction number must average at least 35, with no individual value less than 25	Microsurface distressed area full lane width.
IN	Longitudinal cracking	Two or more cracks in a 100-m segment	Rout and seal all cracks with rubber crack filling material or agreed upon equal.
ME	Alligator cracking	Existence	Remove and replace distressed layer(s), the area to be 150% of the distressed surface to a depth not to exceed the warranted pavement.
ME	Block cracking	10% of the area of a 30-m-long segment	Remove and replace distressed layer(s), the area to be 110% of the distressed surface to a depth not to exceed the warranted pavement.
ME	Flushing	20% of the length of a 30-m-long segment	Remove and replace distressed surface mixture full depth.

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TABLE B1 (Continued)

State	Performance Indicator	Threshold Level	Requirements for Corrective Action
ME	Non-wheel path longitudinal cracks	15 m or more in length of cracks, which average 7 to 13 mm in width	Rout and seal all cracks with rubber crack-filling material or department approved equal.
		5 m or more in length of cracks, which average 13 mm or greater in width	Remove pavement and replace for the affected depth.
ME	Shoving	Existence	Remove and replace distressed layer(s); the area to be 110% of the distressed surface to a depth not to exceed the warranted pavement depth.
ME	Rutting	7 to 13 mm in depth	Mill surface with fine-toothed mill to remove rut or microsurface.
		Greater than 13 mm in depth	Remove and replace surface layer.
ME	Transverse cracks	Existence within a segment	Rout and seal all cracks with a rubberized crack filler or approved equal.
ME	Patching	Existence	Remove and replace distressed area(s), the area to be equal to the distressed area to a depth not to exceed the warranted pavement.
ME	Potholes, slippage, disintegrated areas	Existence	Remove and replace distressed area(s), the area to be equal to 150% of the distressed area to a depth not to exceed the warranted pavement.
MI	Longitudinal cracking	1.5-m cracks, 25% of segment	Full width of the lane replaced for 640 m.
MI	Delamination	Existence	Full width of the lane replaced for 320 m.
MI	Potholes	25% of 160-m segment	Full width of the lane replaced for 320 m.
MI	Raveling	20% of 160-m segment area	Full width of the lane replaced for 640 m.
MI	Flushing	5% of 160-m segment area	Full width of the lane replaced for 320 m.
MI	Rutting	7 mm average depth over a 160-m segment	Full width of the lane replaced for 160 m.
MI	Ride quality***	RQI <55, and may not increase more than 10 points from its starting value	Investigate to determine cause(s) of condition(s). Prepare written report explaining cause(s) for the condition(s) and proposing corrective measures for department approval. Implement approved corrective measures.
MI	Surface distress features***	See Tables MI-1, MI-2, and MI-3	
MI	Rutting (years 1–3)***	Average depth > 0.25 in.	
	Rutting (years 4 and 5)***	Average depth > 0.375 in.	

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TABLE B1 (Continued)

State	Performance Indicator	Threshold Level	Requirements for Corrective Action
MO	Longitudinal cracking	>0.25 in. wide	Seal and clean all joints and cracks greater than or equal to 0.25 in. in width at least annually.
MO	Patching	10% of a segment area for a minimum of 0.10 mile in length has been patched	Remove affected area of pavement to the depth affected and replace.
MO	Potholes	Existence	--Patch.
MO	Raveling	Existence	--Remove and replace.
MO	Rutting	Average rut 0.25 to 0.50 in. deep >0.50 in. deep	--Surface texture or replace at least the top lift of bituminous material. --Remove and replace all warranted layers affected.
			--In lieu of repair/replacement, the contractor may reimburse the department the contract price of the warranted materials found to be defective.
MO	Spalling	Existence	--Patch.
MO	Transverse cracking	>0.25 in. wide	--Seal and clean all joints and cracks at least annually.
OH	Delamination	None	Remove and replace the distressed segment at least 32 mm (1.25 in.) thick.
OH	Flushing	5% of segment area	Remove and replace the surface course of the segment.
OH	Potholes	None	Remove and replace the distressed segment at least 32 mm (1.25 in.) thick.
OH	Longitudinal cracking	150 m (500 ft) of cracks that average 13 mm (0.5 in.) in width in a 160-m (0.1-mile) segment	Rout and seal with Type 1 crack seal.
OH	Previous patching	28 m^2 (300 ft^2) in a 160-m segment	Remove and replace the surface course of the segment.
OH	Disintegrated areas	None	Remove and replace the distressed segment at least 32 mm (1.25 in.) thick.
OH	Raveling	None	Remove and replace the distressed segment at least 32 mm (1.25 in.) thick.
OH	Rutting	6 mm (0.25 in.) on the mainline and 12 mm (0.5 in.) on ramps	Remove and replace the surface course of the segment.
UT	Fatigue cracking	Area of cracks with no or few connecting cracks; cracks are not spalled or sealed; pumping is not evident. 5% of surface area per 1.5 lane-kilometers	Full depth repair and overlay.

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TABLE B1 (Continued)

State	Performance Indicator	Threshold Level	Requirements for Corrective Action
UT	Block cracking	Cracks with a mean width less than or equal to 6 mm (0.25 in.); or sealed cracks with sealant material in good condition and with a width that cannot be determined. 5% of surface area per 1.5 lane-kilometers	Seal cracks and overlay.
UT	Edge cracking	Low severity with no breakup or loss of material. 10% of pavement edge per 1.5 lane-kilometers	Seal cracks.
UT	Longitudinal cracking	Cracks with a mean width less than or equal to 6 mm (0.25 in.); or sealed cracks with sealant material in good condition and with a width that cannot be determined. 10% of surface area per 1.5 lane-kilometers	Reseal cracks and overlay.
UT	Reflection cracking at joints	Unsealed crack with mean width less than or equal to 6 mm (0.25 in.); or sealed cracks with sealant material in good condition and with a width that cannot be determined. 10% per 1.5 lane-kilometers	Reseal cracks and overlay.
UT	Transverse cracking	Unsealed crack with mean width less than or equal to 6 mm (0.25 in.); or sealed cracks with sealant material in good condition and with a width that cannot be determined. 10% per 1.5 lane-kilometers	Seal/reseal crack/joint and overlay.
UT	Patch/patch deterioration	Existence of, at most, low severity distress of any type in a patch	Full depth repair.
UT	Potholes	25 mm (1 in.) deep	Full depth patch.
UT	Rutting	3 mm deep for 5% of traveled surface per 1.5 lane-kilometers	Rotomill and overlay.
UT	Shoving	3 mm deep for 5% of traveled surface per 1.5 lane-kilometers	Full depth repair or rotomill and overlay.

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TABLE B1 (Continued)

State	Performance Indicator	Threshold Level	Requirements for Corrective Action
UT	Bleeding	Area of pavement surface discolored relative to the remainder of the pavement by excess asphalt. 5% of surface area per 1.5 lane-kilometers	Surface treated with plant mix friction course.
UT	Polished aggregate	Reduction in surface friction over 5% of surface area per 1.5 lane-kilometers	Surface treated with skid resistant seal or overlay.
UT	Raveling	Aggregate or binder has begun to wear away, but has not progressed significantly. Some loss of fine aggregate. 5% of surface area per 1.5 lane-kilometers	Surface treated with plant mix surface treatment or overlay.
UT	Lane-to-shoulder drop off	6 mm, mean width less than 6 mm. 5% of joint length per 1.5 lane-kilometers	Restore shoulder elevation.
UT	Water bleeding and pumping	Existence of seepage or ejection of water from beneath the pavement through cracks	Seal/reseal.
WI	Alligator cracking[1]	10% of area in a 0.1-mile segment	Remove and replace distressed layers, the area to be equal to 150% of the distressed area to a depth not to exceed the warranted pavement.
WI	Block cracking	10% of area in a 0.1-mile segment	Remove and replace distressed layers, the area to be equal to 110% of the distressed area to a depth not to exceed the warranted pavement.
WI	Potholes, slippage areas, and other disintegrated areas	Existence	Remove and replace the distressed area(s), the area to be equal to 150% of the distressed area to a depth not to exceed the warranted pavement.
WI	Edge raveling	10% of the 0.1-mile segment length	Remove and replace distressed layers, the area to be equal to 110% of the distressed area.
WI	Flushing	20% of the 0.1-mile segment length	Remove and replace distressed surface mixture full depth.
WI	Longitudinal cracking	--1000 linear feet of cracks, which average 0.5 in. or less in width -OR- --25 cracks per segment with 25% of the linear feet of cracking having band cracking or dislodgment	--Rout and seal all cracks with rubber crack-filling material or agreed upon equal. --Remove and replace distressed layer(s) to a depth not to exceed the warranted pavement.

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TABLE B1 (Continued)

State	Performance Indicator	Threshold Level	Requirements for Corrective Action
WI	Longitudinal distortion	1% of the 0.1-mile segment length	Remove and replace the distressed layer(s), the area to be equal to 110% of the distressed surface to a depth not to exceed the warranted pavement.
WI	Patching	150 linear feet of patching per segment (excluding longitudinal cracking remedial action)	Remove and replace the surface layer or place a 1.25-in. overlay.
WI	Rutting[2]	--0.25 in. deep --0.5 in. deep	--Remove ruts by milling surface with fine-tooth mill, overlaying, or microsurfacing. --Remove and replace surface layer.
WI	Surface raveling	A rating of "none" must be maintained. For segregation this means less than three segregated areas per segment that are 30 ft^2 or more in size	Apply a chip seal coat or a partial depth repair.
WI	Transverse cracking	--25 cracks per segment, which average greater than 0.5 in. in width -OR- --25 cracks per segment with 25% of the linear feet of cracking having band cracking or dislodgment	--Rout and seal all cracks with rubber crack-filling material or agreed upon equal. --Remove and replace distressed layer(s) to a depth not to exceed the warranted pavement.
WI	Transverse distortion	1% of the 0.1-mile segment length	Remove and replace distressed layer(s), the area to be 110% of the distressed area to a depth not to exceed the warranted pavement.

Notes: IRI = International Roughness Index.
*Rubberized asphalt.
**For full-depth asphalt projects.
***5-year pavement warranty.

[1]The contractor will be relieved of responsibility for remedial action for alligator cracking if the pavement in the area in question is of proper thickness (not thinner than 0.5 in. from plan thickness) and the asphalt cement is of acceptable penetration (average recovered penetration of the surface course is above 30) and at least one of the following is true: the base is at least 2.0 in. thinner than plan thickness, the subgrade density is less than 90 percent of the optimum, or the actual accumulated equivalent single-axis loads (ESALs) are 50 percent above the projected fifth-year accumulated ESALs.

[2]The rutting threshold level is waived when the accumulated ESALs are 50 percent above the projected fifth-year accumulated ESALs. The contractor will only be responsible for mixture and placement problems.

TABLE B2 Performance indicators for chip sealing

State	Performance Indicator	Threshold Level	Corrective Actions Required
MI	Bleeding/flushing	40% of pavement surface affected (evenly or localized)	Submit written course of action proposing appropriate corrective measures for needed warranty work 5 days prior to commencement of warranty work, unless it requires immediate emergency repairs as determined by the department.
MI	Loss of cover aggregate	40% of pavement surface affected (evenly or localized)	
MI	Surface patterns	40% of pavement surface affected (evenly or localized)	

TABLE B3 Performance indicators for bridge deck joints

State	Performance Indicator	Threshold Level	Corrective Actions Required
ME	Water leakage through the joint	---	Damaged seals shall be removed and replaced with new seals. Seals that are displaced shall be completely removed; the joint shall be cleaned and the seal may be reinstalled if not damaged during removal. Steel components that are damaged or misaligned shall be restored in accordance with standards.
ME	Separation of the seal from the steel or concrete substrate	---	
ME	Failure of materials such as cracking, chalking, scaling, peeling, and splitting	---	
ME	Sagging of elastomeric seal	---	
ME	Warping of the steel plate or extrusion detrimental to the functioning of the joint	---	
ME	Separation of the steel plate or extrusion from the deck concrete	---	
ME	Spalling or delamination of the deck concrete within 0.5 m of either side of the joint	---	

TABLE B4 Performance indicators for bituminous crack treatment

State	Performance Indicator	Threshold Level	Corrective Actions Required
MI	Adhesion or cohesion of treatment material in crack	10% of cracks in control section fail	Reseal or refill all failed work in the entire control section.

TABLE B5 Performance indicators for microsurfacing

State	Performance Indicator	Threshold Level	Corrective Actions Required
MI	Flushing	5% of area of four segments or 10% of area of one segment	Repair of segments not meeting performance criteria at the end of the warranty period, unless safety concerns dictate otherwise.
MI	Delamination	2% of area of four segments or 10% of area of one segment	
MI	Weathering and raveling	5% of area of four segments or 10% of area of one segment	
MI	Rutting (initial—first 120 days)	6 mm continuously in one segment	
MI	Rutting (end of warranty period)	6 mm or 50% of pre-existing rut depth (whichever is greater) in one segment	
OH	Bleeding/flushing	Limit "high" severity bleeding and flushing to no more than 2% of any 100 m^2 (120 yd^2) area	Repair of areas not meeting performance criteria.
OH	Rutting	Limit ruts exceeding 6 mm (0.25 in.) below grade to 2% in any 30 m lane segment as measured by a 3 m (10 ft) straightedge for 30 days after final inspection check list is completed by contractor or after any warranty work	
OH	Surface loss (debonding/ delamination)	Limit loss of surface interlock by traffic wear or debonding in any 100 m^2 (120 yd^2) area to no more than 2%	
OH	Weathering and raveling	Limit "high" severity weathering and raveling in any 100 m^2 (120 yd^2) area to no more than 2%	

TABLE B6 Performance indicators for bridge painting

State	Performance Indicator	Threshold Level	Corrective Actions Required
IN	Visible rust or rust breakthrough	1% of the surface area of any painted structural member	Repair to meet acceptance criteria set forth in the painting specifications.
IN	Paint blistering	Occurrence	Repair to meet acceptance criteria set forth in the painting specifications.
IN	Peeling	Occurrence	Repair to meet acceptance criteria set forth in the painting specifications.
IN	Scaling	Occurrence	Repair to meet acceptance criteria set forth in the painting specifications.
IN	Nonremoved slivers	Occurrence	Repair to meet acceptance criteria set forth in the painting specifications.
IN	Damage to coating system caused by contractors	Occurrence	Repair to meet acceptance criteria set forth in the painting specifications.
IN	Paint applied over dirt, debris, or rust	Occurrence	Repair to meet acceptance criteria set forth in the painting specifications.
IN	Coating thickness	As stated in specifications	Repair to meet acceptance criteria set forth in the painting specifications.
MD	Blistering	--1%–10% failure of a bridge element or component	--Remove defective paint, rust, etc. Recoat.
MD	Chalking		
MD	Peeling		
MD	Rust	--10% or more failure of a bridge element or component	--Evaluate entire component or element, totally reclean and repaint entire member if necessary.
MD	Scaling		
MD	Fascia	Considered unsightly by the administration	Recoat fascia beam.

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TABLE B6 (Continued)

State	Performance Indicator	Threshold Level	Corrective Actions Required
ME	Visible rust or rust breakthrough	Occurrence	Repair as directed by paint manufacturer's technical department.
ME	Blistering, peeling, or scaling of paint	Occurrence	
ME	Paint applied over dirt, debris, rust products, blasting debris, or mill scale products	Occurrence	
ME	Incomplete coating or coating thickness less than specified by the manufacturer	Occurrence	
ME	Damage to painting system caused by design—builder's operations during construction	Occurrence	
ME	Fading or chalking paint	Occurrence	
MI	Rust/rust breakthrough	Occurrence	Repair in accordance with the painting specifications.
MI	Paint blistering	Occurrence	Repair in accordance with the painting specifications.
MI	Peeling	Occurrence	Repair in accordance with the painting specifications.
MI	Scaling	Occurrence	Repair in accordance with the painting specifications.
MI	Unremoved slivers	Occurrence	Repair in accordance with the painting specifications.
MI	Damage to coating system caused by contractors	Occurrence	Repair in accordance with the painting specifications.
MI	Incomplete coating or coating thickness less than the minimum specified	As stated in specifications	Repair in accordance with the painting specifications.
MI	Paint applied over dirt, debris, or rust	Occurrence	Repair in accordance with the painting specifications.

TABLE B7 Performance indicators for pavement marking

State	Performance Indicator	Threshold Level	Corrective Actions Required
FL	Color *RD*	75% minimum	Replace.
	Red–green reflectance	(–5) to (+5)	
	Yellow–blue reflectance	(–10) to (+10)	
FL	Durability	50% loss of thermoplastic material	Replace.
FL	Retroreflectivity	<150 mcd/l x m^2 for 5 years after installation	Replace.
MN	Retroreflectivity, white	--275 mcd/l x m^2 initial --150 mcd/l x m^2 after one winter	Remove and replace.
MN	Retroreflectivity, yellow	--180 mcd/l x m^2 initial --120 mcd/l x m^2 after one winter	Remove and replace.
MT	Color	Color does not reasonably match the specified federal standard color chips	Replace material.
MT	Durability	Average line width less than 90% of specified width in any 1-mile segment, or deterioration affects reflectivity	Replace material.
MT	Retroreflectivity, yellow	--Initial: 150 mcd/(m^2x lux) --Semi-annual: 100 mcd/(m^2 x lux)	Repair or replace (at the discretion of the engineer) all lines that drop below minimum level within 6 months of request.
MT	Retroreflectivity, White	--Initial: 195 mcd/(m^2 x lux) --Semi-annual: 130 mcd/(m^2 x lux)	Repair or replace (at the discretion of the engineer) all lines that drop below minimum level within 6 months of request.
OR	Reflectivity	150 millicandelas	Repair or replace (at the discretion of the engineer) all lines that drop below minimum level within 6 months of request.

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TABLE B7 (Continued)

State	Performance Indicator	Threshold Level	Corrective Actions Required
PA	Retroreflectivity, white	Average retroreflectivity within any 528-ft (161-m) section less than 125 mcd/(m^2 x lux)	Replace material using equal or better material. $500 per hour lane rental. $2000 per day for each day more than 30 after notification (weather permitting).
PA	Retroreflectivity, yellow	Average retroreflectivity within any 528-ft (161-m) section less than 100 mcd/(m^2 x lux)	
PA	Discoloration or pigment loss	Markings are discolored or exhibit pigment loss and are determined to be unacceptable by the three-member team* based on a visual comparison with the sample color plates with glass beads originally submitted by the contractor	
PA	Missing segments	15% of total area of a line within any 161-m section	
UT	Color contrast and stability**	White markings must provide a minimum yellow index of 30 measured with a mobile colorometer	If threshold values are not maintained, the product is subject to a 100% refund of the installed price of the material as bid in the original plans.
UT	Durability (presence)**	90% of the surface area of the markings on any 1000-ft segment must be present as measured by ASTM D-913 Number 6 Clipping Chart	
UT	Retroreflectivity**	125 millicandles/ft^2/foot candle	
WV	Color	The Yellow Index shall not exceed 32 as measured by a portable colorometer	Replace material using equal or better material.****
WV	Durability***	See Table WV-1	
WV	Retroreflectivity	See Table WV-1	

*Pennsylvania's warranted pavement is evaluated at maximum intervals of 12 months by a three-member team consisting of one member from the department, one member from the contractor, and one member who is mutually acceptable to the department and the contractor.
**The work of the contractor and any subcontractors must be warranted by the material manufacturer for these items.
***Loss due to pavement failure will not be included in the percent loss.
****Loss of material due to snowplow damage or abnormal wear during warranty period is allowed.

TABLE B8 Performance indicators for concrete pavement

State	Performance Indicator	Threshold Level	Corrective Actions Required
ME*	Cracking	Deeper than 15 mm for total length of 100 m	Epoxy injection (contractor must demonstrate that the injection is complete and effective or removed and replaced from curb to curb with transverse joints square to the centerline).
ME*	Debonding from deck	Occurrence	Remove and replace from curb to curb with transverse joints square to the centerline.
ME*	Spalling	>10,000 mm^2 cumulative area >10 m^2	None specified.
ME*	Chloride penetration	Content of 175 g/m^2 or greater to a depth >25 mm	Remove and replace from curb to curb. Transverse joints must be square to the centerline.
UT	Corner breaks	Crack is not spalled for more than 10% of its length, there is no measurable faulting, and the corner piece is not broken into two or more pieces. Two panels per 1.5 lane-kilometers	Full depth repair.
UT	Durability ("D") cracking	Existence of crescent-shaped hairline cracking with no loose or missing pieces	Total slab replacement.
UT	Longitudinal cracking	Cracks of width less than 3 mm (0.125 in.), no spalling, and no measurable faulting; or well sealed and with a width that cannot be determined. Four slabs per 1.5 lane-kilometers	Full depth slab replacement.
UT	Transverse cracking	Low severity cracks of width less than 3 mm (0.125 in.), no spalling, and no measurable faulting; or well sealed and with a width that cannot be determined. Four slabs per 1.5 lane-kilometers	Seal low severity cracks. If cracking exceeds low severity, replace slab full depth.
UT	Transverse joint seal damage	Joint sealant damage as described by SHRP. Extrusion, hardening, adhesive failure, cohesive failure, or complete loss of sealant over 10% of joint length per 1.5 lane-kilometers	Reseal joints.

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TABLE B8 (Continued)

State	Performance Indicator	Threshold Level	Corrective Actions Required
UT	Longitudinal joint seal damage	Joint sealant damage as described by SHRP. Extrusion, hardening, adhesive failure, cohesive failure, or complete loss of sealant over 10% of joint length per 1.5 lane-kilometers	Reseal joints.
UT	Spalling of longitudinal joints	Low severity spalls less than 75 mm (3 in.) wide, measured to the center of the joint, with loss of material, or spalls with no loss of material and no patching. Low extent = less than 5% of joint length per 1.5 lane-kilometers or 25% of an individual joint	Fill void with hot pour sealant if severity is low. If low severity is exceeded, then repair partial depth.
UT	Spalling of transverse joints	Low severity spalls less than 75 mm (3 in.) wide, measured to the center of the joint, with loss of material, or spalls with no loss of material and no patching. Low extent = less than 5% of joint length per 1.5 lane-kilometers or 25% of an individual joint	Fill void with hot pour sealant if severity is low. If low severity is exceeded, then repair partial depth.
UT	Surface crazing	5% of surface area per 1.5 lane-kilometers	Seal.
UT	Scaling	Deterioration of upper concrete surface over 5% of surface area per 1.5 lane-kilometers	Seal.
UT	Map cracking	Existence of cracks that extend only into upper surface of slab compromising structural capacity of pavement	Total slab replacement.
UT	Polished aggregate	Surface mortar and texturing worn away such that skid resistance is less than 40 at the end of 4 and 9 years	Abraid or grind surface to exceed skid resistance values required.
UT	Popouts	Three or more small pieces of pavement broken loose from surface per square meter	Replace as needed.

(*continued on next page*)

TABLE B8 (Continued)

State	Performance Indicator	Threshold Level	Corrective Actions Required
WI	Slab breakup[1]	Transverse cracks or slabs broken into two pieces. More than 8 cracked slabs per 161 m (0.1 mi) segment	Install retrofit dowel bars (six per lane) across all cracks, 6-ft (2-m) wide full-depth repair or alternative method as approved by the CRT.
		One or more slabs broken into three or more pieces	Remove entire slab and replace.
WI	Distressed transverse joints and cracks[2]	2–4 in. (50–100 mm) or more in width in the wheelpaths on 10 joints or cracks in any 0.1 mi (161 m) segment	Clean and remove all debris and patch distress with epoxy concrete or alternative method as approved by the CRT.
		4 in. (100 mm) or greater in width in the wheel paths on 10 joints or cracks in any one 0.1 mi (161 m) segment	Repair pavement with a 6-ft full-lane width full-depth repair or partial depth repair of affected area or alternative method as approved by the CRT. If distress is less than 2 ft (0.61 m) in length and is adjacent to a joint, a full depth repair can be performed on the affected area only.
WI	Longitudinal joint or crack distress[3]	2–4 in. (50–100 mm) in width at the longitudinal joint or crack within a 0.1 mi (161 m) segment	Clean and remove debris from joint and fill with epoxy concrete or other material as approved by the CRT.
		Greater than 4 in. (100 mm) in width at the longitudinal joint or crack within a 0.1 mi (161 m) segment, and one-half the pavement thickness or greater	Remove and repair full depth from transverse joint to transverse joint with the exception of distress less than 2 ft (0.61 m) from a joint.
		Greater than 4 in. (100 mm) in width at the longitudinal joint or crack within a 0.1 mi (161 m) segment, but less than one-half the pavement thickness or greater	Repair in accordance with accepted partial depth repair methods.
		Faulted longitudinal joint greater than 0.5 in. (13 mm)	Retrofit tie bars and diamond grind affected areas.
WI	Transverse faulting[4]	Three or more faulted joints or cracks per station (100 ft or 30.5 m) with faulting greater than 0.25 in. (6 mm)	Retrofit dowel bars across cracks or repair full depth, repair joints full depth and spot diamond grind if necessary to restore ride.

(*continued on next page*)

TABLE B8 (Continued)

State	Performance Indicator	Threshold Level	Corrective Actions Required
WI	Surface distress[5]	Distress less than 1 in. (25 mm) in depth and present on 0.5%–10% of the surface area of any 0.1 mi (161 m) segment	Mill distressed area partial depth and replace partial depth and repair partial depth with concrete.
		Distress less than 1 in. (25 mm) in depth and present on greater than 10% of the surface area of any one 0.1 mi (161 m) segment, or greater than 1 in. (25 mm) regardless of the percentage of the surface area affected	Repair distressed area full depth or use partial depth repair method as approved by the engineer.
WI	Patching	Any patch performed unsatisfactorily	Full depth repair and replacement of all patches not in good condition. All remedial action under this item is contingent upon the repair originally being performed by the contractor as part of a remedial action to another distress.

Notes: SHRP = Strategic Highway Research Program.
*Concrete wearing surface.
[1]The contractor will be relieved of the responsibility for remedial action for slab breakup if the pavement area in question is not thinner than 0.5 in. (13 mm) from plan thickness and 80 percent of the project's compressive cylinders have a strength greater than 4,000 psi (27.6 MPa), cracking did not occur prior to the opening of the roadway to construction traffic indicating sawing of the joints was completed in a timely manner and one or more of the following is true: the base is at least 2.0 in. (50 mm) thinner than plan thickness, subgrade density is less than 90 percent of optimum or does not meet soil deflection specifications, cracks are associated with frost heaves, settlement at culverts or bridge approaches, or the accumulated ESALs are 50 percent above the projected 5-year ESALs.
[2]The contractor will be relieved of the responsibility for remedial action for distressed joints and cracks when the distress is D-cracking if the contractor uses an approved WisDOT aggregate source that meets the soundness and wear testing of the coarse aggregate requirements outlined in the Standard Specifications for Road and Bridge Construction or the accumulated ESALs are 50 percent above the projected 5-year ESALs.
[3]The contractor will be relieved of the responsibility for remedial action for longitudinal joint distress when the parting strip or sawcut is in the correct position, orientation, depth, size, sawed in a timely manner, etc., when the distress is faulting of the centerline joint and it has been determined that the longitudinal tie steel has been installed in the correct position, orientation and spacing as outlined in the standard detail drawings in the plan, and the concrete compressive strength is at acceptable levels.
[4]The contractor will be relieved of the responsibility for remedial action if the following is true: dowel bars have been installed in accordance with the plan and specifications, and the concrete compressive strength is at acceptable levels. The contractor will also be relieved of the responsibility for a remedial action if the faulting is caused by frost heaves, uneven roadbed support, or base-related problems.
[5]The contractor will be relieved of the responsibility for remedial action if the cause is chemical and fuel spills, vehicle fires, excessive use of de-icing salts, snow plows, and other equipment, or mechanical damage.

TABLE B9 Performance indicators for bridge deck joints/waterproof membranes

State	Performance Indicator	Threshold Level	Corrective Actions Required
ME	Membrane leakage	Evidence on the bottom of the bridge deck indicating membrane leakage	Pavement removed to expose the affected membrane and allow replacement membrane to be applied in accordance with the manufacturer's recommendations. The affected membrane shall be completely removed and replaced, the pavement removed to expose the affected membrane shall be replaced, in addition to all pavement markings and rumble strips affected.
ME	Potholes or shoving	Physical damage to the membrane caused by the potholes or shoving	
ME	Other damage resulting from pavement rehabilitation during construction or required warranty repairs caused by the design–builder	Existence	

TABLE B10 Performance indicators for other end products

State	Performance Indicator	Threshold Level	Corrective Actions Required
Roofs			
HA	Roof leakage	Existence	Restoration of watertight condition of roof.
ITS			
NC	Normal operating specifications as supplied by manufacturer	--Above normal frequency of maintenance	Repair and rectification of component to ensure that it operates in accordance with its functional specifications. Written notification of corrective action. Preventative maintenance as recommended by the equipment manufacturer.
		--Failure of equipment to perform as described by the equipment manufacturer	
Planting or Relocating (Trees and Shrubs)			
WY	Death, poor health, dead branches	Existence	Removal and replacement (excepting vandalism losses).
Irrigation Systems			
WY	Material failure	Existence	Correction of defects (excepting damages caused by vandalism).
WY	Settlements	Existence	
Sheeting for Signs*			
WV	Retroreflectivity	See Table WV-2	--First 7 years: The sheeting manufacturer will cover the cost of restoring the sign panel to its original effectiveness at no cost to the agency for materials or labor.
			--Years 8–10: The sheeting manufacturer will replace the sheeting required to restore the sign panel to its original effectiveness.
			--Years 11–12: The sheeting manufacturer will replace 50 percent of the sheeting required to restore the sign panel to its original effectiveness.
WV	Effectiveness for its intended purpose	Not effective when viewed under normal day and night driving conditions	--First 7 years: The sheeting manufacturer will cover the cost of restoring the sign panel to its original effectiveness at no cost to the agency for materials or labor.
			--Years 8–10: The sheeting manufacturer will replace the sheeting required to restore the sign panel to its original effectiveness.
			--Years 11–12: The sheeting manufacturer will replace 50 percent of the sheeting required to restore the sign panel to its original effectiveness.

(*continued on next page*)

TABLE B10 (Continued)

State	Performance Indicator	Threshold Level	Corrective Actions Required
Bridge Components			
ME	Bearings	Failure of any components of the bearing assembly	Remove affected bearing; either replace or restore bearing to new condition and reinstall.
		Cracking, peeling, checking, or rusting of the protective coating on the bearing	
		Bearing freezes or otherwise fails to allow the bridge to move as designed	
ME	Supports of signs and luminaries	Visible rust or rust breakthrough	Repair in accordance with normal industry standards.
		Blistering, peeling, or scaling of coatings	
		Cracking in the welds or base metal	Repair by welding.
		Broken or stripped bolts	Replace.
ME	Sign panels	Retroreflective sheeting becomes ineffective	Restore to new condition.
		Blistering, peeling, or scaling of retroreflective sheeting	
		Cracking in the welds or base metal	
		Broken or stripped bolts	
ME	Luminaries	Luminare fails to operate for any reason other than lamp failure	Replace with new units identical to the original or department-approved alternates.
		Lamp failure is more than 20% higher than expected by lamp manufacturer	
ME	Granite pier protection	Any individual granite blocks come loose	Reattach to the concrete core by drilling and grouting. Upon reattachment, the epoxy joint mortar around the stone shall be removed and replaced.
		Any individual granite blocks are missing	Replace and reattach similar to a loose stone.
		Epoxy joint mortar cracks, erodes, is missing, or exhibits signs of leakage	Completely remove, clean, and replace in accordance with epoxy joint mortar manufacturer's recommendations.
		Any individual granite blocks spall loose or break	Repair in accordance with standard industry standards.
ME	Trapezoidal steel girder system	Welds exhibit cracking	Repair to a condition satisfactory to the department.
		Discontinuities exist in the base metal	

*Material only.

TABLE CO-1 Colorado distress levels for potholes

Depth (in.)	Area (sq. ft)		
	<1	1–3	>3
<1	Low	Low	Moderate
1–2	Moderate	Moderate	High
>2	Moderate	High	High

TABLE CO-2 Colorado distress levels for transverse cracking

Severity	Quantity
Low	<0.25 in. wide
Moderate	0.25 in. wide to 0.75 in. wide
	0.25 in. wide with spalling or random cracking
High	>0.75 in. wide
	0.25 in. wide to 0.75 in. wide with spalling and random cracking

TABLE MI-1 Maximum allowable distress points for surface distress in Michigan 5-year warranted asphalt projects

Year of the Warranty	Total Distress Points for 0.10-mile segment
1	3
2	6
3	9
4	12
5	15

TABLE MI-2 Flexible pavement distress types

Distress Type	Associated Distress Categories		Point Range per Occurrence
	Length	Width	
Transverse Crack	>0 ft	<4 in.–>2 ft	0.5–4
Longitudinal Crack	>0 ft	<4 in.–>2 ft	0.5–16*
Zipper Crack	>5 ft	---	1–16*
Alligator Crack	>5 ft	<4 in.–>2 ft	1–16*
Overlapped Unsawn Patches	>5 ft	>0 ft	12–50*
Potholes	---	---	2
Repair Area	---	---	2
Block Cracked	No. of crack intersections		2–4

*Points based on percentage of 0.10-mile segment that is affected by the distress.

TABLE MI-3 Composite pavement distress types

Distress Type	Associated Distress Categories		Point Range per Occurrence
	Length	Width	
Transverse Crack	>0 in.	>4 in.	0.5–4
Longitudinal Crack	>0 ft	>4 in.	0.5–8*
Misc. Cracks	No. of crack intersections		5–60*
Overlapped Unsawn Patches	>5 ft	>0 ft	12–50*
Potholes	---	---	2
Repair Area	---	---	5
Zipper Cracked	>5 ft	---	1–8*

*Points assigned based on percentage of 0.1-mile segment that is affected by the distress.

TABLE WV-1 Retroreflectivity and durability requirements for pavement markings under the West Virginia warranty specifications

Year	Color	Minimum Retroreflectivity (mcd/m^2/lx)	% Loss (Durability)
Initial	White	300	0
Initial	Yellow	250	0
First	White	200	3
First	Yellow	200	3
Second	White	200	6
Second	Yellow	200	6
Third	White	200	9
Third	Yellow	150	9
Fourth	White	150	12
Fourth	Yellow	150	12

TABLE WV-2 Minimum coefficient of retroreflection (candelas per foot candle per square foot; 0.2° divergence and –4° incidence)[1]

Sheeting Color	Minimum Coefficient of Retroreflection (7 Years)	Minimum Coefficient of Retroreflection (12 Years)
White	212	200
Yellow	144	136
Green	38	36
Red	38	36
Blue	17	16
Brown	10	9

[1] All measurements shall be made after sign cleaning.

APPENDIX C

HMAC QUALITY PARAMETER EXAMPLE

This appendix contains an example describing the partial development of a quality parameter for hot-mix asphalt concrete pavement that can be used in multi-parameter bidding in the form A+B+Q, where Q is a measure of quality. The process model from the quality parameter guidelines in Chapter 3 is presented again before the example (Figure C1). The example only includes information for Steps 4 through 10 of the Quality Parameter.

Step 4. Select End Product

The example has been developed for hot-mix asphalt concrete (HMAC) pavement.

Step 5. Determine Measurable Indicators of Quality

One measure of quality that can be used in performance models is life-cycle cost (LCC). However, the performance models based on LCC are not as well developed for HMAC as they are for portland cement concrete. Therefore, it has been decided to use the quality level analysis (QLA) as the most appropriate measure of quality for the HMAC example. This quality measure is contained in the *AASHTO Quality Assurance Guide Specification*. A recent survey conducted through NCHRP 10-39A, *Testing and Inspection Levels for Hot-Mix Asphalt Concrete Overlays*, reported that 20 of 38 agencies replying to the survey use QLA for the measurement of one or more mixture or construction properties.

The QLA is used to predict a percent within limits (PWL) or percent defective (PD) quantity. This statistical procedure was developed for the U.S. Department of Defense and has been used since the late 1950s for procurement under their contracts. Its use in the highway materials and construction field has grown significantly since the establishment of the National Policy on the Quality of Highways in 1992. The PWL is determined based on an estimate of the average and variability as related to specification limits. The standard deviation is used as the most appropriate measure of variability for this example. The indicators of quality chosen for HMAC were a combination of mixture quality properties and construction quality properties.

Asphalt Mixture Quality Properties

Three asphalt mixture quality properties are used in this example: asphalt content (AC), the volumetric properties of laboratory compacted air voids (AV), and voids in the mineral aggregate (VMA). These three properties are believed to adequately measure the mixture binder content and the effects of the aggregate gradation. AC is defined as the percent of asphalt cement by the total weight of the mix. AV is the total volume of air voids between the coated aggregate particles in a laboratory compacted mixture sample. The VMA is the volume of the intergranular void space between the aggregate particles of a laboratory compacted mixture sample, which includes the AV and volume of AC not absorbed into the aggregates. The limits selected in this proposed example for mixture quality are shown in Table C1. These proposed limits were either used or simulated in a pilot PWL specification by the Virginia DOT in 1996.

Asphalt Construction Quality Properties

Two asphalt construction quality properties are used in this example: ride quality (RQ) as measured by a South Dakota response-type road roughness meter and in-place AV (IPAV) measured from cores. The specification limits used for RQ and IPAV are shown in Table C2. The limits are related to those developed for a prototype roughness specification by the Virginia Transportation Research Council and those for the IPAV are based on research performed there several years ago.

Step 6. Determine Best Measurement Method of Each Indicator

This example of a HMAC quality parameter does not include a discussion or a determination of the best measurement method for the five properties (or indicators) of quality. For a discussion of this subject, the reader might see *Hot Mix Asphalt Materials, Mixture Design and Construction*, published by the National Asphalt Pavement Association (NAPA).

Step 7. Select Best Indicator of Quality for End Product

For this example of a HMAC quality parameter, all five indicators (AC, AV, VMA, RQ, and IPAV) will be used in the determination of the quality parameter.

Step 8. Draft Process to Make Quality Indicator(s) Biddable

A method to combine the individual quality parameters must be proposed. As part of this methodology the example uses a day's production for a lot. For mixture quality properties the sample size is four per lot. For construction quality, 10 cores per day are used to establish the construction IPAV

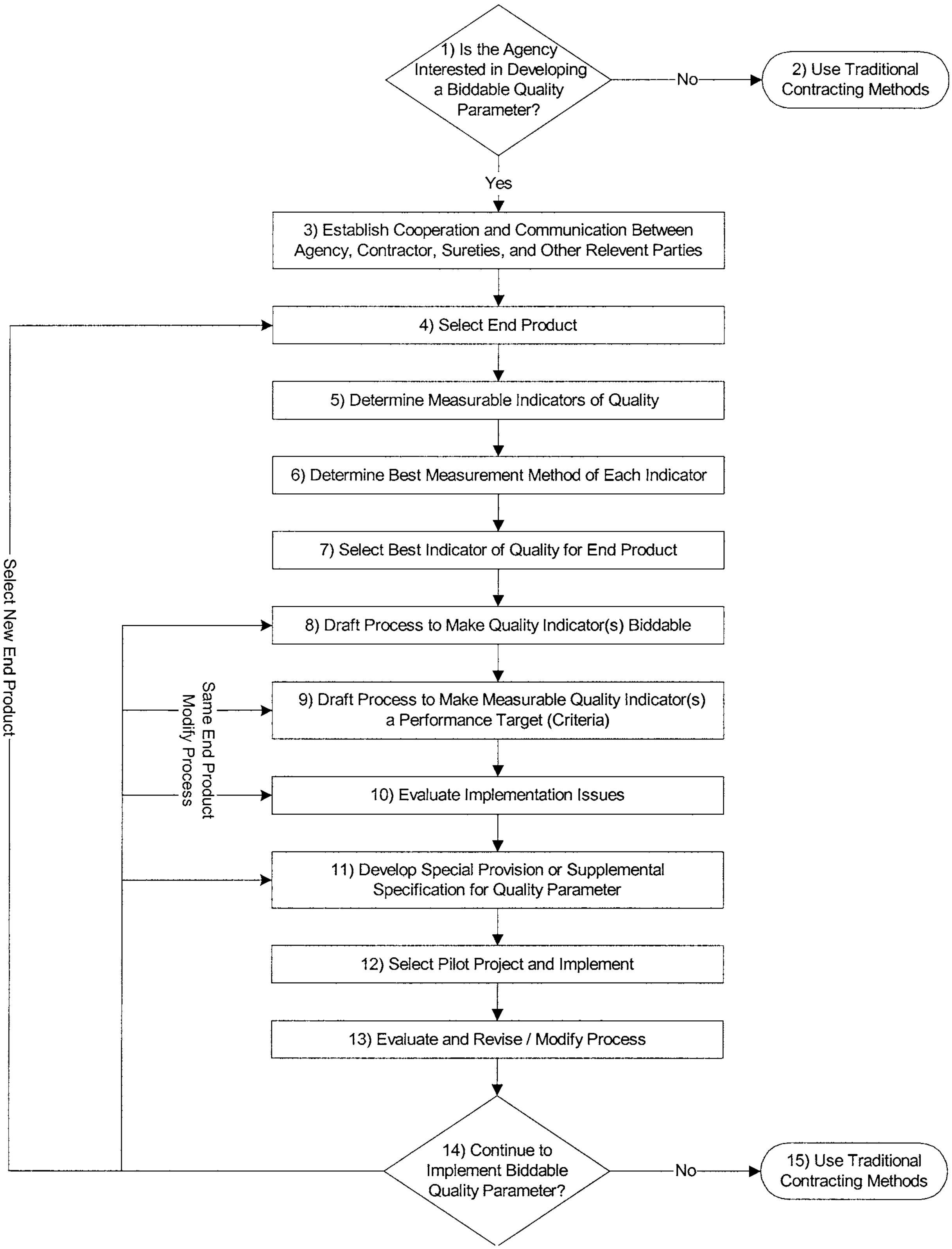


Figure C1. Quality parameter implementation process.

TABLE C1 Specification tolerances for asphalt mixture quality properties

Mixture Properties	Lower Tolerance*	Upper Tolerance*
Asphalt Content, %	–0.15**	+0.15**
Air Voids, %	–1.2	+1.2
VMA, %	–0.7	---

*Lower and upper tolerances are applied to the approved job mix formula values to establish the specification limits.

** Asphalt content as measured by the ignition oven. If another test procedure is used these limits may need to be changed.

quality parameter and for RQ the length paved per day is accumulated in 160 m (0.1 mi) sublots made up of 16 m (0.01 mi) increments. However, because the length paved will differ from day to day, the sample size for each lot will vary for RQ, but because the length sampled is accumulated based on 16 m increments, the sample size, n, will always be large.

Combining Quality Parameters

There are several ways these five quality parameters can be combined. This example will average the three mixture properties and weight these as 40 percent of the total, allowing the two construction properties to be averaged and weighed as 60 percent of the total. These weighed factors would then be combined in terms of PWL to produce a DOQP.

DOQP or PWL Determination

The procedure for determination of the DOQP or PWL is explained in the following five steps.

1. For the mixture quality parameters calculate the LSL and USL using these equations:

$$\text{LSL} = \text{JMF} - \text{Lower Tolerance}$$

$$\text{LSL} = \text{JMF} + \text{Lower Tolerance}$$

where JMF is the approved job mix formula,
LSL is the lower specification limit (from Table C1), and
USL is the upper specification limit (from Table C1).

For the construction quality parameters, the LSL and USL are given in Table C2.

2. Calculate the Q_l and Q_u using the equations below:

$$Q_l = \frac{\bar{x} - \text{LSL}}{s}$$

$$Q_u = \frac{\text{USL} - \bar{x}}{s}$$

where Q_l is the lower quality index,
Q_u is the upper quality index,
$\bar{x}$ is the lot average, and
s is the lot standard deviation.

3. Estimate the lot lower PWL (LPWL) and upper PWL (UPWL) by using Q_l and Q_u and the appropriate sample size (n) to enter Table C3. If Q_l or Q_u fall between two values of PWL in Table C3, the contractor is given the benefit of the doubt by rounding up to the higher PWL value.
4. Determine the total PWL (TPWL) for each quality parameter using the following equation:

$$\text{TPWL} = (\text{LPWL} + \text{UPWL}) - 100$$

5. Determine the mixture quality parameter (MQP) and construction quality parameter (CQP). The DOQP using the MQP and CQP is determined as follows:

Mixture Quality Parameter (MQP)
$= \frac{1}{3}(\text{AC} \times \text{TPWL} + \text{AV} \times \text{TPWL} + \text{VMA} \times \text{TPWL})$

Construction Quality Parameter (CQP)
$= \frac{1}{2}(\text{RQ} \times \text{TPWL} + \text{IPAV} \times \text{TPWL})$

Daily Overall Quality Parameter (DOQP)
$= 0.4(\text{MQP}) + 0.6(\text{CQP})$

TABLE C2 Specification limits for asphalt construction quality properties

Construction Properties	LSL	USL
Ride Quality, mm/km	---	1400
In-Place Air Voids, %	4	8

Note: LSL = lower specification limit; USL = upper specification limit.

TABLE C3 Quality level analysis by the standard deviation method

P_U or P_L	Upper Quality Index (Q_U) or Lower Quality Index (Q_L)													
	n=3	n=4	n=5	n=6	n=7	n=8	n=9	n=10 to n=11	n=12 to n=14	n=15 to n=18	n=19 to n=25	n=26 to n=37	n=38 to n=69	n=70 to n=200	n=201 to n=∝
100	1.16	1.50	1.79	2.03	2.23	2.39	2.53	2.65	2.83	3.03	3.20	3.38	3.54	3.70	3.83
99		1.47	1.67	1.80	1.89	1.95	2.00	2.04	2.09	2.14	2.18	2.22	2.26	2.29	2.31
98	1.15	1.44	1.60	1.70	1.76	1.81	1.84	1.86	1.91	1.93	1.96	1.99	2.01	2.03	2.05
97		1.41	1.54	1.62	1.67	1.70	1.72	1.74	1.77	1.79	1.81	1.83	1.85	1.86	1.87
96	1.14	1.38	1.49	1.55	1.59	1.61	1.63	1.65	1.67	1.68	1.70	1.71	1.73	1.74	1.75
95		1.35	1.44	1.49	1.52	1.54	1.55	1.56	1.58	1.59	1.61	1.62	1.63	1.63	1.64
94	1.13	1.32	1.39	1.43	1.46	1.47	1.48	1.49	1.50	1.51	1.52	1.53	1.54	1.55	1.55
93		1.29	1.35	1.38	1.40	1.41	1.42	1.43	1.44	1.44	1.45	1.46	1.46	1.47	1.47
92	1.12	1.26	1.31	1.33	1.35	1.36	1.36	1.36	1.37	1.37	1.39	1.39	1.40	1.40	1.40
91	1.11	1.23	1.27	1.29	1.30	1.30	1.31	1.31	1.32	1.32	1.33	1.33	1.33	1.34	1.34
90	1.10	1.20	1.23	1.24	1.25	1.25	1.26	1.26	1.26	1.27	1.27	1.27	1.28	1.28	1.28
89	1.09	1.17	1.19	1.20	1.20	1.21	1.21	1.21	1.21	1.22	1.22	1.22	1.22	1.22	1.23
88	1.07	1.14	1.15	1.16	1.16	1.16	1.17	1.17	1.17	1.17	1.17	1.17	1.17	1.17	1.17
87	1.06	1.11	1.12	1.12	1.12	1.12	1.12	1.12	1.12	1.12	1.12	1.12	1.12	1.13	1.13
86	1.04	1.08	1.08	1.08	1.08	1.08	1.08	1.08	1.08	1.08	1.08	1.08	1.08	1.08	1.08
85	1.03	1.05	1.05	1.04	1.04	1.04	1.04	1.04	1.04	1.04	1.04	1.04	1.04	1.04	1.04
84	1.01	1.02	1.01	1.01	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	0.99	0.99	0.99
83	1.00	0.99	0.98	0.97	0.96	0.96	0.96	0.96	0.96	0.96	0.96	0.96	0.95	0.95	0.95
82	0.97	0.96	0.95	0.94	0.93	0.93	0.93	0.92	0.92	0.92	0.92	0.92	0.92	0.92	0.92
81	0.96	0.93	0.91	0.90	0.90	0.89	0.89	0.89	0.89	0.88	0.88	0.88	0.88	0.88	0.88
80	0.93	0.90	0.88	0.87	0.86	0.86	0.86	0.82	0.82	0.82	0.85	0.84	0.84	0.84	0.84
79	0.91	0.87	0.85	0.84	0.83	0.82	0.82	0.82	0.82	0.81	0.81	0.81	0.81	0.81	0.81
78	0.89	0.84	0.82	0.80	0.80	0.79	0.79	0.79	0.78	0.78	0.78	0.78	0.77	0.77	0.77
77	0.87	0.81	0.78	0.77	0.76	0.76	0.76	0.75	0.75	0.75	0.75	0.74	0.74	0.74	0.74
76	0.84	0.78	0.75	0.74	0.73	0.73	0.72	0.72	0.72	0.71	0.71	0.71	0.71	0.71	0.71
75	0.82	0.75	0.72	0.71	0.70	0.70	0.69	0.69	0.69	0.68	0.68	0.68	0.68	0.68	0.67
74	0.79	0.72	0.69	0.68	0.67	0.66	0.66	0.66	0.66	0.65	0.65	0.65	0.65	0.64	0.64
73	0.76	0.69	0.66	0.65	0.64	0.63	0.63	0.63	0.62	0.62	0.62	0.62	0.62	0.61	0.61
72	0.74	0.66	0.63	0.62	0.61	0.60	0.60	0.60	0.59	0.59	0.59	0.59	0.59	0.58	0.58
71	0.71	0.63	0.60	0.59	0.58	0.57	0.57	0.57	0.57	0.56	0.56	0.56	0.56	0.55	0.55
70	0.68	0.60	0.57	0.56	0.55	0.55	0.54	0.54	0.54	0.53	0.53	0.53	0.53	0.53	0.52
69	0.65	0.57	0.54	0.53	0.52	0.52	0.51	0.51	0.51	0.50	0.50	0.50	0.50	0.50	0.50
68	0.62	0.54	0.51	0.50	0.49	0.49	0.48	0.48	0.48	0.48	0.47	0.47	0.47	0.47	0.47
67	0.59	0.51	0.47	0.47	0.46	0.46	0.46	0.45	0.45	0.45	0.45	0.44	0.44	0.44	0.44
66	0.56	0.47	0.45	0.44	0.44	0.43	0.43	0.43	0.42	0.42	0.42	0.42	0.41	0.41	0.41
65	0.52	0.45	0.43	0.41	0.41	0.40	0.40	0.40	0.40	0.39	0.39	0.39	0.39	0.39	0.39
64	0.49	0.42	0.40	0.39	0.38	0.38	0.37	0.37	0.37	0.36	0.36	0.36	0.36	0.36	0.36
63	0.46	0.39	0.37	0.36	0.35	0.35	0.35	0.34	0.34	0.34	0.34	0.34	0.33	0.33	0.33
62	0.43	0.36	0.34	0.33	0.32	0.32	0.32	0.32	0.31	0.31	0.31	0.31	0.31	0.31	0.31
61	0.39	0.33	0.31	0.30	0.30	0.29	0.29	0.29	0.29	0.29	0.28	0.28	0.28	0.28	0.28
60	0.36	0.30	0.28	0.27	0.27	0.27	0.26	0.26	0.26	0.26	0.26	0.26	0.26	0.25	0.25
59	0.32	0.27	0.25	0.25	0.24	0.24	0.24	0.24	0.23	0.23	0.23	0.23	0.23	0.23	0.23
58	0.29	0.24	0.23	0.22	0.21	0.21	0.21	0.21	0.21	0.21	0.20	0.20	0.20	0.20	0.20
57	0.25	0.21	0.20	0.19	0.19	0.19	0.18	0.18	0.18	0.18	0.18	0.18	0.18	0.18	0.18
56	0.22	0.18	0.16	0.16	0.16	0.16	0.16	0.16	0.16	0.15	0.15	0.15	0.15	0.15	0.15
55	0.18	0.15	0.14	0.13	0.13	0.13	0.13	0.13	0.13	0.13	0.13	0.13	0.13	0.13	0.13
54	0.14	0.12	0.11	0.11	0.11	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10
53	0.11	0.09	0.08	0.08	0.08	0.08	0.08	0.08	0.08	0.08	0.08	0.08	0.08	0.08	0.08
52	0.07	0.06	0.06	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05
51	0.04	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.02
50	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

Example Determination of a Daily Overall Quality Parameter

The following is an example illustrating how a DOQP can be calculated from the individual quality parameters. The data in the example that follows are for one typical construction day and are summarized in Table C4. The materials, RQ, and IPAV data were taken from different projects.

- Mixture Quality Parameter

Asphalt Content Quality Parameter

JMF = 5.8%

$n = 4, \bar{x} = 5.87\%, s = 0.12\%$

Using the lower and upper tolerances from Table C1:

$$\text{LSL} = \text{JMF} - \text{Lower Tolerance} = 5.8\% - 0.15\% = 5.65\%$$

$$\text{USL} = \text{JMF} + \text{Upper Tolerance} = 5.8\% + 0.15\% = 5.95\%$$

$$Q_l = \frac{\bar{x} - \text{LSL}}{s} \qquad Q_l = \frac{5.87 - 5.65}{0.12} = 1.83$$

$$Q_u = \frac{\text{USL} - \bar{x}}{s} \qquad Q_u = \frac{5.95 - 5.87}{0.12} = 0.67$$

From Table C3:

For $Q_l = 1.83$ and $n = 4$, LPWL = 100

For $Q_u = 0.67$ and $n = 4$, UPWL = 73

(Note: Because $Q_u = 0.67$ falls between 72 and 73 in Table C3, UPWL is rounded up to 73.)

TPWL = (LPWL + UPWL) − 100

TPWL = (100.0 + 73) − 100 = 73% for Asphalt Content

Air Voids Quality Parameter (Laboratory Compacted)

JMF = 4.0%

$n = 4, \bar{x} = 4.1\%, s = 0.51\%$

Using the lower and upper tolerances from Table C1:

LSL = 4.0% − 1.2% = 2.8%

USL = 4.0% + 1.2% = 5.2%

$$Q_l = \frac{4.1 - 2.8}{0.51} = 2.55$$

$$Q_u = \frac{5.2 - 4.1}{0.51} = 2.16$$

From Table C3:

For $Q_l = 2.55$ and $n = 4$, LPWL = 100

For $Q_u = 2.16$ and $n = 4$, UPWL = 100

TPWL = (100 + 100) − 100 = 100% for Air Voids

VMA Quality Parameter

JMF = 15.2%

$n = 4, \bar{x} = 15.1\%, s = 0.69\%$

Using the lower and upper tolerances from Table C1:

LSL = 15.2% − 0.7% = 14.5%

No Upper Tolerance = No USL, so UPWL = 100

$$Q_l = \frac{15.1 - 14.5}{0.69} = 0.87$$

From Table C3:

For $Q_l = 2.55$ and $n = 4$, LPWL = 79

TPWL = (100 + 79) − 100 = 79% for VMA

TABLE C4 Example data for one construction day (one lot)

Indicator	JMF	n	$\bar{x}$	s
Asphalt Content	5.8%	4	5.87%	0.12%
Air Voids	4%	4	4.1%	0.51%
VMA	15.2%	4	15.1%	0.69%
Ride Quality	---	200	1090	220
In-Place Air Voids	---	10	7.1%	1.1%

Mixture Quality Parameter (MQP)
$= \frac{1}{3}(AC \times TPWL + AV \times TPWL + VMA \times TPWL)$
$= \frac{1}{3}(73\% + 100\% + 79\%) = 84.0\%$

- Construction Quality Parameter

Ride Quality Parameter

$$n = 200\left(\begin{array}{l}\text{based on 3.2 km paved,}\\ 3.2\text{ km}/0.016\text{ km} = 200\end{array}\right)$$

$\bar{x} = 1090$ mm/km, $s = 220$ mm/km

From Table C2:

No LSL, so LPWL = 100.0

USL = 1400 mm/km

$$Q_u = \frac{1400 - 1090}{220} = 1.41$$

From Table C3:

For $Q_u = 1.41$ and $n = 200$, UPWL = 92

TPWL = (100 + 92) − 100 = 92% for Ride Quality

In-Place Air Voids Quality Parameter

$n = 10$, $\bar{x} = 7.1\%$, $s = 1.1\%$

From Table C2:

LSL = 4%, USL = 8%

$$Q_1 = \frac{7.1 - 4.0}{1.1} = 2.82$$

$$Q_u = \frac{8.0 - 7.1}{1.1} = 0.82$$

From Table C3:

For $Q_1 = 2.82$, and $n = 10$, LPWL = 100

For $Q_u = 0.82$ and $n = 10$, UPWL = 79

TPWL = (100 + 79) − 100
= 79% for In-Place Air Voids

Construction Quality Parameter (CQP)
$= \frac{1}{2}(RQ \times TPWL + IPAV \times TPWL)$
$= \frac{1}{2}(92\% + 79\%) = 85.5\%$

The Daily Overall Quality Parameter (DOQP)
for Mixture and Construction
$= 0.4(MQP) + 0.6(CQP) = 84.0 \times 0.4 + 0.6 = 84.9\%$

The DOQP in this example is lower than the acceptable quality level (AQL) of 90 percent (i.e., the overall quality level for that day was less than what was desired as defined by the specifications.) This methodology would be repeated on a daily basis and accumulated for an entire project. Because these calculations are time consuming when performed by hand, most state highway agencies (SHAs) that are using this type of methodology have developed computer programs to make these calculations.

Overall Project Quality Parameter for Bid Adjustment

The DOQP is accumulated and averaged over the time period of the project to determine the POQP. The use of the POQP can then be tied into the A + B + Q equation using an inverse function. This inverse function is required because the bid value should decrease as the quality parameter (POQP) increases.

One approach to applying this concept is to use the multiparameter equation in the form (A + B)Q, where Q is measured by the inverse function of a pay factor (PF), which is a function of the accumulated POQP as shown in Equation C1. In this approach the quality parameter, POQP, combined with a PF, is used to establish a factor that would determine a dollar amount for bidding purposes based on anticipated quality. The pay equation contained in the *AASHTO Quality Assurance Guide Specification* (PF = 55 + 0.5PWL) is used in this example. The pay equation is based on an AQL of 90 PWL and an assumed rejectable quality level (RQL) of 50 PWL. The equation allows a maximum incentive of 5 percent (at 100 PWL), and pays an average of 100 percent of the bid price at the AQL and 80 percent of the bid price at the RQL.

$$Q_1 = \frac{1}{PF} = \frac{1}{55 + 0.5PWL} \qquad \text{(Equation C1)}$$

where PWL = POQP

<u>Example of Project Overall Quality Parameters for Three Contractors</u>

Three contractors (A, B, and C) bid on a typical, new SHA project. Each of the contractors bid a HMAC cost of \$35 per ton based on a HMAC quantity for the project of 100,000 tons and a duration of 50 days. The road user cost set by SHA is \$2000/day. The purpose of presenting an example in which all three contractors bid the same cost per ton and time is to illustrate the effect of high, average, and low quality history of contractors on the award of the project.

The following data were collected by the SHA from each contractor's last hot-mix asphalt project in lots; that is, construction days. Construction data for contractors A, B, and

TABLE C5 Contractor A—Project overall mixture quality parameter

	AC, %			AV, %			VMA, %		
JMF	5.8			4.0			15.2		
LSL	5.65			2.8			14.5		
USL	5.95			5.2			---		
Lot No.	$\bar{x}$	s	TPWL	$\bar{x}$	s	TPWL	$\bar{x}$	s	TPWL
1	5.72	0.13	68	4.2	0.68	99	14.8	0.32	82
2	5.74	0.08	88	3.9	0.26	100	15.1	0.17	100
3	5.78	0.09	98	4.1	0.50	100	15.3	0.50	100
4	5.83	0.05	100	3.9	0.29	100	15.3	0.29	100
5	5.75	0.06	100	3.9	0.28	100	15.1	0.29	100
6	5.83	0.10	90	3.7	0.43	100	15.2	0.24	100
7	5.78	0.13	78	3.8	0.57	100	15.1	0.40	100
8	5.90	0.05	84	3.4	0.39	100	15.2	0.33	100
9	5.85	0.11	81	3.3	0.39	93	14.9	0.30	95
10	5.82	0.19	53	3.5	0.48	99	15.3	0.38	100
Average	---	---	84.0	---	---	99.1	---	---	97.7

C are found in Tables C5 and C6, Tables C7 and C8, and Tables C9 and C10, respectively. Tables C5, C7, and C9 contain the mixture quality data and the calculated average total percent within limits (TPWL) values for AC, AV, and VMA. Tables C6, C8, and C10 contain the construction quality data and the calculated average TPWL values for RQ and IPAV.

Contractor A: Average Project Overall Quality Parameter

Project Mixture Quality Parameter (PMQP)
$= \frac{1}{3}(\text{AC} \times \text{TPWL} + \text{AV} \times \text{TPWL} + \text{VMA} \times \text{TPWL})$
$= \frac{1}{3}(84.0 + 99.1 + 97.7) = 93.6\%$

TABLE C6 Contractor A—Project overall construction quality parameter

	Ride Quality, mm/km				In-Place Air Voids, %		
LSL	---				4		
USL	1400				8		
Lot No.	Length, km*	$\bar{x}$	s	TPWL	$\bar{x}$	s	TPWL
1	2.2	1204	222	81	7.0	0.9	87
2	2.5	1072	309	86	7.4	0.7	81
3	2.2	1192	301	76	6.2	1.1	95
4	2.4	992	230	97	6.8	1.2	84
5	3.6	976	251	96	6.6	1.4	83
6	1.5	992	244	96	5.5	0.8	99
7	3.0	1008	375	85	5.2	1.5	78
8	4.1	1136	308	81	6.3	1.6	80
9	2.5	960	213	99	6.5	0.9	97
10	3.8	656	139	100	5.1	1.0	87
Average	---	---	---	89.7	---	---	87.1

*The length paved in kilometers divided by 0.016 provides the sample size for ride quality.

TABLE C7 Contractor B—Project overall mixture quality parameter

	AC, %			AV, %			VMA, %		
JMF	5.8			4.0			15.2		
LSL	5.65			2.8			14.5		
USL	5.95			5.2			---		
Lot No.	$\bar{x}$	s	TPWL	$\bar{x}$	s	TPWL	$\bar{x}$	s	TPWL
1	5.65	0.13	50	4.5	0.70	84	14.8	0.72	64
2	5.70	0.20	51	4.4	0.75	86	14.8	0.65	66
3	5.80	0.22	46	4.4	0.79	84	14.9	0.61	72
4	5.75	0.15	68	4.6	0.84	74	15.0	0.27	80
5	5.73	0.16	67	4.7	0.66	76	14.6	0.59	56
6	5.80	0.18	56	4.9	0.53	69	14.7	0.50	64
7	5.81	0.17	60	4.5	0.50	97	14.9	0.83	67
8	5.86	0.18	56	4.7	0.54	81	15.0	0.74	73
9	5.83	0.20	50	4.8	0.67	70	15.2	0.68	85
10	5.86	0.15	67	4.4	0.60	95	15.3	0.52	100
11	5.81	0.13	77	4.4	0.73	87	15.3	0.65	91
12	5.85	0.16	63	4.3	0.81	87	15.3	0.66	91
Average	---	---	59.3	---	---	82.5	---	---	75.8

TABLE C8 Contractor B—Project overall construction quality parameter

	Ride Quality, mm/km				In-Place Air Voids, %		
LSL	---				4		
USL	1400				8		
Lot No.	Length, km*	$\bar{x}$	s	TPWL	$\bar{x}$	s	TPWL
1	3.2	1304	252	65	7.3	0.8	81
2	4.5	1265	315	67	7.2	0.6	92
3	4.2	1288	320	64	6.9	1.1	84
4	4.4	1222	230	78	7.0	1.2	80
5	3.6	1116	278	85	7.1	1.4	74
6	3.7	1292	278	65	6.5	1.0	95
7	4.0	1233	356	68	7.2	1.1	77
8	4.1	1196	308	75	6.9	1.3	80
9	4.5	1160	273	81	7.0	0.9	87
10	3.8	1204	239	80	7.0	1.0	84
11	4.4	1188	293	77	6.8	0.9	92
12	4.3	1212	248	78	6.7	0.8	96
Average	---	---	---	73.6	---	---	85.2

*The length paved in kilometers divided by 0.016 provides the sample size for ride quality.

TABLE C9 Contractor C—Project overall mixture quality parameter

	AC, %			AV, %			VMA, %		
JMF	5.8			4.0			15.2		
LSL	5.65			2.8			14.5		
USL	5.95			5.2			---		
Lot No.	$\bar{x}$	s	TPWL	$\bar{x}$	s	TPWL	$\bar{x}$	s	TPWL
1	5.78	0.10	94	4.3	0.30	100	15.8	0.62	100
2	5.75	0.08	92	4.4	0.35	100	15.8	0.60	100
3	5.80	0.12	84	4.2	0.39	100	15.9	0.61	100
4	5.75	0.07	98	3.8	0.24	100	16.0	0.57	100
5	5.77	0.10	90	4.0	0.36	100	15.6	0.69	100
6	5.80	0.08	100	3.9	0.43	100	15.7	0.50	100
7	5.81	0.07	100	4.1	0.50	100	15.9	0.63	100
8	5.83	0.08	100	4.3	0.44	100	16.0	0.54	100
9	5.83	0.10	89	4.3	0.47	100	16.2	0.68	100
Average	---	---	94.1	---	---	100	---	---	100

Project Construction Quality Parameter (PCQP)
= ½ (RQ × TPWL + IPAV × TPWL)
= ½ (89.7% + 87.1%) = 88.4%

The Project Overall Quality Parameter (POQP)
= 0.4PMQP + 0.6PCQP
= 93.6 × 0.4 + 88.4 × 0.6 = 90.5%

PWL = PODQ = 90.5%

PF = 55% + 0.5PWL = 55 + 0.5(90.5) = 100.25%.

Contractor A's adjusted bid price
= ($35 × 100,000 + $2,000 × 50)1/1.0025
= $3,591,022

Contractor B: Low Project Overall Quality Parameter

Project **Mixture** Quality Parameter (PMQP)
= ⅓ (AC × TPWL + AV × TPWL + VMA × TPWL)
= ⅓ (59.3 + 82.5 + 75.8) = 72.5%

TABLE C10 Contractor C—Project overall construction quality parameter

	Ride Quality, mm/km				In-Place Air Voids, %		
LSL	---				4		
USL	1400				8		
Lot No.	Length, km*	$\bar{x}$	s	TPWL	$\bar{x}$	s	TPWL
1	4.2	1004	242	95	6.3	0.9	99
2	4.5	965	205	99	6.2	0.7	100
3	5.2	988	260	95	5.9	1.0	99
4	4.8	911	220	99	6.0	1.0	98
5	4.6	1004	218	97	6.1	1.1	96
6	4.7	992	218	97	6.5	1.0	95
7	4.1	922	256	97	6.2	0.9	99
8	4.3	936	248	97	5.9	1.2	94
9	4.9	958	223	98	6.0	0.9	100
Average	---	---	---	97.1	---	---	97.8

*The length paved in kilometers divided by 0.016 provides the sample size for ride quality.

Project **Construction** Quality Parameter (PCQP)
$= \frac{1}{2}(RQ \times TPWL + IPAV \times TPWL)$
$= \frac{1}{2}(73.6\% + 85.2\%) = 79.4\%$

The Project Overall Quality Parameter (POQP)
$= 0.4PMQP + 0.6PCQP = 72.5 \times 0.4 + 79.4 \times 0.6 = 76.6\%$

$PF = 55 + 0.5PWL = 55 + 0.5(76.6) = 93.3\%$.

Contractor B's adjusted bid price
$= (\$35 \times 100{,}000 + \$2{,}000 \times 50)1/0.9330$
$= \$3{,}858{,}521$

Contractor C: High Project Overall Quality Parameter

Project **Mixture** Quality Parameter (PMQP)
$= \frac{1}{3}(AC \times TPWL + AV \times TPWL + VMA \times TPWL)$
$= \frac{1}{3}(94.1 + 100.0 + 100.0) = 98.0\%$

Project **Construction** Quality Parameter (PCQP)
$= \frac{1}{2}(RQ \times TPWL + IPAV \times TPWL)$
$= \frac{1}{2}(97.1\% + 97.8\%) = 97.5\%$

The Project Overall Quality Parameter (POQP)
$= 0.4PMQP + 0.6PCQP$
$= 98.0 \times 0.4 + 97.5 \times 0.6 = 97.7\%$

$PF = 55 + 0.5PWL = 55 + 0.5(97.7) = 103.85\%$.

Contractor C's adjusted bid price
$= (\$35 \times 100{,}000 + \$2{,}000 \times 50)1/1.0385$
$= \$3{,}466{,}538$

Comparison of Bid Prices with Quality Parameter

The bids for each contractor are summarized in Table C11. This summary demonstrates the impact of different levels of a contractor's history of quality as determined using the proposed methodology. As Table C11 shows, Contractor C (with the high quality parameter) would have had the lowest bid—$124,484 below the next bidder (Contractor A with an average quality parameter) and $391,983 below Contractor B who had the lowest quality parameter.

Three Approaches to the Biddable Quality Parameter

There are three basic ways to consider the past quality history of a contractor when awarding a project. One way would apply the past quality history in the Contract Pre-Award stage of the project; i.e., to include a Contractor Pre-Qualification requirement that allows only contractors with a certain minimum level of quality history (POQP) to bid on the project. The requirement would be a pass/fail measure determined by the SHA. The two alternatives would affect the Bid Award project stage. One would allow the SHA to use the contractor's quality history (POQP) to determine the amount of bid adjustment. The other would allow the contractor to bid a quality rating (POQP) based on the contractor's self-assessment of past performance. All of these scenarios are schematically illustrated in Figure C2.

Alternative I—Pre-Bid Qualification

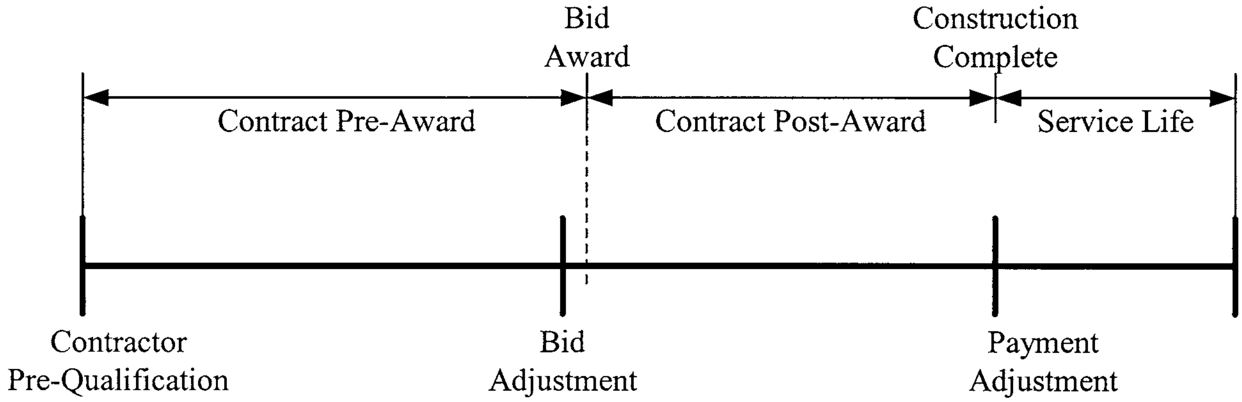
The first alternative is based on the SHA establishing a pre-bid rating system for materials and construction using a contractor's POQP based on prior performance. This quality parameter would be used directly as a prerequisite to allow a contractor to bid on the project. Contractors would either pass or fail the minimum quality parameter value. The quality rating, or POQP, could be determined by contractor performance on the most recent project or series of projects for the previous year. For example, the performance on the last project, or the last five projects, of the type under consideration could qualify. If past performance history was required only for the last project, the POQP of 90.5 percent, based on the previous example, would be used as a quality rating for Contractor A to determine bid eligibility. If the minimum AQL for prequalification was a POQP of 90 percent, then Contractor A would qualify. Contractor C with a quality rating of 97.7 percent would also be eligible, whereas Contractor B would not meet prequalification requirements with a POQP of 76.6 percent.

Alternative II—Bid Adjustment by SHA

The second alternative requires a SHA to apply a contractor's POQP based on prior performance (quality history) to adjust the bid value for award of the project. Prior performance would be collected by the SHA through the monitoring of all projects for this purpose. The POQP would be used with the pay equation to determine the quality factor for bid evaluation. This alternative would reward contractors for higher levels of quality delivered on previous projects. If the history collected by the SHA was only the last project of Contractor C, based on the previous example, 97.7 percent would be used as the POQP to determine the Q

TABLE C11 Comparison of bid prices using the quality parameter

Contractor	Adjusted Bid Price
A (Average POQP = 90.5%)	$3,591,022
B (Low POQP = 76.6%)	$3,858,521
C (High POQP = 97.7%)	$3,466,538



Alternative I:
Criteria: Greater than Min. % (Pass/Fail Measure)
Contractor Q% Determined From:
Last Job, Last 5 Jobs, This Season, Company Life
Challenges: Out-of-State and New Start-Up Contractors, How to raise quality history measure if fallen below minimum criteria

Alternative II:
Criteria: SHA uses contractor's prior performance to determine quality rating.
Contractor Q% Determined From: Last Job, Last 5 Jobs, This Season, Company Life
Challenges: Out-of-State and New Start-Up Contractors, How to raise quality history measure if fallen below minimum criteria

Alternative III:
Criteria: Contractor bids quality rating knowing own past performance
Contractor Q% Determined From: Contractor's Own Past Quality History
Challenges: How to limit contractor from using overly optimistic assessment of quality rating

Figure C2. Q parameter alternative applications.

adjustment of the bid. An adjustment of 96.3 percent would be made to compare the bid price. This adjustment was calculated as follows:

$$Q = \frac{100\%}{PF} = \frac{100}{55 + 0.5PWL} = \frac{100}{55 + 0.5POQP}$$

$$= \frac{100}{55 + 0.5(97.7)} = \frac{100}{103.85} = 96.3\%$$

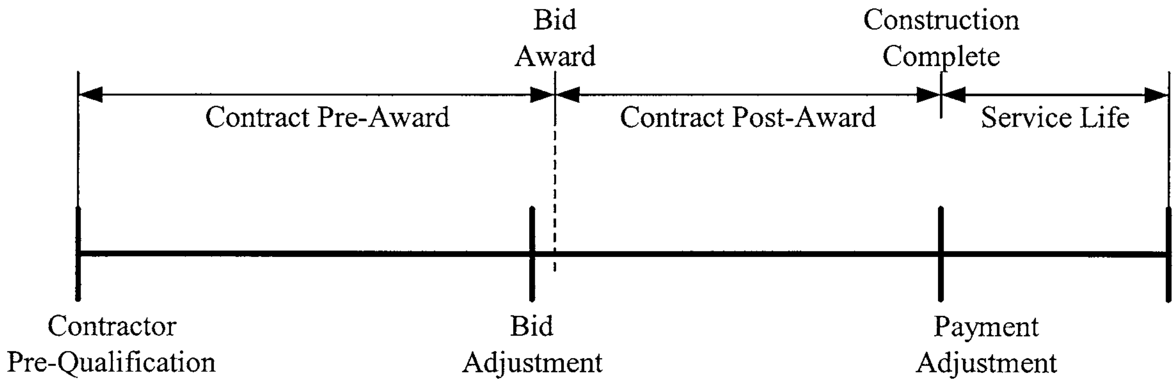
Because this adjustment is less than 100 percent, Contractor C's bid would be lowered for comparison with the other bids.

Alternative III—Bid as a Parameter by Contractor

The third alternative would allow for contractors to bid their estimate of their quality parameter (POQP), at least in theory, based on prior performance. This estimated quality parameter would be used with the pay equation to determine the quality factor for bid evaluation. One inherent weakness in this alternative is that the contractor could bid a quality rating that was not comparable with past quality history. For example, Contractor A has a history of achieving quality equal to 90.5 percent, but would be free to bid a POQP for example of 95 percent, even though this contractor's quality history does not indicate that the contractor can achieve this quality level. This may result in a contractor being awarded the project based on a quality history that has never been demonstrated. All three contractors would be able to bid on the project, including Contractor B, whose quality history does not demonstrate that a POQP of 90 percent could be achieved.

Step 9. Draft Process to Make Measurable Quality Indicator(s) a Performance Target (Criteria)

A process for making the measurable quality indicator(s) a performance target or criteria must be developed. The approach to the biddable quality parameter procedure should determine the method in which the contractor's pay is adjusted, whether the quality parameter is a pre-bid qualification, an adjustment made by the SHA, or a bid value by the contractor. The relationships between the bid adjustment and the pay adjustment are shown in Figure C3.



Alternative I:
Criteria: Greater than Min. % (Pass/Fail Measure)
Contractor Q% Determined From:
Last Job, Last 5 Jobs,
This Season,
Company Life
Challenges: Out-of-State and New Start-Up Contractors, How to raise quality history measure if fallen below minimum criteria

Alternative II:
Criteria: SHA uses contractor's prior performance to determine quality rating.
Contractor Q% Determined From: Last Job, Last 5 Jobs, This Season, Company Life
Challenges: Out-of-State and New Start-Up Contractors, How to raise quality history measure if fallen below minimum criteria

Alternative III:
Criteria: Contractor bids quality rating knowing own past performance
Contractor Q% Determined From: Contractor's Own Past Quality History
Challenges: How to limit contractor from using overly optimistic assessment of quality rating

Alternatives I and II Pay Adjustments:
Pay Adjustment Based On AQL = 90%

PF = 55 + 0.5PWL
PWL = Quality Performed
(AASHTO Pay Factor Equation)

Alternative III Pay Adjustment:
Pay Adjustment Based On AQL = 90%

PF = (55 + 0.5PWL)(PWL/Q_{bid})
PWL = Quality Performed
Q_{bid} = Quality Bid
(Modification to the AASHTO Pay Factor Equation)

Figure C3. Q parameter alternative applications and pay adjustments.

Alternative I—Pre-Bid Qualification

Only contractors with a certain minimum level of quality history (POQP) are allowed to bid on the project. The project is awarded to the lowest cost bidder. The contractor is held to achieving the AQL in the resulting quality performance to receive 100 percent pay. Contractors would be motivated to produce higher than AQL quality on their projects in order to prequalify for future projects by increasing the value of their quality history.

Alternative II—Bid Adjustment by SHA

The SHA collects and uses the contractor's quality history (POQP) to determine the amount of bid adjustment. In actual application, the quality parameter would be determined for the work on the new project and applied to the pay schedule at the completion of the project. The contractor would only be required to achieve the AQL to receive 100 percent pay. Contractors would be motivated to produce higher than AQL quality on the project in order to increase the value of the quality history tracked by the agency.

Alternative III—Bid as a Parameter by Contractor

The contractor would bid a quality rating (POQP) based on the contractor's own assessment of past project performance. The contractor must be held to achieving the quality level bid on the contract to receive 100 percent pay. This means that the contractor could achieve the AQL on the project and receive less than 100 percent pay because the quality bid was higher than the AQL. One potential solution to holding the contractor to achieving the quality bid is to use a multiplication factor of the ratio of Q_{actual}/Q_{bid} when applying the PF equation. For instance, if the selected contractor bid a POQP of 95 percent, and achieved a POQP on the project of 97 percent, the PF equation would be modified by a factor of 1.021 (or 97/95). If, on the other hand, a POQP of only 90.5 percent was obtained, the factor to modify the PF equation would be 0.953 (or 90.5/95). The use of a factor in this manner would place the burden on the contractor to achieve the quality level that was bid on the project.

Examples of Pay Adjustment at Project Completion

For each of the three approaches to the biddable quality parameter procedure (shown as Alternatives I, II, and III in

Figure C3), an example has been created to show what would happen to the contractor's pay adjustment under different scenarios at project completion. These different scenarios support the above discussions of the different biddable quality parameter alternatives.

A contractor is awarded a typical SHA project with an A+B+I/D+Q contract. The contractor bid a HMAC cost of \$35 per ton based on a HMAC quantity for the project of 100,000 tons. The duration bid for the project is 50 days. The road user cost set by SHA is \$2000/day. Scenarios X, Y, and Z have been created to illustrate three possible quality results on the project. The purpose of illustrating these scenarios is to compare the pay adjustments of the three different scenarios under each of the bid award alternatives (I, II, and III). This will show the effect of high, average, and low quality performance by the contractor on the project pay adjustment. For comparison purposes it is assumed that the contractor had a quality history level of 90 percent and the AQL set by the SHA for the project was also 90 percent. The potential project payment if completed at the AQL and on time is \$3,600,000.

$$\text{Price} = (\$35 \times 100{,}000 + \$2{,}000 \times 50) = \$3{,}600{,}000$$

To demonstrate each scenario, the following data hot-mix asphalt project are measured in lots, that is, construction days. The construction data are found in Tables C12 and C13, Tables C14 and C15, and Tables C16 and C17 for scenarios X, Y, and Z, respectively. Tables C12, C14, and C16 contain the mixture quality data and the calculated average total percent within limits values for AC, AV, and VMA. Tables C13, C15, and C17 contain the construction quality data and the calculated average total percent within limits values for RQ and IPAV.

Scenario X—Average Project Overall Quality Parameter

Project **Mixture** Quality Parameter (PMQP)
$= \frac{1}{3}(\text{AC} \times \text{TPWL} + \text{AV} \times \text{TPWL} + \text{VMA} \times \text{TPWL})$
$= \frac{1}{3}(83.7 + 99.1 + 97.7) = 93.5\%$

Project **Construction** Quality Parameter (PCQP)
$= \frac{1}{2}(\text{RQ} \times \text{TPWL} + \text{IPAV} \times \text{TPWL})$
$= \frac{1}{2}(89.8\% + 86.7\%) = 88.2\%$

The Project Overall Quality Parameter (POQP)
$= 0.4\text{PMQP} + 0.6\text{PCQP}$
$= 0.4(93.5) + 0.6(88.2) = 90.3\%$

Scenario Y—Low Project Overall Quality Parameter

Project **Mixture** Quality Parameter (PMQP)
$= \frac{1}{3}(\text{AC} \times \text{TPWL} + \text{AV} \times \text{TPWL} + \text{VMA} \times \text{TPWL})$
$= \frac{1}{3}(78.0 + 92.3 + 95.2) = 88.5\%$

Project **Construction** Quality Parameter (PCQP)
$= \frac{1}{2}(\text{RQ} \times \text{TPWL} + \text{IPAV} \times \text{TPWL})$
$= \frac{1}{2}(89.0\% + 87.0\%) = 88.0\%$

The Project Overall Quality Parameter (POQP)
$= 0.4\text{PMQP} + 0.6\text{PCQP}$
$= 0.4(88.5) + 0.6(88.0) = 88.2\%$

TABLE C12 Scenario X—Project overall mixture quality parameter

	AC, %			AV, %			VMA, %		
JMF	5.8			4			15.2		
LSL	5.65			2.8			14.5		
USL	5.95			5.2			---		
Lot No.	$\bar{x}$	s	TPWL	$\bar{x}$	s	TPWL	$\bar{x}$	s	TPWL
1	5.83	0.13	79	4.2	0.68	99	14.8	0.32	82
2	5.78	0.08	100	3.9	0.26	100	15.1	0.17	100
3	5.9	0.09	69	4.1	0.5	100	15.3	0.5	100
4	5.85	0.05	100	3.9	0.29	100	15.3	0.29	100
5	5.82	0.06	100	3.9	0.28	100	15.1	0.29	100
6	5.72	0.1	74	3.7	0.43	100	15.2	0.24	100
7	5.74	0.13	74	3.8	0.57	100	15.1	0.4	100
8	5.78	0.05	100	3.4	0.39	100	15.2	0.33	100
9	5.83	0.11	87	3.3	0.39	93	14.9	0.3	95
10	5.75	0.19	54	3.5	0.48	99	15.3	0.38	100
Average	---	---	83.7	---	---	99.1	---	---	97.7

TABLE C13 Scenario X—Project overall construction quality parameter

	Ride Quality, mm/km				In-Place Air Voids, %		
LSL	---				4		
USL	1400				8		
Lot No.	Length, km*	$\bar{x}$	s	TPWL	$\bar{x}$	s	TPWL
1	3	1314	202	68	5.4	0.9	95
2	4.1	994	308	91	7.1	1	82
3	2.5	1154	213	88	6.7	1.1	89
4	3.8	989	222	97	7.4	1.2	69
5	2.2	1003	309	91	6.2	1.4	87
6	2.5	1189	301	76	6.1	1.5	83
7	2.2	945	230	98	5.1	1.6	73
8	2.4	1036	251	93	6.4	0.8	99
9	3.6	986	244	96	6.8	0.9	92
10	1.5	765	139	100	5.3	0.7	98
Average	---	---	---	89.8	---	---	86.7

*The length paved in kilometers divided by 0.016 provides the sample size for ride quality.

Scenario Z—High Project Overall Quality Parameter

Project **Mixture** Quality Parameter (PMQP)
= ⅓ (AC × TPWL + AV × TPWL + VMA × TPWL)
= ⅓ (93.7 + 99.9 + 97.8) = 97.1%

Project **Construction** Quality Parameter (PCQP)
= ½ (RQ × TPWL + IPAV × TPWL)
= ½ (94.0% + 93.2%) = 93.6%

The Project Overall Quality Parameter (POQP)
= 0.4PMQP + 0.6PCQP
= 0.4(97.1) + 0.6(93.6) = 95.0%

Alternative I—Pre-Bid Qualification

The contractor is required to achieve the AQL set by the agency to receive 100 percent pay. The contractor's pay is adjusted using the standard pay adjustment equation, where

TABLE C14 Scenario Y—Project overall mixture quality parameter

	AC, %			AV, %			VMA, %		
JMF	5.8			4			15.2		
LSL	5.65			2.8			14.5		
USL	5.95			5.2			---		
Lot No.	$\bar{x}$	s	TPWL	$\bar{x}$	s	TPWL	$\bar{x}$	s	TPWL
1	5.93	0.13	56	4.4	0.68	90	15.3	0.32	100
2	5.78	0.08	100	3.7	0.26	100	15.3	0.17	100
3	5.9	0.09	69	4.1	0.5	100	14.9	0.33	91
4	5.85	0.15	68	3.9	0.29	100	15.1	0.3	100
5	5.82	0.06	100	3.2	0.28	100	14.8	0.38	77
6	5.72	0.1	74	3.7	0.43	100	15.2	0.29	100
7	5.74	0.13	74	4.8	0.57	75	15.1	0.29	100
8	5.78	0.09	98	3.4	0.39	100	15.2	0.42	100
9	5.83	0.11	87	2.9	0.39	59	14.9	0.4	84
10	5.75	0.19	54	3.5	0.48	99	15.3	0.5	100
Average	---	---	78	---	---	92.3	---	---	95.2

TABLE C15 Scenario Y—Project overall construction quality parameter

	Ride Quality, mm/km				In-Place Air Voids, %		
LSL	---				4		
USL	1400				8		
Lot No.	Length, km*	$\bar{x}$	s	TPWL	$\bar{x}$	s	TPWL
1	2.4	1287	202	72	7	0.9	87
2	4.3	887	308	96	6.6	1	93
3	2.7	1121	213	91	7.3	1.1	74
4	2.5	989	422	84	6.3	1.2	92
5	3.2	1003	309	91	6.2	1.4	87
6	2.8	1203	301	75	5.2	1.5	78
7	2.6	945	230	98	5.8	1.6	81
8	3.1	851	451	89	6.8	0.8	95
9	2.1	994	244	96	5.2	0.9	92
10	3.1	746	339	98	7.1	0.7	91
Average	---	---	---	89	---	---	87

*The length paved in kilometers divided by 0.016 provides the sample size for ride quality.

PWL is equal to the POQP. Table C18 shows the project payment for each scenario.

$$\text{Price} = ([\$35 \times 100{,}000] + [\$2{,}000 \times 50]) \times \frac{\text{PF}}{100}$$

where PF = 55 + 0.5PWL

Scenario Z, where the contractor achieved the highest quality, would receive the most money for completion of the project. Scenario Y, where the contractor did not achieve a POQP greater than the AQL, would receive less than 100 percent pay for the project.

Alternative II—Bid Adjustment by SHA

The adjustments for Alternative II are exactly the same as for Alternative I. The contractor is required to achieve the AQL set by the agency in order to receive 100 percent pay. The quality history of the contractor does not impact the project payment amount, even though it impacts the project award.

TABLE C16 Scenario Z—Project overall mixture quality parameter

	AC, %			AV, %			VMA, %		
JMF	5.8			4			15.2		
LSL	5.65			2.8			14.5		
USL	5.95			5.2			---		
Lot No.	$\bar{x}$	s	TPWL	$\bar{x}$	s	TPWL	$\bar{x}$	s	TPWL
1	5.78	0.07	100	3.8	0.68	99	14.8	0.32	83
2	5.83	0.08	100	3.7	0.26	100	15.1	0.17	100
3	5.82	0.09	99	3.6	0.5	100	15.3	0.5	100
4	5.72	0.05	97	4.2	0.29	100	15.3	0.29	100
5	5.88	0.06	89	4.3	0.28	100	15.1	0.29	100
6	5.73	0.1	77	3.7	0.43	100	15.2	0.24	100
7	5.74	0.08	88	3.9	0.57	100	15.1	0.4	100
8	5.79	0.05	100	4.1	0.39	100	15.2	0.33	100
9	5.83	0.07	100	4.3	0.39	100	14.9	0.3	95
10	5.85	0.09	87	3.9	0.48	100	15.3	0.38	100
Average	---	---	93.7	---	---	99.9	---	---	97.8

TABLE C17 Scenario Z—Project overall construction quality parameter

	Ride Quality, mm/km				In-Place Air Voids, %		
LSL	---				4		
USL	1400				8		
Lot No.	Length, km*	$\bar{x}$	s	TPWL	$\bar{x}$	s	TPWL
1	3.2	987	144	100	5.4	0.9	95
2	2.7	994	301	92	6.1	1	99
3	4	1154	213	88	6.3	1.1	95
4	3.6	989	233	97	5.5	1.2	90
5	3.8	1003	309	91	5.2	0.9	92
6	2.4	1189	177	89	6	1.5	84
7	2.9	945	308	94	6.2	1.1	95
8	2.1	1036	251	93	5.4	0.8	98
9	1.5	986	251	96	4.9	0.9	84
10	3.7	765	176	100	6.4	0.7	100
Average	---	---	---	94	---	---	93.2

*The length paved in kilometers divided by 0.016 provides the sample size for ride quality.

The contractor's pay is adjusted using the standard pay adjustment equation, where PWL is equal to the POQP. The project payment for each scenario will be identical to that calculated for Alternative I and shown in Table C18.

Alternative III—Bid as a Parameter by Contractor

The contractor is required to achieve the quality level bid for the contract in order to receive 100 percent pay. This quality level will either be equal to or greater than the AQL set by the agency. For these scenarios, the quality level bid by the contractor was 92 percent (Q_{bid}), which was greater than the AQL required for the project. The contractor's pay is adjusted using the standard pay adjustment equation, where PWL is equal to the POQP for the scenario, and an additional factor of Q_{actual}/Q_{bid}, where Q_{actual} is equal to the PF determined by the POQP achieved in the scenario. Table C19 shows the project payment for each scenario.

$$\text{Price} = ([\$35 \times 100{,}000] + [\$2{,}000 \times 50]) \times \frac{PF}{100} \times \left(\frac{Q_{actual}}{Q_{bid}}\right)$$

where PF = 55 + 0.5PWL

Scenario Z, where the contractor achieved the highest quality and where the POQP was greater than the quality level bid, would receive the most money for completion of the project. Scenario X, where the contractor did not achieve a POQP greater than the quality level bid, would receive a reduced payment, even though the POQP exceeded the AQL. Scenario Y, where the contractor did not achieve a POQP greater than the quality level bid or the AQL, would receive the least amount of money for the project.

Step 10. Evaluate Implementation Issues

There are several issues that should be considered when implementing the quality parameter factor illustrated in this example. These include:

- It is likely that an agency considering the use of a quality parameter will already have in place many of the elements included in this procedure such as lot sizes, individual quality parameter specification limits, and PFs that should make implementing this concept very straightforward.

TABLE C18 Comparison of project payment for Alternatives I and II

Scenario	PWL	PF	Project Payment
X	90.3	100.15	\$3,605,400
Y	88.2	99.1	\$3,567,600
Z	95.0	102.5	\$3,690,000

TABLE C19 Comparison of project payment for Alternative III

Scenario	Q_{bid}	PWL (Q_{actual})	PF	Q_{actual}/Q_{bid}	Project Payment
X	92.0	90.3	100.15	0.9815	$3,538,700
Y	92.0	88.2	99.1	0.9587	$3,420,260
Z	92.0	95.0	102.5	1.0326	$3,810,300

- If a Q parameter factor is desired for HMAC in the immediate future, a QLA appears to be the best choice. LCC analyses are desirable, but do not appear to be ready for HMAC implementation at this time.
- Although the QLA procedure is being used by an increasing number of SHAs, there are many that have not adopted this procedure.
- Educational issues should be addressed. Both contractor and SHA personnel should have a rudimentary understanding of the statistical principles used in the development and application of the quality parameter. The SHA should know how to develop the tolerances to be used in specifications and test methods and should be able to develop computer programs to perform the arduous calculations to determine the quality parameter.
- The quality parameter would be explained in the request for bids and contract document with reference to a special provision, which would include the methodology.
- The quality parameter would have two functions: a $Q_{bid,}$ which would be used solely to determine the low bidder in the A + B + Q equation, and a $Q_{assessed}$, which would be used to determine contract compliance and the project PF through the PF equation.
- Although tested on a small regional basis, the specification limits suggested herein for AC, AV, VMA, RQ, and IPAV, are considered guides for a starting place. No one should feel that they are the final and only choice. They have been tested in Virginia and found to be reasonable. For example, for AC determination a Virginia DOT Special Provision for HMAC was pilot tested in 1996 using the QLA procedure. At the same time, the ignition oven was introduced as an optional test method for AC determination. Because the ignition oven has many advantages, it is favored by most contractors. The suggested specification limits in this example were established based on this usage; the level of variability found for Virginia aggregates and contractors will not necessarily apply nationwide. However, the concept is the important issue and it works.
- Combining the materials and construction quality measures at 40/60 is suggested, although other combinations may be more appropriate. This ratio was chosen partially from the belief that a good mix can be constructed poorly, resulting in a less than desirable quality, and that a poor mix, within reason, can be improved with good construction practices, making the construction operation relatively more important than the mix production.
- The example considers a contractor's recent past history. However, a contractor may not have a recent past history; e.g., the contractor may have just started business or just moved into the state. Development of a program consisting of quality certification should be considered to handle such instances in which the contractor would specify that a certain level of quality can and will be provided.
- It would be desirable to establish the relationship between the increased levels of quality and the added cost

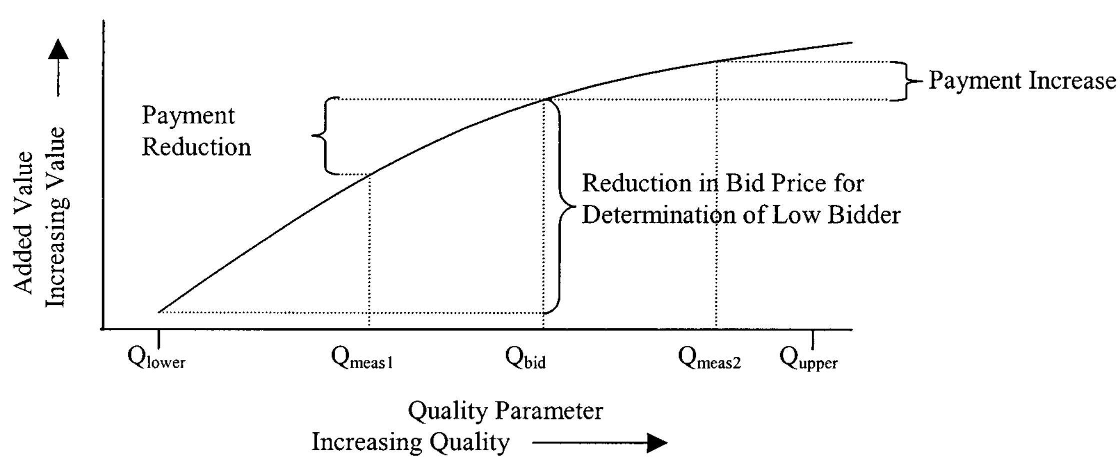


Figure C4. Relationship between quality parameter and cost benefits (value).

benefits, or value, associated with them. This would permit establishing a value to the quality level bid by a contractor and providing for incentives/disincentives related to the change in value associated with the quality level achieved when compared with the quality level bid. Figure C4 illustrates this concept. The definitions of the terms indicated in Figure C4 are as follows:

Q = specified quality parameter,
Q_{lower} = lower limit of quality parameter,
Q_{upper} = upper limit of quality parameter,
Q_{bid} = quality parameter bid by the contractor,
Q_{meas1} = quality parameter measured for Lot 1, and
Q_{meas2} = quality parameter measured for Lot 2.

For bidding purposes the contractor's quality parameter bid would be required to be within the range between the Q_{lower} and Q_{upper}. As illustrated, the contractor's bid would be reduced by the added value resulting from the higher quality. The cost benefits (value) at Q_{lower} would be used as the base value for this comparison. This bid adjustment would be used only for comparing bids and determining the low bidder.

For contractor pay purposes the Q_{bid} would become the base value. If the Q_{meas} for a lot was less than the Q_{bid}, the payment to the contractor for that lot would be reduced by the reduced cost benefits associated with the lower quality. Similarly, if the Q_{meas} for a lot was greater than the Q_{bid}, the payment to the contractor for that lot would be increased by the increased cost benefits associated with the higher quality.

- Other questions that should be considered include:
  - Are there other parameters that are more significant that should be included?
  - Is it reasonable to assume that contractors understand the methodology and the relationship with their operations/performance to prepare a rational bid or is an educational process necessary?
  - Is the incentive/disincentive pay schedule adequate to motivate improved quality or is another pay schedule more appropriate?