University of Nevada, Reno

Techniques for Improving the Production Control of Asphalt Mixtures

A thesis submitted in partial fulfillment of the
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ABSTRACT

Enhancements in the control of asphalt mixture quantities are vital to uphold precise production accuracy. This holds particular significance as the majority of funds for asphalt mixture production originate from the Federal Government, making it crucial to maintain accurate proportions to ensure the intended performance of the mixture is observed. Various techniques aimed at refining quantity control were explored by adjusting equipment and conveyance methods. Extensive document analysis was conducted to discern current practices adopted by State Departments of Transportation (DOTs), AASHTO standards, and plant equipment manufacturers. The proposed strategies suggest a shift from the volumetric to the weighing approach where quantity control would be more precise.

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Chapter 1: Introduction

1.1 Background

Asphalt plants are specialized facilities that produce hot mix asphalt (HMA) for road construction and other civil engineering applications. Over the years, advancements in technology and equipment have significantly influenced the efficiency, environmental impact, and quality control aspects of asphalt production. The history of asphalt plants can be traced back to the late 19th century, with the emergence of simple mixing operations that have evolved into highly sophisticated production facilities. Modern asphalt plants are a result of continuous advancements aimed at optimizing efficiency and reducing environmental impacts. There are two primary types of asphalt plants: batch plants and drum mix plants. Batch plants offer precise control over the amount of each material used in the mix, while drum plants are known for higher production rates and continuous operation (Asphalt Pavement Association of Oregon, 2003)[1]. With advancements in technologies and the ability to produce large quantities without interruption, the demand for continuous drum mix plants has increased and the demand for batch plants has diminished. Both plants are made to serve the ultimate purpose of mixing the asphalt materials together, but the equipment, flow, and operation of these different types of plants differ. Batch plants are composed of several key equipment needed for precise production of the asphalt mixture. An illustration of the batch plant equipment is found in Figure 1 below and a description of the flow and operation follows in Figure 2.

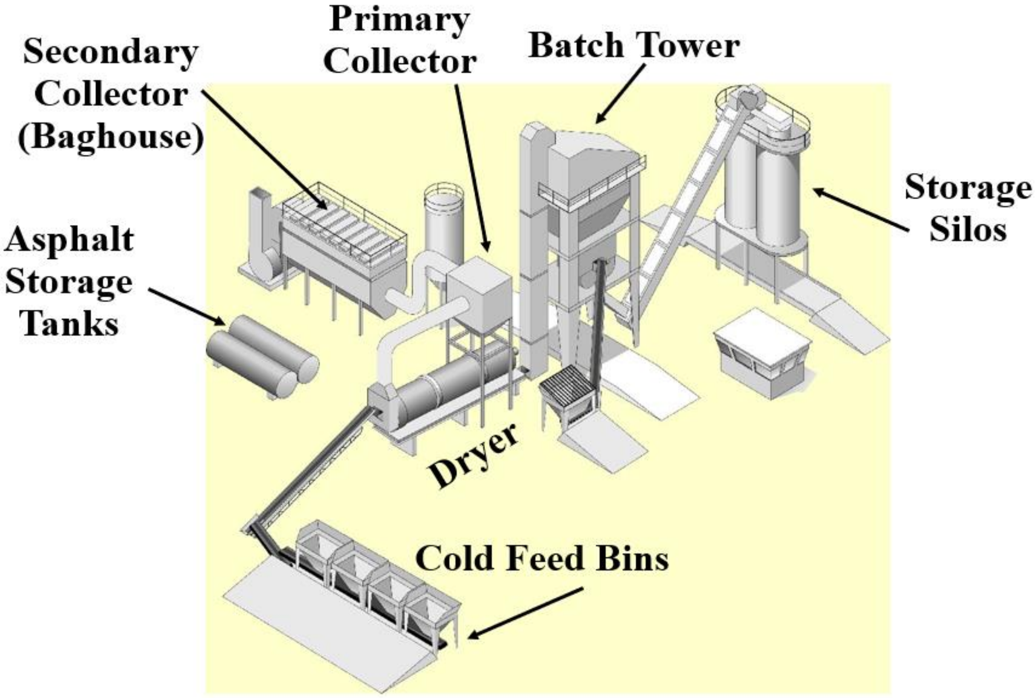

Figure 1. Batch Plant Components[2]**.**

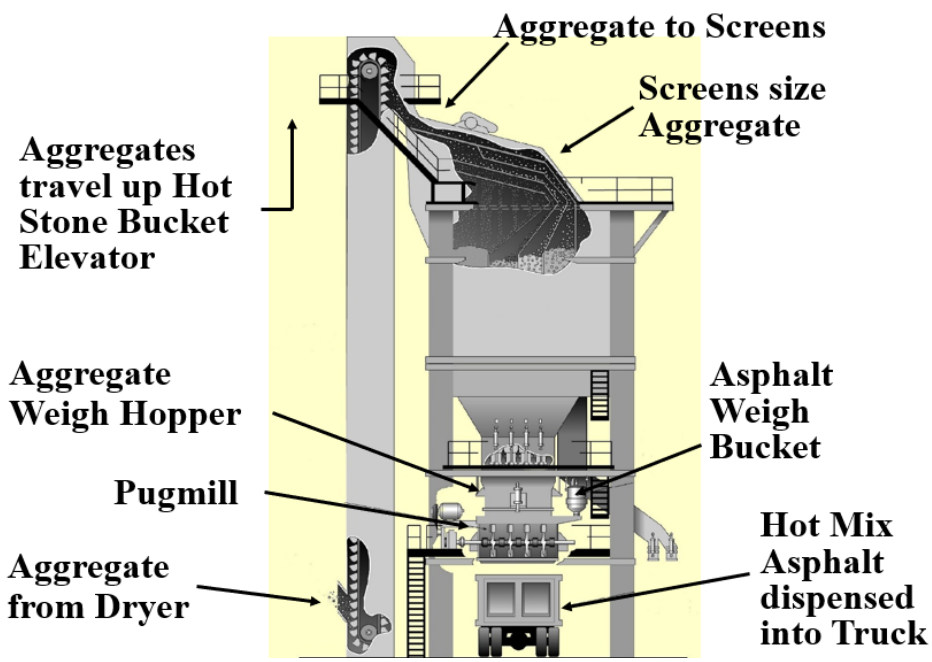

Figure 2. Material Flow in Batch Plants[2]**.**

Each cold feed bin has its own conveyor belt that transfers the aggregates from the cold feed bins to the collector conveyor belt. In the dryer, moisture is removed, and aggregates are heated before ascending to the batch plant tower via a hot elevator. The hot elevator discharges onto screens at the top of the batch tower where the aggregates into sizes stored in hot bins. From these bins, sizes are weighed and proportioned into a weigh hopper, simultaneous to asphalt cement being pumped into the asphalt weigh bucket. The materials are then mixed in the twin-shaft pugmill and discharged for transport or storage. If reclaimed asphalt concrete is utilized, it can be introduced at different stages. Each batch plant incorporates an air pollution control device to meet environmental standards, which may include dry or wet collectors, fabric filters, or a combination. Collected fines may be discarded or reintroduced into the plant, often as mineral filler in the aggregate weigh hopper.

Continuous drum plants are like batch plants when comparing raw materials and end products, however the flow and operation of these types of plants differ since it is a continuous on-going process. It enables a higher production rate than that of the batch plants. Figure 3 below represents the continuous drum plant components where the use of the equipment presented is described hereafter. The cold feed bins store coarse and fine aggregates at ambient temperature. These aggregates are proportioned from the bins, transported by a belt conveyor over a weigh bridge system, and introduced into the upper section of the drum mixer. Inside the drum, the aggregates undergo heating and drying so that the moisture content present evaporates. Additionally, asphalt cement is introduced, coating the aggregates with asphalt supplied from a storage tank and pumped into the drum mixer. Reclaimed Asphalt Pavement (RAP) or Reclaimed Asphalt Shingles (RAS) material has its own dedicated entry point around the middle of the drum, to reduce their exposure to the burner flame. Adequate mixing temperatures and mixing time enable the binder from the RAP to melt without additional aging. As the drum rotates, flights inside the drum lift the aggregate and drop it through the hot bitumen, ensuring each particle is coated evenly. This continuous mixing process eliminates the need for batch cycles. Baghouse fines are collected and re-introduced into the dryer at the correct portions. The asphalt mixture is then transferred into isolated storage silos, by means of a slat conveyor, to be temporarily stored and then distributed in loads into the trucks for delivery. This process uses automated systems to ensure minimal temperature loss and segregation of the mix.

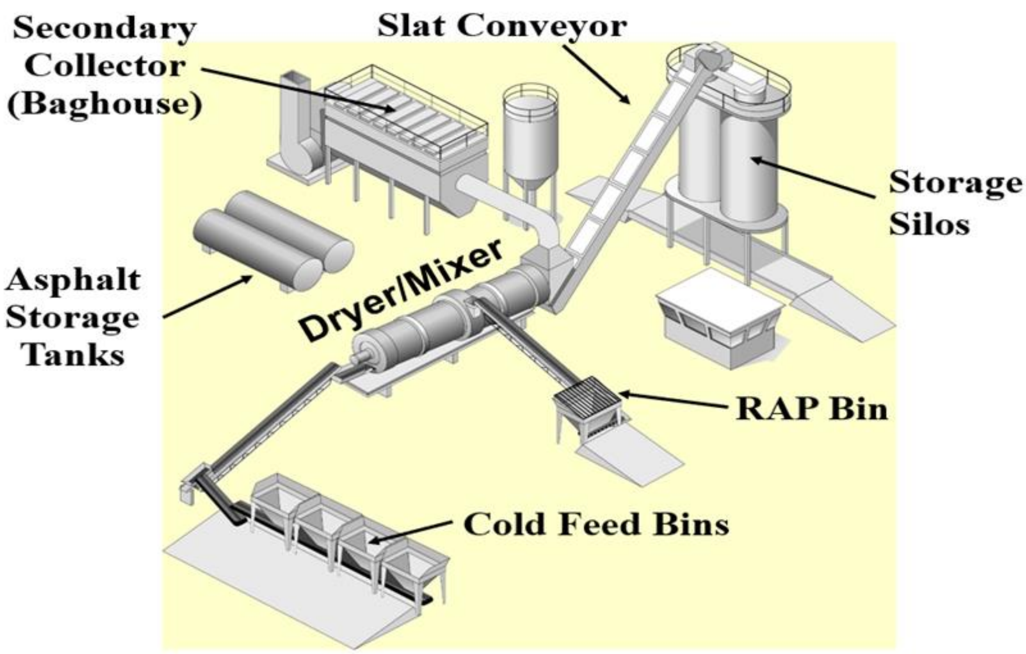

Figure 3. Continuous Drum Plant Components[2]**.**

1.2 Research Objective

The aim of this research is to enhance the precision of asphalt mixture quantity control at asphalt plants through the implementation of innovative techniques. Comprehensive analysis of documents sourced from various agencies, asphalt producers, and equipment manufacturers were conducted to identify techniques aimed at refining the quantity control processes for asphalt materials.

1.3 Scope of Work and Experimental Plan

Essential information was gathered to identify techniques for achieving an increased level of accuracy in controlling the quantity of asphalt mixtures. Recommendations for implementing the techniques identified are also provided. The experimental plan of this effort is defined by the flow chart illustrated in **Error! Reference source not found.**.

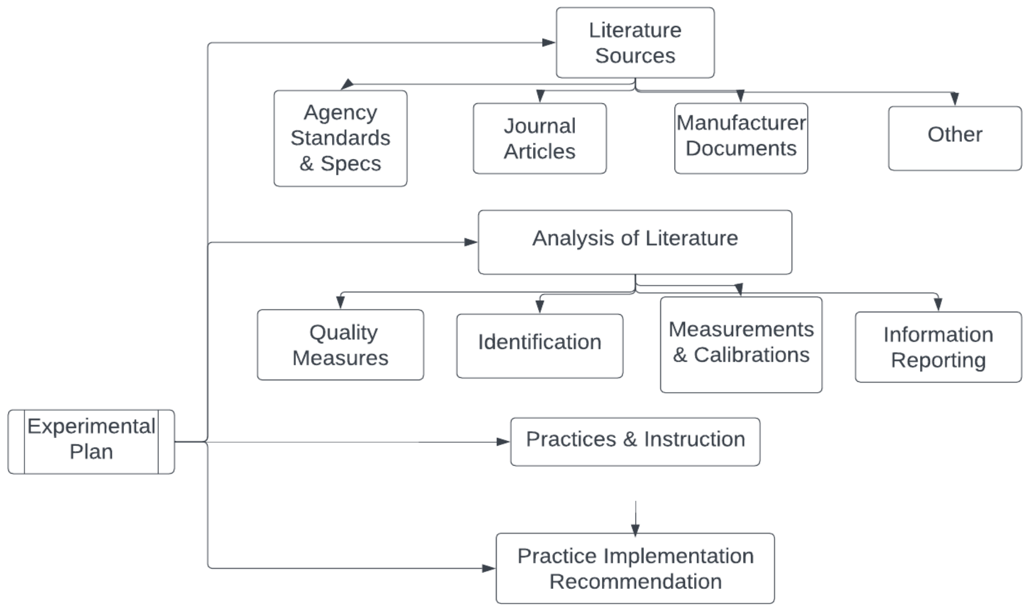

Figure 4. Experimental Plan Summarizing Key Activities.

Chapter 2: Literature Review

The equipment employed in asphalt plants exhibits similarities between batch and continuous drum mix configurations. A more in-depth exploration of the equipment utilized, along with an explanation of the operational methods, will be provided in the subsequent discussion.

2.1 Cold Feed Bins

Cold feed bins are containers designed to store the necessary aggregate sizes and feed them to the dryer/drum of an asphalt plant in proportions closely matching the specifications outlined in the Job Mix-Formula (JMF) for the specific mix being produced. Cold feed bins are made of steel material to be able to withstand the weight of the aggregates. Most asphalt plants have 4 to 6 cold feed bins at their facilities and of various sizes depending on the total production rate of the plant. The cold feed bins are designed with steep slope walls to facilitate the flow of aggregates. Scalping screens are also used to prevent the oversized material from entering the cold feed bins as shown in Figure 5. Cold feed bins can also be equipped with vibrators or air cannons that help dislodge any stuck or clumped material specially when dealing with fine wet material as illustrated in Figure 6 below.

Figure 5. Cold Feed Bin with Scalping Screens to Remove Clumps[3]**.**

Figure 6. Air Cannon and Vibrators on a Cold Feed Bin[3]**.**

Aggregates are fed from the stockpiles into the cold feed bins by means of front-end loaders. Cold feed bins store different aggregate sizes in different bins to prevent contamination and disruption to the aggregate gradation. Plants use the volumetric approach to feed the aggregates or RAP from the cold feed bins in the desired proportions. The gate opening of the cold feed bin and the speed of the conveyor belts determines the aggregate production rate. Cold feed bins can be equipped with of a limit switch to ensure material flow out of the cold feed bins as shown in Figure 7. Calibrations are essential for this type of measurement where calibration relations are obtained by having at least 3 samples run at 3 different gate openings and 3 different belt speeds and consequently the weight is calculated based on the volume. Then, this portion of material is weighed using a certified weighing scale and both weights are compared to develop the calibration relations. An illustration of the calibration curves is presented in **Error! Reference source not found.** below.

Figure 7. Limit Switch Used to Positively Identify Material Flow[3]**.**

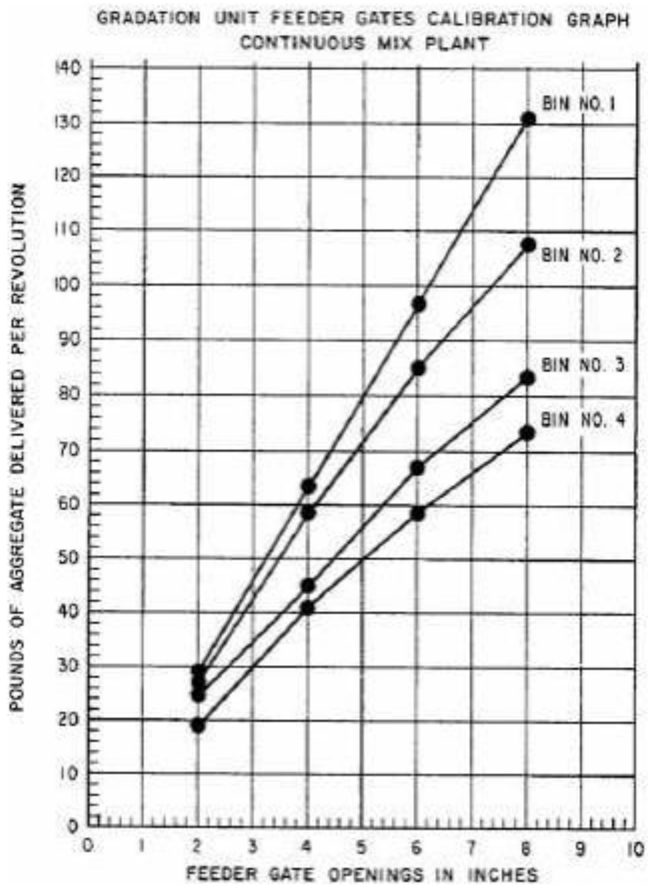

Figure 8-6.-Calibration chart, gradation feeder gates.

Figure 8. Cold Feed Bin Calibration[4]**.**

2.2 Conveyor Belt

Conveyor belts are made of heavy-duty rubber, designed with some reinforcement such as fibers or metal wires to provide additional strength and durability. The width of the conveyor belt depends on the production rate of the asphalt plant where wider belts are used in higher production plants. The length of the belt is a function of the layout of the plant and how far the cold feed bins are from the drum or the pugmill. The conveyor belts are equipped to be ability to run at different speeds and are calibrated as mentioned in section 2.1. It is desirable to keep the belt speed running between 20 to 80 percent of the belt's maximum speed. Modern conveyor belts are integrated with automated plant control systems that regulate the speed of the belt based on the production needs. This integration ensures that the correct amount of material is delivered for the mix being produced. Siemens Industry identified key factors in selecting conveyor-belt scales for mining operations, emphasizing easy installation, low maintenance, fast response, and high accuracy [5]. Another document discussed electronic weighing conveyor belts, emphasizing the significance of the tension wheel's position for accuracy, and highlighting the correlation between material height on the belt and measurement error [6].

An important aspect that needs to be addressed is the moisture content of the aggregates and recycled materials (could be RAP, RAS, RAP/RAS blend) material. Moisture content can be measured using different means by sampling from the cold feed bin, sampling from the conveyor belt, inserting a probe into the stream of material traveling on the conveyor belt, and nuclear moisture gauge. As per R. West and P. Turner, "The probe is based on microwave technology which instantaneously senses the microwave energy absorbed by the material. The energy absorbed is proportional to the moisture content of that material"[7]. The typical moisture content measurement method used in the same study consisted of placing a sample in an electric heating drier at a temperature of 400°F. The dryer was mounted on load cells attached to a programmable logic controller (PLC) that can determine when the mass has reached a constant level and consequently report the mass and determine the moisture content of the sample. Samples ranged between 20 to 30 pounds and can took up to 100 minutes depending on how wet the sample was.

These belt conveyors transfer the material to a collector conveyor that also transfers the material to the weigh bridge on the way into the drum. The weigh idler is installed midway across the weigh bridge where it measures the weight of material at a specific instant of time. Combining this measure with the belt speed enables the determination of the weight of material passing through. This calculated weight is in tons per hour, and it includes moisture. The plant control system is responsible for converting this wet measurement to a dry one and proportionating all materials accordingly. Belt conveyor scrapers are important, because if wet fines get stuck to the conveyor belt, this specific amount will be measured again and again and will end up in false weight reading. Thus, as per R. West and R. Turner, “The belt scraper should be in place, cleaning the incline conveyor belt as it carries aggregates to the mixing drum.” Wind shields are also important to cover the conveyor belts to prevent the loss of fine material when transferring it, as shown in Figure 9, especially on windy days as heavy wind on the conveyor belt can lead to inaccurate weighbridge indicated weights.

Figure 9. Conveyor Belt with Windshield Covering[8]**.**

2.3 Asphalt Binder Storage Tanks

Asphalt binder storage tanks are made up of carbon steel to withstand the high temperature of the asphalt binder. The tanks are in circular shape for uniform heating and circulation and are insulated with fiberglass material to prevent heat loss and maintain pumping and mixing temperature of the asphalt binder. Preserving the binder quality, consistency and homogeneity agitation systems shall be used, especially if the binder is modified. The heating systems used include hot oil heaters or electric heaters. Tank size it is a function of the asphalt plant production rate, typically ranging between 10,000 to 35,000 gallons[9]. Hot oil systems circulate heated thermal fluid through coils or a jacket around the tank, while electric heaters use immersion elements directly within the binder. The typical temperature range of e asphalt binder is between 300 to 350°F, depending on the type and grade of the asphalt binder [10]. Tanks are interlocked with the plant control systems to regulate the heat and maintain the required temperature of the asphalt binder. Asphalt binder tanks are also equipped with pressure relief valves, alarms, overflow protection, and in and out supply valves. A typical illustration of an AC tank is represented in Figure 10. Calibrating the asphalt tank is done by allowing the asphalt meter system to run and fill a known volume of asphalt binder into an asphalt distributor truck and then measuring the weighting the truck before and after adding the asphalt binder using certified scales. Another approach would save time and energy, by using a skid-mounted calibration tank with an integral scale as shown in Figure 11.

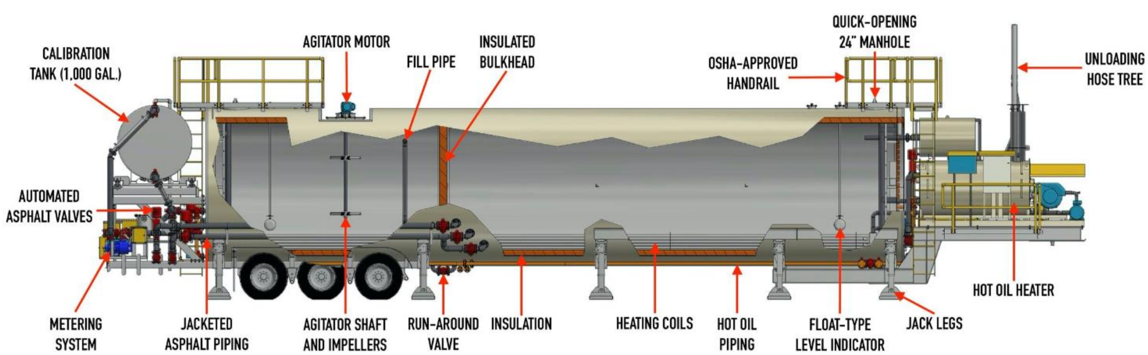

Figure 10. Horizontal AC tank[9]**.**

Figure 11. Skid-mounted Calibration Tank[9]**.**

2.4 Asphalt Binder Meters

Asphalt binder meters are used to measure and control the amount of asphalt binder incorporated in the asphalt mixture, which is in fact a function of the aggregate amount added. Since the binder has a visco-elastic behavior, as the temperature increases the viscosity decreases. This is a crucial property of the binder since it needs to be fluid to be pumped and mixed. Thus, specific gravity of the asphalt binder is an important aspect in determining the volume at 60°F [10]. Conversion charts are used in determining the volume of asphalt binder at 60°F since the meters measure asphalt binder at higher temperatures and report the temperature and volume to the plant control, at which the specific gravity of the binder is entered manually and the volume of asphalt at 60°F is calculated. Asphalt binder material is supplied from the tank to the drum or weigh pod by means of pipes. If the asphalt binder is not yet to be added, a valve is responsible for recirculating the asphalt binder into the tank. The US Department of Commerce addressed different liquid properties influencing the material flow [11]. A document from the Automated Process Equipment Corporation (APEC) delves into the details of liquid addition systems, specifically examining the advantages and drawbacks of employing scales and meters in batch plants [12]. This exploration sheds light on the benefits associated with each method, offering a comprehensive analysis of their respective strengths and limitations within the context of batch plant operations.

In the few decades the use of the Coriolis mass flowmeter has become more common in the oil and gas industry [13]. Coriolis meters are made of stainless steel and titanium with no restrictions on piping and streams' direction. They are used in many different industries including petroleum, food and beverage, and pharmaceutical due to their characteristics and compact size. They are also used for batching, inventory, process control, precision filling of containers, and custody transfer [13]. The biggest advantage of the Coriolis meter is that it directly measures the mass of the flow, instead of measuring the volume of the flow as any meter does [14]. Not only can it measure the mass flow, but it also measures the volume flow, density, viscosity, and temperature of the asphalt binder. As per Plache, measurements of mass can only be done while having an acting force on the system and then measuring the acceleration can be taken [15]. Figure 12 demonstrates a U-tube motion of the fluid observed while using the Coriolis meter. In practice two of the U-tubes would work in opposition, sharing the flow of material. Considering a force applied upward on the tube, the material flowing outward would have an increased angular momentum since the radius from the hinge got bigger. The other side of the U-tube is having completely the opposite scenario where the angular momentum is reduced. This process is known as the Coriolis acceleration that is developed by the flow of the liquid material through the tube.

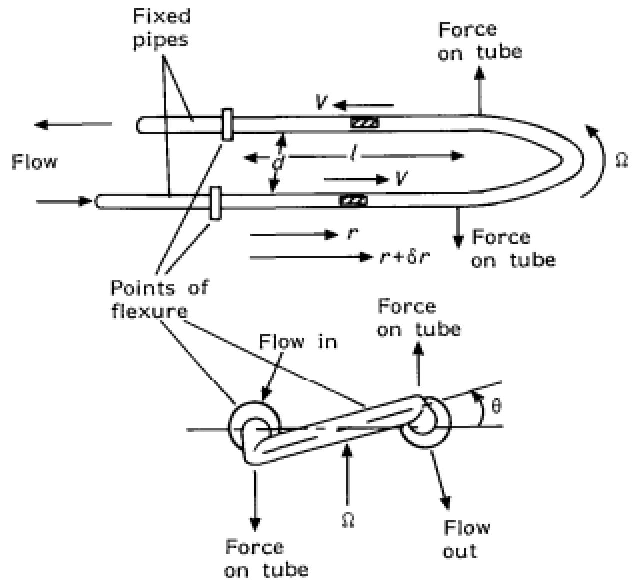

Figure 12. Diagram of the U-tube motion and forces.

2.5 Screw Conveyors

Screw conveyors are circular or U-shaped tubes that have a helical screw blade attached within the tube that rotates to move the material. The length and width of the screw conveyor is dependent on the distance it needs to transfer the material, and the type of material it is used for. It is usually used for low-weight low-dosage solids like baghouse fines and mineral fillers. The conveyor is sealed to prevent loss of fine materials. It also can be run at different speeds, taking control of the correct proportion to be added. Peshtawar et al. cited several studies, indicating that screw speed and conveying angle significantly influenced conveyor power requirements, with considerations for volumetric efficiency and conveying capacity. Additionally, the design of the screw conveyors covered aspects like bulk material characteristics, selection of conveyor size and speed, lump size limitations, and bearing recommendations [15]. The content underscores the importance of considering material properties, volumetric feeders, and conveying capacity in determining conveyor size and speed.

2.6 Pneumatic Conveyors

Pneumatic conveyors, integral to both batch and continuous drum mix asphalt plants, are mechanical systems designed for the efficient transportation of dry bulk materials, utilizing air pressure or vacuum. Pneumatic conveyors are composed of many components such as an air source, conveying pipeline, material feed inlet, and receiving vessel. These conveyors facilitate the precise movement of materials like aggregate and filler. Constructed with materials such as stainless steel or carbon steel, they contribute to the controlled and automated handling of substances within asphalt production processes. The benefits of pneumatic conveyors in asphalt plants is their capacity for precision, efficiency, reduced environmental impact, and flexibility in accommodating diverse plant layouts.

Chapter 3: Literature Sources

Throughout this project, a diverse array of documents from various sources were examined. The targeted documents encompassed special standards, provisions, and operational guidelines from multiple agencies and entities. Additionally, detailed reviews were conducted on documentation provided by plant equipment manufacturers. Actively engaging with plant operator personnel, discussions were initiated to explore and assess different operational techniques, with a particular focus on identifying opportunities for enhancement and improvement in plant operations.

AASHTO standards were examined to determine the available techniques currently used, of which two standards were of highly significant input. AASHTO R61, Establishing Requirements for Equipment Calibrations, Standardizations, and Checks, categorized the calibrations and checks based on the probability that the uncertainty exceeds the accuracy requirements and the measurement's influence on the test result [16]. These criteria were categorized into do nothing, standardize, and calibrate as shown in Table 1. As for the allowable intervals between each calibration, standardization, and checks, the probability that time is affecting the instrument and the influence of the measurement on the test result is studied in Table 2. Note that AASHTO R61 recommends intervals for the different monitoring conditions: 1 to 4 months for frequent monitoring, 4 to 12 months for moderate monitoring, and 12 to 24 months for infrequent monitoring.

Table 1. Guidance for Determining Whether Equipment Shall be Calibrated, Standardized, or Neither[16]**.**

		Probability That the Uncertainty of Measurement Could Exceed the Accuracy Requirement of the Measurement		
		Low	Moderate	High
Measurement's Influence on the Test Result	High	Standardize	Calibrate	Calibrate
	Moderate	Standardize	Standardize	Calibrate
	Low	Nothing	Standardize	Standardize

Table 2. Determining the Interval between Equipment Calibrations, Verification of Calibrations, Standardizations, and Checks[16]**.**

		Probability That Time or Usage Will Affect the Instrument/Device		
		Low	Moderate	High
Measurement's Influence on the Test Result	High	Monitoring (Moderate Risk)	Frequent Monitoring (High Risk)	Frequent Monitoring (High Risk)
	Moderate	Infrequent Monitoring (Low Risk)	Monitoring (Moderate Risk)	Frequent Monitoring (High Risk)
	Low	Infrequent Monitoring (Low Risk)	Infrequent Monitoring (Low Risk)	Monitoring (Moderate Risk)

AASHTO M156, Requirements for Mixing Plants for Hot-Mixed Hot-Laid Bituminous Paving Mixtures, specifies that, prior to delving into equipment requirements and calibration techniques, the scales utilized for material weighing in production or calibration must be certified in accordance with Certified Public Scales [17]. These scales need to undergo testing to maintain certification, with the frequency determined by the agency, upon relocation, or at least every six months. Similarly, weighing devices at the plant, such as hopper scales or weigh bridges, should be calibrated at a frequency parallel to that of the certified public scales. To facilitate the calibration process of weighing devices, the asphalt plant is required to always keep 10 certified 50-pound test weights on-site.

Apart from weight measurements, AASHTO M156 underscores the necessity of having individual cold feed bins for each aggregate size, RAP, and RAS. The standard also mandates the continuous monitoring of all equipment involved in the production process to prevent it from running empty. Furthermore, there is a requirement for interlocking all plant equipment to ensure that if one component ceases operation, production will come to a halt at all other feed points.

Documents from agencies were studied, encompassing standard specifications, special provisions, construction manuals, and test methods aimed at providing guidance on the quantity control at asphalt plants. Additionally, requirements and documentation concerning material acceptance and supply were examined. The critical aspects considered during the document review were categorized into two primary groups. For confirming the source of the supplied material, key elements included traceability, MSHA Individual Identification Number (MIIN), unique identification numbers for each mixture component, details of binder suppliers and product lots, agency witness of sampling, chain of custody, and records of plant calibration. Regarding the accuracy of material proportions supplied, key elements addressed encompassed equipment calibration and requirements, specialized equipment prerequisites for solids and liquids, plant control requirements, monitoring of plant controls, tolerances and alarms, and the verification of correct raw material moisture content in the plant controls.

Additional documents were sourced from equipment manufacturers, predominantly focusing on the operational manuals of various equipment. It's worth emphasizing that for low-dose liquids, manufacturers are mandated to ensure the precise performance of their products to obtain approval from agencies. Furthermore, insights from asphalt plant experts emphasized the importance of using equipment for its designated purpose, ensuring interlock mechanisms are maintained among all plant equipment, conducting regular calibrations with frequent calibration verification checks, and upholding well-organized record-keeping practices.

A crucial document outlining requirements for weighing and measuring devices is the National Institute of Standards and Technology (NIST) Handbook 44 [15]. Various chapters within NIST HB44 are dedicated to different plant weighing equipment, including scales, bulk weighing scales, belt conveyor scales, and liquid measuring devices. The handbook provides guidelines for scale designs, covering aspects such as calibration, maintenance, accuracy, and repeatability. Each scale is required to bear markings indicating its capacity, unit of measurement, manufacturer information, approval markings, and calibration markings. The load-receiving element is mandated to sustain the entire load in a single weighing measurement and transfer the weight to the weighing element. Weighing elements are categorized based on their accuracy classes in accordance with the scale division. As per the NIST Handbook 44 guidelines, a belt-conveyor scale must be equipped with a primary indicating element in the form of a master weight totalizer, along with a recording element and a rate of flow indicator and recorder [18]. An audio or visual signal shall be given when the rate of flow reaches or falls below 20% and when it equals or exceeds 100% of the scale's rated capacity. The weighing element should automatically combine belt travel with belt load to determine the weight of the material passing over the scale. A speed sensor and overload protection with a capacity of 150% of the rated belt capacity is needed. The marked information on the belt includes its rated capacity, scale division value, belt speed, load (pounds per foot), operational temperature range, and accuracy classification. Scales are classified based on accuracy or scale division, where a class 0.1 scale, for instance, can detect changes in weight in 0.1-unit increments. After installation, a belt-conveyor scale must undergo a minimum of two consecutive test runs under the same conditions at each flow rate, within a tolerance of 0.25% for class 0.25 and 0.1% for class 0.1.

As for liquid measuring devices, preventing air passage through the meter and valves is crucial [19]. These devices should incorporate a thermometer to measure temperature in both the liquid chamber and the meter's inlet or discharge line. One-way flow is mandated to prevent liquid diversion through multiple outlets simultaneously. Marking requirements include indicating the minimum and maximum working air pressure, and the minimum discharge rate should not exceed 20% of the maximum discharge rate. Devices with automatic temperature compensation should be marked to reflect volume adjustments at 60°F. Repeatability tests necessitate a minimum of three consecutive test drafts of similar size under controlled conditions to mitigate variations in temperature, pressure, and flow rate. Acceptable and maintenance tolerances vary by class and application, typically falling within the range of 0.2% to 1%.

Chapter 4: Analysis of Literature

Reviewing the key elements across different agencies and evaluating the best practices done per element enabled prioritizing potential procedures and suggesting some modifications to others. Table 3 compares attributes among different agencies. Subsequently, a ranking system was developed to compare methods. Reviewing agency documents led to an overall ranking of methods, highlighting gaps in the highest ranking of them. A tiered system was established with three levels (low, medium, and high), and corresponding points were assigned based on the level for each considered evaluation factor for evaluation criteria. The point distribution for each level was as follows: 1 point for low, 3 points for medium, and 5 points for high. As for the factors considered for evaluation, they included: measurement of material, measurement of quantity, measurement of proportion, applicability to different technologies, level of traceability, and level of effort required to obtain all the above. Only the level of effort had another distribution of points where 5 points were used for low, 3 points for medium, and 1 point for high level of effort. Points were tallied using a scoring approach, assigning rankings of 1 through 5 based on total points ranges (96-100, 92-96, 88-92, and 84-88 points). After assessing the various evaluation factors for all agencies, points were assigned based on each studied factor. A cumulative total of points was then calculated, and agencies were ranked according to their total sum. Public agencies 1 and 7 came in the first place with a total of 100 points, agencies 2 and 3 were ranked second with a total of 96 points, agencies 4 and 5 were third with a total of 92 points, and agency 6 came fourth with a total of 88 points.

Table 3. Comparison of Plant Key Elements for Different Agencies.

Attributes	Agency 1	Agency 2	Agency 3	Agency 4	Agency 5	Agency 6	Agency 7	Agency 8
Additives BOL/COC	X		X	X		X		X
Asphalt Binder BOL	X	X	X	X	X	X	X	
Asphalt Binder COC	X	X	X	X	X		X	X
Asphalt Metering Device	X	X	X		X		X	X
Belt-Conveyor Scale	X	X	X		X		X	X
Data Documents/Forms	X		X	X		X	X	
Equipment Calibration			X			X	X	X
Equipment Inspection	X	X	X	X	X	X	X	X
Equipment Verification	X	X		X			X	X
Hopper Scale	X	X	X	X			X	
Load-Out Systems	X				X		X	
Material Certification	X			X	X	X	X	X
Material Quality	X	X	X	X	X	X	X	X
Material Records	X	X	X	X	X	X	X	X
Mix Design APL/QPL	X	X	X	X	X	X	X	
Mix Design Submittals	X	X	X	X	X	X	X	X
Mixture Storage	X	X	X	X	X	X	X	X
Scale Certifications	X		X	X	X		X	X
Test Strips		X	X		X		X	X
Truck Delivery Ticket	X	X	X	X	X	X	X	
Vehicle Scale	X	X	X		X		X	

4.1 Quality Measures

Often materials that are used in asphalt mixtures are listed on an Approved Product List (APL). Once listed on a APL, a Bill of Lading (BOL) which arrives with every shipment of material specifies the material identification number from the APL, along with the quantity of supplied material, and the date. If a material is not yet part of an APL, agencies usually require contractors to send samples of the material to an independent 3rd party laboratory within a given period prior to production. For aggregates, the most pivotal role in proportioning the material at the asphalt plants is that of the moisture content.

The concept of updating the material moisture content (MM) to the plant moisture setting (PS) is of high importance. A demonstration of the difference in MM and PS against the binder content is discussed to highlight the importance of updating the PS according to the MM. Table 4 and Table 5 show the difference in binder content when the MM and PS differs. The MM shall be updated into the PS on regularly basis throughout the day.

Table 4. PS - MM vs Difference in Binder Content.

PS- MM (%)	Binder Content (%)		
	4.5%	5.5%	6.5%
	Difference in Binder Content (%)		
0	0.0	0.0	0.0
1	0.0	0.1	0.1
2	0.1	0.1	0.1
3	0.1	0.2	0.2
4	0.2	0.2	0.2
5	0.2	0.3	0.3

Table 5. AMC - PMS vs Difference in Binder Content.

MM - PS (%)	Binder Content (%)		
	4.5%	5.5%	6.5%
	Difference in Binder Content (%)		
0	0.0	0.0	0.0
1	0.0	0.1	0.1
2	0.1	0.1	0.1
3	0.1	0.2	0.2
4	0.2	0.2	0.3
5	0.2	0.3	0.3

One percent difference in MM and PS, results in 0.05% change in binder content. This number may not seem as significant, but for a 4,000 tons of asphalt mixture (production assumed as 500 tons per hour for 8 hours of production = 4,000 tons), the binder tonnage would differ by 2 tons for each 1% difference in moisture. In terms of cost, 4 tons difference in binder for a $520/ ton binder would result in $1,040 loss. If the MM was greater than the PS, then the mix is under-dosed in binder content, and if the PS was greater than the MM then the mix is over-dosed in binder content and both approaches are negatively affecting the performance of the mixture.

When dealing with RAP, a different analysis takes place where if AMC was greater than the PMS for RAP material then the control will reduce the virgin binder. Thus, moisture effects on virgin aggregates and RAP offset each other but don't necessarily cancel out as the proportions of virgin aggregates and RAP will differ. No matter how much the RAP would push the binder content down, the aggregates push it more up because of its higher portion in the mixture. It is also a function of the binder percent and the moisture content of the RAP which can be significantly different than the virgin aggregates.

Asphalt binder is commonly listed on an APL and then information as the quantity delivered, date of delivery, and special characteristics of the binder are present on a purchase order (PO) or bills of lading (BOL).

As for the mixture additives, many states allow the addition of RAP in percentage ranging from 15 to 30 percent. In 2021, 95% of the RAP generated was integrated in the asphalt mixtures [20]. Agency often mandate contractors submit a certification of the RAP source with binder and aggregates characteristics and properties. Some require no more than 30%

of RAP. Others limit sampling and testing of RAP to a frequency of one sample per a given tonnage, with a minimum of a given number of samples per stockpile.

4.2 Identification

In general, traceability allows for the confirmation of the history, location, or application of an item through documented identification. The traceability documents give information about the source and manufacturing details of a product. This concept is relevant to all types of businesses and facilities, with a specific focus on asphalt pavement plants, which are the main subject of interest in this report. Figure 13 shows the different traceability items required to be maintained.

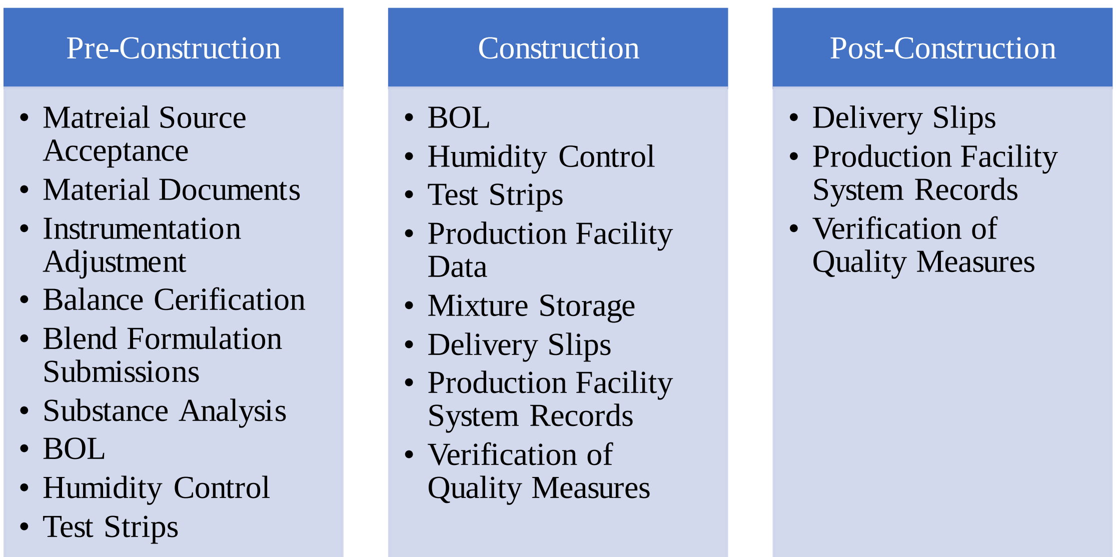

Figure 13. Identification Items Classified According to the Stages of Construction

Examples of identification items follow. For instance, material certifications which should be obtained before production confirm that the specified material used meets the specifications. A different definition for the material certification as it is not considered to be a material source acceptance, however it only states that the material testing done represents compliance with the specifications. This type of certification needs to be approved before the use of the material in the production of asphalt mixtures. If there is no access to the material certifications, then the material testing is performed at an agreed laboratory. In some cases, the engineer is responsible for testing the materials even if the material certification states compliance. In addition to the material certification, an aggregate source approval and a geological source approval for active aggregates are required. Agencies also mandate the distinct certification of each material shipment and requires a new certificate to be issued every 30 days or upon the use of a new material.

The material blend formulation submittals are another important identification item used in the quantity control of the asphalt mixtures produced. In the material blend formulation submittals, the proportion of each material used is identified. Sometimes these material blend formulation submittals don't have the final proportions of materials, since they may be subjected to adjustments based on production calibrations or upon the evaluation of the test strips. Agencies require the inclusion of information such as the individual aggregate gradation, source, specific gravity, percentage of each material, N design level, test results, distinct identification number, and the mix design date. Moreover, the material blend formulation for some agencies must include asphalt binder information that are used in the asphalt mixture productions as the binder grade PG, binder specific gravity at 60 and 77°F, mixing and compaction temperatures, percentage of liquid antistrip. Also, the inclusion of aggregate consensus properties, as well as the trial blends material and proportions incorporated to reach the final blend should be provided. Moreover, some agencies require the contractor to provide certain amounts of raw materials to be tested for compliance with the specifications.

Before initiating with the HMA production, materials to be used should be part of the material sources acceptance list (MSA) which refers to a list of materials that have received approval for use within a given agency. This list is developed as a result of a series of laboratory testing conducted by the agency. It is crucial that the materials proportions chosen by the contractor are sufficient to satisfy the specified volumetric requirements. Therefore, test strips are performed by the contractor to attain the optimum desired volumetrics. Consequently, the blend formation report is adjusted accordingly, and all the modifications are documented in log sheets. The adjusted blend formation is then entered into the asphalt production facilities, serving as the basis for validating proportions at asphalt facilities.

Delivery slips are considered identification items as well. These can be either hardcopy tickets or automated e-tickets. A printed delivery slip typically contains essential details such as a unique ticket number, facility identification number, lot/batch number, contract number, mix code, quantity of material (gross, net, tare), date, time, and a signature. Agencies should utilize an e-ticket system accessible through the web or mobile applications, ensuring operational capability even in the absence of internet connection. This minimizes the potential for data loss and enables contractors and engineers to approve or reject e-tickets and offer feedback. In contrast, some other agencies employ pre-numbered delivery slips, with one copy retained by the resident engineer overseeing material delivery. It imposes specific criteria for liquid materials, which include details such as the source location, type, grade, tank number, specific gravity at 60°F, and viscosity at 140 and 275°F. Other agencies incorporate trucks on a daily recorded data form with a weight ticket for each truck loaded with asphalt binder.

Bill of Lading documents are known to be a useful identification method used by primary source or terminal supplier to validate shipments and identify the certified lot of material along with quantity delivered. The material considered in a BOL includes materials such as asphalt binders, liquids (WMA, LAS, , etc.), aggregates, and additional mixture additives like fiber and ground tire rubber. Some agencies have specific requirements for BOLs for asphalt binders, including information like the shipment date, material type and grade, loaded quantity, loading temperature, delivery destination, flash point, specific gravity, and detailed information about any anti-strip additives.

Certificate of Compliance (COC), which is an official document or statement provided by the manufacturer, confirms that the materials comply with specified standards. This document involves essential details such as the primary source name, location, and actual test results. These certificates play a crucial role in confirming tanks of PG binder for use in various states. Some agencies require entries to include primary source name and location, refinery and crude source information, lot number, and actual test results. An additional COC is employed specifically for liquid antistrip, covering details such as signature and printed name, shipment number, material type, material specific gravity, refinery, consignee, destination, quantity, contact or purchase order number, and shipment date. In the case of each delivery to an asphalt plant, a sample must be sent indicating the liquid antistrip type, application rate, sample date, and contract number. Any modification to the material to be reported in the BOL or COC.

4.3 Measurements, Calibrations & Tolerances

Contemporary asphalt mixtures comprise diverse raw materials, encompassing natural and manufactured aggregates, RAP, RAS, virgin and modified asphalt binders, recycling agents, antistrip additives, warm mix asphalt (WMA) additives, fibers, ground tire rubber, polymers, plastics, mineral fillers, pelletized materials, and others. Despite their minimal doses, some materials, like chemical additives and lightweight substances, require precise controls, metering, and monitoring. Asphalt binder modifications involve introducing polymers, with both chemicals and binder modifications subject to introduction at asphalt terminals or plants. Handling heavy-weight solids involves cold-feed bins, conveyor belts, and chutes, while light-weight solids may utilize reverse-weight cold-feed bins or pneumatic conveyance. Liquid materials, such as asphalt binder, are conveyed through piping systems with volumetric or measured metered control. The focus of this research is on controlling quantities and proportions in asphalt materials, with batch plants offering simpler verification due to direct weight measurements, although challenges arise when blending materials, and continuous drum mix plants being the most used in the US.

4.3.1 Plant Inspection, Verification, and Calibration

To ensure accuracy, asphalt producers subject scales, continuous weigh systems, and meters to rigorous testing, with agencies overseeing or participating in these checks. For instance, some agencies require a qualified technician, capable of making necessary adjustments, to perform the required checks, with inspection records initiated by an independent qualified technician. Producers must certify proper calibration and accuracy of all scales and meters within a 90-calendar day interval, and engineers may request full access to plant components contributing to production at any time. Scale checks shall occur 60 days after an initial inspection, with periodic checks during production. Scales must be checked at the start of the paving season, upon plant relocation, and as determined by the engineer. A dynamic test is conducted, including assessing plant interlock systems, material leakage, specific gravity, batch lockout, and device functionality before accepting equipment accuracy. The process of recalibration of the loss-in-weight meter is as follows:

1. Include at least one complete system refill cycle during each calibration test run.

2. Operate the device in a normal run mode for 10 minutes immediately before starting the calibration process.

3. Isolate the scale system within the loss-in-weight feeder from surrounding vibration.

4. Check the scale system within the loss-in-weight feeder for accuracy before and after the calibration process. As well as, daily during mix production.

5. Use a minimum 15 minute or minimum 250 lbs. test run size for a dry ingredient delivery rate of less than 1 ton per hour.

6. Comply with the limits of Table 6, "Conveyor Scale Testing Extremes".

Table 6. Conveyor Scale Testing Extremes.

		Maximum Error		Test Size Minimum	Witness Scale		Testing Range
		Average	Individual		scale, max	grad, max	
AC Aggregate	Aggregate	1%	2%	3 min*	40 tonnes	10 Kg	30%, 65%, 100%
AC Aggregate	Dust	1%	2%	15 min	2.5 tonnes**	0.5 Kg	30%, 65%, 100%
Aggregate Antistrip		1%	2%	3 min*	40 tonnes	10 Kg	30%, 65%, 100%
Marinated Lime	Aggregate	1%	2%	3 min*	40 tonnes	10 Kg	30%, 65%, 100%
Marinated Lime	Lime	0.5%	1%	0.5 tonnes	2.5 tonnes	0.5 Kg	30%, 65%, 100%
Dry Lime	Aggregate	1%	2%	3 min*	40 tonnes	10 Kg	30%, 65%, 100%
Dry Lime	Lime	0.7%	1%	0.5 tonnes	2.5 tonnes	0.5 Kg	30%, 65%, 100%
All Others	>100 tph	1%	2%	3 min*	40 tonnes	10 Kg	30%, 65%, 100%
All Others	<100 tph	1%	2%	0.5 tonnes	2.5 tonnes	0.5 Kg	30%, 65%, 100%

* Use a 3 minute or longer calibration run unless the calibration rate exceeds 365 tonnes per hour.

** The witness scale size for baghouse dust will depend on the amount of material delivered during the 15-minute test run.

4.3.2 Cold Feed Bins

Cold feed bins measurements shall maintain an accuracy specified by each agency. The main goal is to ensure a uniform continuous flow of material with limit switches that go on when the flow is interrupted. Interlocking with the plant control is key in this case. The calibration of cold feed bin openings and belt speeds is conducted for each material (aggregate or RAP source or size) by allowing the system to operate at various bin openings and belt speeds, followed by weighing the material on a certified scale. This process establishes relationships linking bin opening and belt speed to the accurate measured weight of the specific material. To establish these relations, it is necessary to perform at least three runs per bin opening and three per belt speed. The allowable tolerance has an accuracy of ±1.0% of the actual material quantity for RAP and aggregate cold feed bins, and ± 0.5% for RAS. For fibers, the proportions shall stay in the limit of ±10% of the fibers proportion.

4.3.3 Belt Conveyor Scales

The system combines belt travel with belt load to calculate the weight of material passing over the scale. A belt sensor shall be mounted to detect if the belt is empty or loaded. Windshields and sunscreens may be required by the engineer at the weighing sections. For calibration of belt conveyors, agencies require the belt to run for 10 minutes empty and any weight recorded is considered an error. The conveyor belt is kept running for a specific period of time and then measurements are compared to an approved truck scale. Acceptance tolerance and maintenance tolerance are set as 0.5% and 1% of the test load. The test is carried out at 50 and 100% of the plant capacity.

4.3.4 Hopper Scales

The substitution method is adopted to test hopper scales, by using 25 kg test weights. These test weights are weighed by the hopper scales indicating any discrepancies in the scale. The tolerance is determined for automatic bulk weighing systems, where the acceptance and maintenance tolerances are 0.1% and 0.2% of the test loads, respectively. Acceptance tolerances are required when the hopper is installed for the first time, after relocation, or after rejection. A suspended hopper is offered for the small amounts of material to end up with a precise batch quantity.

4.3.5 Asphalt Metering Device

Volumetric measurements of asphalt binder are accomplished using a calibrated pump and tachometer or with a calibrated flow meter. Coriolis mass flow meters, providing direct mass reporting, simplify calibration verification and reported binder quantities. Agencies specify requirements for asphalt binder systems, necessitating a temperature-compensating meter and pump, allowing alternative systems with the engineer's approval. Automatic shutdown mechanisms and a meter capacity exceeding the batch's binder quantity by 15% are required, with control systems permitting locking at any dial setting. Calibration tests cover probable minimum and maximum asphalt output, adhering to accuracy stipulations of 0.1% of the theoretical total mix produced. 0.4% accuracy is required for the actual metered material, with liquid anti-strip additive integration governed by an approved in-line blending system. Agencies mandates batch plants to sample asphalt binder of 4-8% of capacity, and drum plants to sample 2.5-7%, with calibration procedures aligning with theoretical percentages. Asphalt binder measurement involves comparing net weight to determine volume, with a 1% accuracy for component materials and 0.4% for payment. Liquid anti-strip precision is gauged by comparing metered to measured weight, with a 5% allowable difference. Most agencies conduct an annual meter check, with additional checks mandated after each plant relocation.

4.3.6 Vehicle Scales

Similar to the hopper scales, vehicle scales are calibrated using the substitution method for annual inspections, new installations, and acceptance tolerances. The strain method is used for all other calibrations. The main difference between the two methods is that the substitution method allows loading material and then replacing it with test loads so that the difference between the two readings is the error. As for the strain method, a known test weight is added to an already loaded vehicle, and then check if the weight increases by the same test weight. Acceptance and maintenance tolerances are a function of the scale division in which they are 0.5d and 1d per 500d, respectively. Agencies require the availability of a recording device to report delivered HMA quantities printed on a ticket having the date, time, and weights (tare, gross, and net). Agencies also require the installation of tarps on all trucks as well as measuring the whole truck and trailers in a single draft.

4.4 Reporting Requirements

Another indication of an identification item is the daily recording of various operations at the asphalt plant. Agencies use the daily production facility records to keep track of the production process throughout the day. These records include details about the targeted values, the measured responses, the material inventories, the moisture measurements at different times, and the production rates. Some agencies mandate the recording of plant inspection details in which an asphalt plant production report is obtained daily with the above-mentioned detailed information. These daily reports ensure the accurate recording of items with an allowable tolerance of 1.0%. Those reports have an emphasis on mix design, production and placement tests, control charts, and thermal profiles.

Chapter 5: Findings: Practices and Instructions

Practices and instructions are suggested for six combinations of material types. Practices were identified to address each raw material type, dose levels, and feeder systems outlined in **Error! Reference source not found.**.

Table 7. Asphalt Plant Materials, Feed Types, and Control.

Material			
Solids	Heavy Weight	Coldfeed Bin / Belt Conveyor	Aggregates
			RAP
	Light Weight	Reverse Weigh Coldfeed Bin / Belt Conveyor	RAS
			GTR
		Various Feed Bins / Pneumatic	Fibers
			GTR
		Screw Auger / Silo-Reverse Weight Pod	Bag house fines
			Lime
			Mineral Filler
Liquids	High Volume	Volumetric: Pump & Tack Measured: Flow Meter & Reverse Weigh Vessel	Asphalt Binder
	Low Volume		LAS
			WMA

The following items are included in the practice descriptions:

- Plant Calibration
- Facility Information Records
- Plant Controls and Operations
- Materials Accounting
- Quality Assurance and Plant Control Reporting

It is acknowledged that different agencies may have distinct operational requirements. Furthermore, the nature and scale of a project influence the precision required in operations; larger projects demand more accuracy than smaller ones, making quantity control a relative aspect.

Quantity control operations considering differing agency and contractor capabilities and project sizes follow.

At each tier of quantity control, there exists an associated level of risk, with lower risks corresponding to more accurate and precise quantity control. The introduction of distinct levels is aimed at encouraging adherence to specified quantity control limitations, thereby fostering a standardized quantity control practice. The purpose is to establish a framework that promotes consistency and adherence to quantity control standards and mitigating risks.

In establishing the conditions for different risk levels, it is imperative to define the industry's prevailing methods as the minimum benchmark. In the realm of quantity control operations, not all procedures involve direct weighing of materials integrated into the production of asphalt mixtures at production facilities. Consequently, the standard operational control practices should be set as the minimum for quantity control methods. The typical control of operations, being the baseline, is associated with the highest risk.

A lower risk level can be considered when quantity control operations employ a more advanced approach than the industry standard, aiming to enhance overall quantity control. Ideally, the optimal quantity control operation involves weighing each proportion of material incorporated into the mixture. While this may not be entirely achievable with continuous mix drum plants that produce mixes continuously, efforts can be made to optimize the process as closely as possible to the pure weighing quantity control, thereby minimizing associated risks.

To enhance control over quantity measurements, it is imperative to segregate plant operations into two categories. Given the distinct characteristics and conveyance methods of solid and liquid materials, separating the operations for these two entities becomes crucial for effective quantity control.

5.1 Solids

Solids, being the biggest constituent in asphalt mixtures, need an accurate measurement of quantity control to help serve the intended performance of the asphalt mixture and to prevent the misuse of the funds allocated to this proportion of the material. Starting with the aggregates and RAP, the materials are first introduced into the cold feed bins with means of loads transferred from the stockpiles by trucks or loaders. At this stage, segregation of the material is as important as at previous stages since the loading of material in the cold feed bins can promote segregation. Also, the cold feed bins are to be equipped with screens to get rid of the oversized materials that are out of the specified gradation of aggregates, and that may get stuck at the bin openings and prevent the continuous flow of material through the bins. For RAP cold feed bins, they also shall be equipped with such screens to keep the clumps of material out of the bins.

Usually, 4 to 6 cold feed bins are used at the asphalt plant, each associated to an aggregate stockpile and separate bins are also available for RAP and RAS storage, respectively. Cold feed bins are designed with steep walls to prevent the material from sticking to the walls. Also, the cold feed bins are equipped with air cannons and vibrators to help prevent material, especially the wet fines from sticking to the walls of the cold feed bins. An enhanced control approach of the material flow is obtained by having limit switches or partial flow switches that would monitor the flow of material out of the cold feed bins and notify the plant controls if anything is not of proportion.

Now that all the quality measures are tackled, the quantity control of the aggregates leaving the cold feed bins are a function of the cold feed bin openings and the speed of the belt conveyors beneath it. The cold feed bin and the conveyor belt are calibrated by letting the belt conveyor run for a specified amount of time at a given gate opening and then measure the weight of the material. When comparing the measured weight and the calculated run of the material, calibration relations are established. Note that at least 3 runs per one belt speed are required to have a good representation of the calibration relations. Hence, the conveyor belt is directly related to the aggregates transferred from the cold feed bins. However, the conveyor belt also has some policies that need to be followed for its optimal function. First the belt speed shall be from 20 to 80% of its maximum speed, and it shall be integrated with the plant controls in order to regulate the speed based on the production needs. Aggregates are tested for moisture content by taking samples off the conveyor belt or the cold feed bin, and they can also be taken using probe or nuclear gauge. Moisture measurements shall be at least taken twice a day, at the beginning of production and at any other time indicated by the engineer. Updating the plant setting by the actual moisture is crucial because any difference in the moisture is directly related to the amount of asphalt binder added to the mixture. Lower moisture setting than real measurements will result in adding binder content more than needed and consequently the performance of the asphalt mixture changes.

Belt scrapers are also essential to clean the conveyor belt of any wet fines stuck to the belt and prevent the re-weighing of this already weighed material. Windshields are designed to prevent the loss of fine materials and to accurately measure the weight of aggregates on the weigh bridge. An enhanced control is evident by installing alarms to monitor the desired belt speed for any deviation. For RAP, an electronic weighing belt is used to monitor the flow of RAP material.

It's noteworthy that recalibrating the cold feed bin is essential whenever there is a change in the aggregate source or stockpile due to variations in material specific gravity between sources or sizes. Volumetric feed systems have drawbacks, including the need for recalibration when the aggregate changes, as density and flow characteristics may vary. Moreover, since a tachometer controls the belt speed, the plant controls may inaccurately assume the correct amount of aggregate is being discharged even if the bin is empty. Weight-controlled cold feed bins address these issues, reducing the risk of inadequate material addition to the mix. For RAP, a verification testing is required once every 1,000 tons of materials with a minimum of 6 samples taken for stockpile.

Blending of two RAP sources, can be done with a front-end loader but consistency would not be a good as with a mixing unit. A drum mixer plant used to blend one material through the virgin bin system and the other through the RAP bin using two belt scales is a positive method, but costly. Another approach is to have a separate plant only for blending of material, but again this would be inefficient in terms of funds used. The choice of blending method depends on factors such as material characteristics, available equipment, and the desired level of blending consistency to minimize risks and ensure uniformity in the final asphalt mixture.

Enhanced blending approaches are comprised in having separate bins for each RAP source and utilizing a weigh conveyor belt for each RAP source providing accurate measurements and minimized risk. Alternatively, a single weigh conveyor belt can be installed under one RAP source, with a collector weighing belt subtracting the weight of the first RAP source to calculate the weight of the second RAP source. Another approach can be by mounting the RAP or RAS bins on load cells and use the approach of reverse weighing when calculating the amount of material added from each bin. These are different approaches that would minimize the inconsistency of the blended mixture and consequently minimize the blending risk.

For other solid materials that constitute smaller portions of asphalt mixtures, various techniques can be employed to introduce them into the mixture. They can be introduced using a screw auger or a pneumatic conveyor, or it even can be reverse weigh cold feed bin. The easiest approach is the reverse weigh cold feed bin and conveyor belt, since everything is the exact same as mentioned before except for the weighing process where the bin is mounted on top of load cells and as the material goes out of the cold feed bin, the weight is measured reversely. This measurement is precise since it is a measurement of weight and not volumetrics. The only thing needed here is to control the opening valve of the tank.

Ground tire rubber (GTR) is an example of material in which these conveyance methods are used for. RAS is another that is similar to RAP, but due to its high binder content and very lose doses used, precise control of it is needed. The moisture content for the RAP is similar to that of the aggregates and RAP where samples need to be taken prior to production and at other times during production. As for the calibration process for this type of feed involves allowing the bin to dispense a specific amount of material for a designated period, followed by measuring the weight of the added material. Subtracting the bin weight after the material was added from the bin weight before the material was added and comparing it to the intended amount of material deems precise calibration.

Pneumatically conveyed materials are another feed method used to convey small quantities of solid materials into the asphalt mixture. An example of this material is the aramid fibers. The pneumatic systems are widely used and known for their precise control over the discharge of the materials from the bin. The pneumatic systems use air pressure to transport material from the bin to various stages of the production process. Pneumatic feed bins and conveyors are equipped with flexible hoses for both inlet and discharge connections and are usually used to transfer material over relatively short distances in the plant. An automated control system is employed to enable precise monitoring and adjustment of the pneumatic feed bin's operations. This system utilizes PLC technology to ensure accurate control and automation of the pneumatic feed bin's functions. Importantly, there is an interlock feature with the overall plant control system, guaranteeing the addition of correct proportions of materials during the production process. A log data system is implemented to record essential factors and monitor the pressure and the material flow.

Pneumatic feeds are equipped with an easy point where sampling can take place to test material properties and moisture content. Similar to all moisture content measurements, the material shall have the same frequency of moisture content measurements as other materials. This approach ensures that moisture content adjustments are precisely reflected in the plant controls, upholding the integrity of mix designs and meeting quality standards. The calibration of pneumatic feed bins involves establishing calibration relations at different speed settings by measuring the quantity of material discharged over a specific period. Multiple runs at different speed settings should be conducted to validate the calibration, ensuring consistent material flow that aligns with desired specifications.

Lastly, for small quantities of solids, the last feeding method uses a screw auger. A screw auger is a circular or U-shaped tube with helical screw blade that rotates to move material from one point to another. To have an accurate feed system, a silo is utilized to store the material at first, and then convey them into the screw auger. An example of these materials are bag house fines, mineral fillers, and lime. Baghouse fines are directed into the silo from the top, and the silo is equipped with load cells to measure the weight of the material. The feeding of this material into the asphalt mixture is regulated through a tachometer that gauges the material output at the base of the silo. A variable-speed screw auger then conveys the material back into the drum at the point where asphalt binder is introduced to the mix, effectively controlling the quantity of dust or fine materials incorporated. Like all equipment in the plant, the silos are interlocked with the plant controls. To enhance control and reduce risks, a negative weighing pod suspended beneath the silo on load cells can be employed. The load cells capture and output the material's weight, facilitating the establishment of an actual flow rate.

The feeding system is integrated with the plant's central control system, which could be a PLC or computer-based system. This integration enables automatic control of the feed rate based on the specific mix design requirements. To prevent the ingress of air back into the baghouse and ensure a consistent flow of fines, airlocks, often in the form of rotary valves, are commonly installed at the outlet of the storage silo or hopper. In some plants, a return system is implemented, conveying fines directly from the baghouse back to the mixing drum. This return system is equipped with dampers that can be controlled to adjust the quantity of fines reintroduced into the mix. The calibration procedure involves running the screw auger at specified speeds for specific durations and measuring the transferred weight. Calibration relations are established by comparing the measured weight with the weight recorded by the weigh pods.

5.2 Liquids

Liquids make up only a small portion of asphalt mixture weight, but the quantity control is an essential aspect to adhere to since liquids are the most expensive materials incorporated in the asphalt mixture production process. Moreover, the percentages of liquids added to the asphalt mixture can alter the performance of the asphalt mixture drastically. No matter how much the proportion of liquid is, incorporated in the asphalt mixture, the feeding systems are the same except that they are scaled up or down depending on the proportions needed. The process that the asphalt binder follows at production facilities is constructed in a way to maintain all the asphalt binder properties especially that of the mixing temperature. To maintain this desired mixing temperature of the asphalt binder, the asphalt plants shall be equipped with qualified storage tanks. Those storage tanks are required to have efficient heating systems, such as hot oil systems or electric heaters. Asphalt tanks are either vertically or horizontally oriented tanks with agitation requirements such as the mechanical agitators, primarily to prevent the settle down and the separation of the asphalt binder. Pumps used to transfer the asphalt binder in-line systems to the pugmill, or drum shall also be insulated to preserve the asphalt binder desired temperature. Minimal piping lengths and minimal bends in the pipes used to transport the asphalt binder, allow optimal accuracy of the flowmeter measurements. A flowmeter or tachometer is used to monitor the addition of the material into the mixing chamber. Flow meters and pumps are calibrated by allowing the asphalt binder to flow into a truck or a calibration tank for a specific time and then measure the weight of the added material. Interlock with the plant control is crucial to add the desired amount of binder needed and to cease production if any material in the plant stopped working. For the automation and monitoring of asphalt binders, PLC systems are used.

An enhanced control approach involves the use of a Coriolis flow meter, recommended for measuring asphalt binder. The Coriolis mass flow meter relies on the Coriolis effect, which is the apparent deflection of the material's path, independent of density, temperature, and viscosity, providing a more accurate measurement. The Coriolis flow meter consists of a flow tube subjected to vibrations that cause oscillations, detected by sensors. The Coriolis effect induces a phase shift in the tube's oscillation, proportional to the mass flow rate of the fluid. Electrodynamic sensors are commonly used for detecting this displacement, offering high accuracy and reliability.

Liquid Anti-Strip (LAS) agent is introduced into the asphalt mixture by means of blending it with the asphalt binder before its introduction into the asphalt mixer. The LAS is introduced by an in-line system with the asphalt binder where a meter is used to monitor the accurate addition of material. Similar piping system as that of the asphalt binder is used to add the LAS into the asphalt mixture. Moreover, similar calibration methods as the asphalt binder are used for the accurate proportioning of LAS material into the asphalt mixture. Note that this blending method is used for blending LAS with asphalt binder at the plant. The mixing time that the whole asphalt mixture needs is required to have sufficient time for the complete mixing and coating of the asphalt binder and LAS material added.

5.3 Asphalt Mixtures

After discussing the solids and liquids that are parts of the asphalt mixture production process and their way of conveyance into the asphalt mixture with the calibration operations followed and the corresponding equipment of operations, there are some regulations that needs to be applied to the asphalt mixture as a whole. For the frequency of calibration of the different equipment used, the agency usually states how frequent the equipment shall be calibrated depending on the intended use and the time an equipment can run without having to recalibrate it. Also, in addition to the agency’s requirement, if an equipment fall out of tolerance it should be recalibrated, and if the equipment is relocated or at the beginning of each new project.

An identification number is required for each, and every material and mixture involved in the production process since it is easier to reconcile the lot or batch of material shipped on a specific date from the sole identification number of the material. Identification of all items can help in the process of understanding production problems.

Plant records are essential documents that can include information about all the material incorporated in the production of asphalt mixtures. The proportions of materials are also evident in the plant records, which helps in the quantity control of the materials and mixtures. Those records may have the total tonnage used in one day of production, and production rates of the plant during that specific date with the rate of production of the raw materials. That information should be made available to be printed and shared daily. Also, it is needed to have a backup of it and to keep it in the records as long as the project is running.

Chapter 6: Recommendation

Recommendations follow that an agency or plant owner might follow when considering implementing some or all the practices and instructions identified above. The first recommendation is to compare the current plant equipment, monitoring, and controls to what the latest technology is for the plant type. There may be opportunities to update all three or just one and in the case of relatively new plants maybe none. Conduct an assessment of cost and benefit of implementing change(s). Some could be low cost and high benefit, while others could be higher in cost. It is also recommended that the effectiveness of changes be evaluated. Examples could include the entire spectrum of the implemented instructions, from material identification to calibration processes, moisture management, and plant record requirements. Continuous improvement is integral to this approach, ensuring that the practice remains adaptive and responsive to the dynamic nature of asphalt plant operations. This iterative process is suggested to enhance the overall robustness and applicability of the practice.

Chapter 7: References

[1] "Asphalt Pavement Association of Oregon. (2003). 'Warm Mix Asphalt Shows Promise for Cost Reduction, Environmental Benefit.'".

[2] "FHWASo-BOO4 am Park, lllb-, far ih. Faded-kr*ay."

[3] "'Practices and Lessons Learned When Using Reclaimed Asphalt Shingles in Asphalt Mixtures,' Federal Highway Administration, Technical Brief, FHWA-HIF-22-001.".

[4] "https://enginemechanics.tpub.com/14080/css/Figure-8-6-Calibration-Chart-Gradation-Feeder-Gates-168.htm".

[5] J. Dronette and T. Pendergras, "Key Criteria for Choosing a Conveyor Belt Scale for Mining Applications."

[6] K. Zhang, H. Zhang, and Q. Song, "Research on the Influence of Weighing Accuracy Caused by the Position of Tension Wheel on the Electronic Belt-Conveyor Scale," in *IOP Conference Series: Earth and Environmental Science*, Institute of Physics Publishing, Jan. 2018. doi: 10.1088/1755-1315/108/2/022059.

[7] R. C. West and P. Turner, "UTILIZATION OF AUTOMATION AND REAL-TIME TESTING TO IMPROVE QC/QA PROCEDURES FOR HOT MIX ASPHALT," 2007.

[8] "https://cwmfcorp.com/asphalt-plant-components/conveyor-belt-system/".

[9] "https://almix.com/liquid-asphalt-storage".

[10] T. W. Kennedy, J. A. Scherocman, and M. Tahmoressi, "lF 4. Title ond Subtitle DRUM MIX PLANTS-EQUIPMENT AND OPERATIONS 7. Authorls)."

[11] Olsen and Lief O, "Introduction to Liquid Flow Metering and Calibration of Liquid Flowmeters."

[12] "Introduction Accurate measurement saves money."

[13] M. Anklin, W. Drahm, and A. Rieder, "Coriolis mass flowmeters: Overview of the current state of the art and latest research," *Flow Measurement and Instrumentation*, vol. 17, no. 6, pp. 317–323, Dec. 2006, doi: 10.1016/j.flowmeasinst.2006.07.004.

[14] M. Henry, "Advances in Coriolis Mass Flow Metering Research and Technology," *R. Mercado*.

[15] "• Plache, K. O. 'Coriolis/gyroscopic flow meters', ASME 77-WA/ FM-4, 1977 (Also Australian Process Engineering, Vol. 6, No. 9, pp. 47-51, Sept. 1978) (Also Mechanical Engineering, March 1979)".

[16] "AASHTO-R61 Establishing Requirements for Equipment Calibrations, Standardizations, and Checks," 2020.

[17] "AASHTO-M156 Requirements for Mixing Plants for Hot-Mixed Hot-Laid Bituminous Paving Mixtures," 2021.

[18] J. W. Barton, S. L. Bowers, T. G. Butcher, R. A. Harshman, G. D. Lee, and L. Warfield, "Specifications, Tolerances, and Other Technical Requirements for Weighing and Measuring Devices - Belt-Conveyor Scale," Gaithersburg, MD, Nov. 2021. doi: 10.6028/NIST.HB.44-2022.

[19] J. W. Barton, S. L. Bowers, T. G. Butcher, R. A. Harshman, G. D. Lee, and L. Warfield, "Specifications, Tolerances, and Other Technical Requirements for Weighing and Measuring Devices - Liquid Measuring Device," Gaithersburg, MD, Nov. 2021. doi: 10.6028/NIST.HB.44-2022.

[20] B. A. Williams, J. Richard Willis, and J. Shacat, "Asphalt Pavement Industry Survey on Recycled Materials and Warm-Mix Asphalt Usage 2021 Information Series 138 12th Annual Survey," 2016.