Towards Developing a National Guidelines in Design, Implementation, and Maintenance of Pavement Instrumentation Systems in Canada

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ABSTRACT

With the recent evolutions of Mechanistic-Empirical (M-E) pavement design methods in Canada, there is an ever-increasing demand for measuring and monitoring of key structural and environmental parameters using turnkey pavement instrumentation solutions. However, the effectiveness of such experiments can be challenged if appropriate and reliable systems are not used.

This paper presents a summary of common evaluation criteria and important site factors for consideration depending on the principal problems under study. The characteristics and benefits of various innovative technologies that are deployed for pavement instrumentation are discussed. The paper aims to offer a methodological and decision-based approach in design and implementation of pavement instrumentation programs.

This is a practical paper based on field and authors experience related to design, execution, and maintenance of heavily instrumented pavement structures. Details provided in this paper will provide a roadmap required in developing a national-level guideline that is much required for Canadian pavement industry in transferring some of the roadway sections into a data collection hub. All information and guidelines provided in this paper can be further aggregated into a decision-making approach on how essentially “smart pavements” can be constructed and maintained over intended design years, and how such pavements can help transportation agencies in their informed decision-making concerning material selection and construction practice.

1. INTRODUCTION

The main objective of this paper is to present state-of-the-art methodologies for in-situ evaluation of pavement materials and their performance through real-time monitoring of substrates under typical traffic and local environmental conditions. It aims to provide guidance for the instrumentation of roadway test sections, monitoring, data collection and processing, preventative maintenance, and operation for transportation agencies and departments in Canada. As a matter of fact, the existing methods are known to be behind the time, relatively inconsistent, and therefore could be improved by adopting new guidelines focused on better consistency with monitoring campaigns, efficient data processing, and enhanced flexibility, in view of future needs. As such, expanding network monitoring could offers more flexibility and coordination around real-time information management. This aspect combined with intelligence to determine next steps and ability to coordinate and adjust, roadways become smart.

Likewise, as sufficient data becomes available with time, calibrated performance prediction models for use in mechanistic-empirical (M-E) design can be developed and leverage cloud computing for scalability. The current M-E design approach incorporates the computation of pavement structural responses (deflections, stresses, strains) within the layers using physical models. The correlation between these responses and the pavement performance is given by the empirical component which heavily rely on evaluating different construction-related variables and pavement performance with realistic results to assist decision makers through data-driven insights.

The success of any instrumentation fieldwork in satisfying the project objectives depends on the quality of planning and design of the field experiments, preventative maintenance, and the effectiveness of its implementation [1]. The preliminary design of a field experiment includes three stages named; a) Planning and design; b) Construction; and c) Performance monitoring [1].

1.1. Scope and Objectives

The paper's primary objective is to present a framework needed to capture the effect of temporal variations in critical pavement response and in-situ material properties due to the direct and indirect effects of temperature, moisture, and freeze/thaw cycles. It highlights the necessary stages for evaluating different construction-related variables and pavement performance via in-situ measurements. It is intended to serve as a resource for identifying and evaluating good practices that may benefit the public infrastructures in Canada.

2. SITING AND INSTRUMENTATION NEEDS

2.1. Site Selection

The candidate instrumentation site should consider a number of variables associated with the type of pavement structure, construction materials, traffic and history of performance distresses. Pavement test sections should be selected given their different structures, unique traffic patterns and weather conditions. The experiment is sought to prove the technical viability of an innovation compared with conventional alternatives. In general, these sections would provide relatively quick and cost-efficient insights into the performance of innovative techniques under evaluation by the road agency or owner. Ideally, a control section built with conventional materials, and or, technique shall be constructed for the sake of comparison. As previously mentioned, the purpose for monitoring these test sections is to observe the performance affected by a specific design feature including, but not limited to, the asphalt mixture type and thickness. Hence, it is clearly recognized that in some cases, test site results would take long to realize, while the insights offered will be often valuable.

While selecting the location of the instrumented site, it is crucial that the outside factors remain as constant as possible between the control and test section. External factors such as traffic, subgrade soil and drainage condition are among the most critical items for consideration. The length of experimental sections will depend on the investigation type and the method of construction. Each experimental section should only include one independent variable for testing at each individual cell or panel which is typically around 10-20 m in length.

It is also imperative that the minimum length of these experimental sections should be compatible with the frequency of thickness adjustments that can reasonably be achieved by the paving machine. Clearly, site locations close to a weather station, with uniform pavement structure, and detailed traffic data are of higher priority for experimental studies. Such sections can be selected to match SHRP, or LTPP pavement section or weather stations used for MEPDG or AASHTO M320 PGAC selection.

Instrumenting a new full-depth construction pavement is recommended as the sensors can be installed during construction. However, retrofitting instrumentation into existing roadways can be relatively more difficult to navigate during road repair or utility repair, and or, replacement. Precautions should be taken to ensure that the performance of the instrumented section(s) does not dramatically deviate from the surrounding or existing road structures. Unless for safety, structural, or other immediate reasons, performing future pavement rehabilitation should be avoided or delayed for instrumented sections.

2.2. Instrumentation Needs

To design an effective and economical pavement monitoring system, one should consider addressing both the structural and environmental response of the pavement as well as the atmospheric data [3]. The type and arrangement of pavement layers are of utmost importance when determining the type of instrumentation to be used. It is obvious that adopting reliable and durable sensors which remain operational over the intended monitoring period is key to the success of the project.

The selected sensors and data acquisition system should be capable of capturing the response of the pavement under dynamic loading conditions. These sensors could be embedded within the pavement structure as shown in Figure 1. This is to ensure that in-motion stress, strain, and deformations under the action of traffic loading as well as the static readings associated with the build-up of permanent deformation with time are accurately measured. Furthermore, the equipment installed at the site should include instrumentation to measure temperature, moisture, frost depth, and depth to water table. This is mainly accomplished by installing thermistor temperature sensor strings in order to measure the temperature gradient through the pavement and into the subgrade.

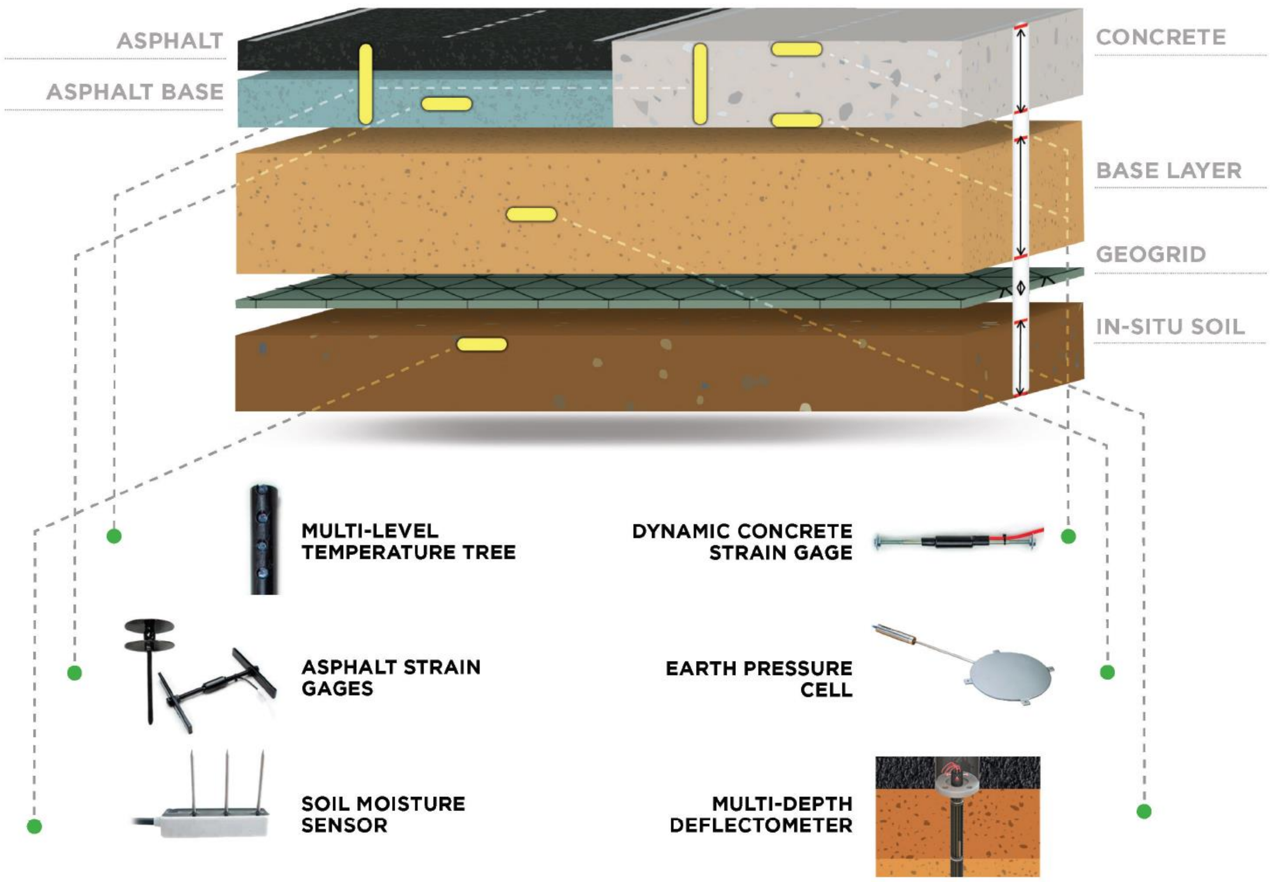

Figure 1: An Example of Different Pavement Instruments [2]

With respect to moisture, Time-Domain Reflectometry (TDR) or high frequency dielectric probes are among the most common sensors for determining soil volumetric water content. A single suite of atmospheric instruments is also recommended, data can be extrapolated from a nearby weather station, or atmospheric instruments could be deployed at the pavement monitoring system. The planning process should consider leveraging an existing weather station that would provide representative climate data.

The weather station should satisfy World Meteorological Organization (WMO) guidelines with respect to siting and instrumentation arrangement and installation.

3. MEASUREMENT SYSTEM (MS) OVERVIEW

To ensure practical and implementable Measuring System (MS), durable and flexible programmable dataloggers need to be used. Such datalogger(s) shown in Figure 2 can be powered with both chargeable battery and AC source, which can operate over a wide range of temperature are recommended. Likewise, it is recommended to consider both high-speed and low-speed dataloggers for the measurement system to facilitate the frequency response of suggested sensor types and intended use. The dataloggers are responsible to accommodate interfacing requirements of different sensor types, sensor sampling, recording and reporting of measurements used in the project.

Figure 2: Example of a Terminal Nodes, Data Logger, and Cabinet Arrangements [2]

A high-speed datalogger is suggested to monitor high frequency responses such as in-motion structural responses (for example stress and strain, and deformation) from full bridge strain gauges, earth pressure cells. The number of highspeed dataloggers would be dependent of the number of sensors to be deployed. In addition, the high-speed datalogger should have the capability to measure all sensors concurrently to minimize the temporal variance between connected sensors when measurements are conducted. A low-speed datalogger is suggested to monitor static environmental responses from embedded thermistors, water content reflectometers, and atmospheric sensors if applicable.

3.1.Remote Processing Unit (RPU)

The Remote Processing Unit (RPU) houses all ancillary components that make up the data acquisition system such as the dataloggers, power distribution system, uninterruptable power supply, sensor terminations, and telemetry.

Pavement monitoring systems process and analyse large data streams retrieved from various sensors. Such systems enable continuous monitoring of pavement by sensing and transmitting measurements such as stress, strain, deformation, temperature and moisture to the data centre. Hence, the system should allow for communicating remotely with different types of sensors either to download the data, and or, remote maintenance monitoring to timely adjust different functional and operating programs for on-site dataloggers.

Data types referred to as “static measurements”, such as temperature and water content will be collected via low-speed data logger. On the other hand, “dynamic measurements” such as pressure and strain will be collected via high-speed data logger. In the assembled data acquisition system, consideration should be given to the type and number of sensors fitted in the various pavement layers (asphalt concrete, granular base, and native soil) in the planning and design process given this may impact the size of the enclosure and power demands. This may impact footing size to mount the enclosure.

The RPU design should consider two independent grounding systems (i.e. Alternating Current (AC) grounding and equipment grounding), should operate from a clean Direct Current (DC) power source to mitigate AC bleed or ripple injection into the measurement system, and panel layout should adhere to best practices to mitigate electromagnetic interference (EMI) between the power sources and various sensor signals as this could impact analog measurements. Figure 1 shows the master plan and communication links that should be prepared prior to the beginning of construction.

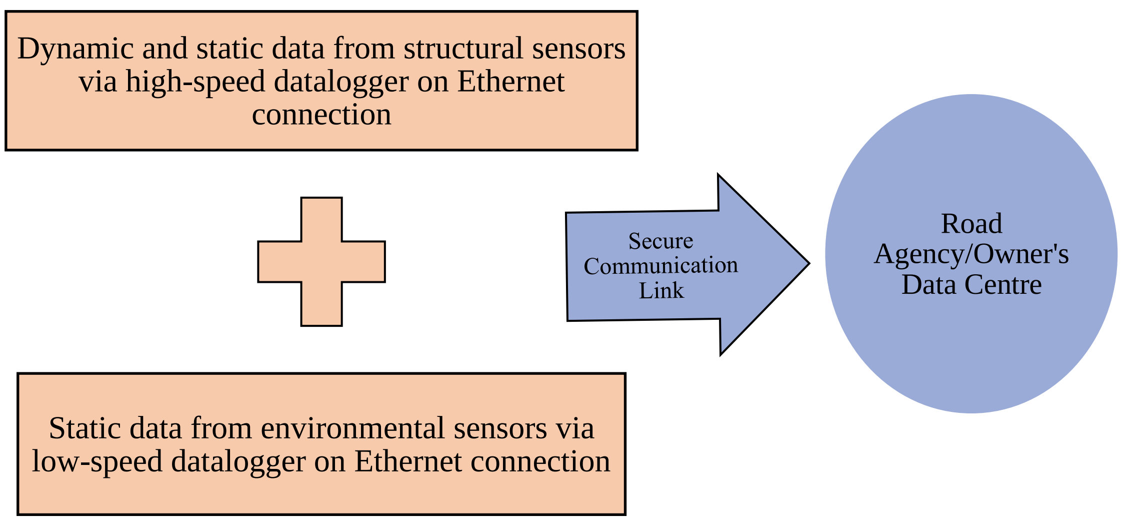

Figure 1: Instrumentation Master Plan and Communication Link

3.2. Power & Telemetry

An adequate, clean, and stable power source is essential for powering and establishing communication between sensors, different dataloggers, system processing software, and telemetry to a data center. An AC power source is recommended, the RPU design should include an Uninterruptible Power Source (UPS), and appropriate surge and transient protection. The UPS acts both as a power backup, should an interruption occur with the AC power source, and it regenerates isolated and clean power.

System autonomy (i.e. duration the UPS will keep the system powered when an AC power interruption occurs) should consider typical response times to resolve power interruptions but a suggested autonomy is at least 24 to 48-hours. System wiring and terminations should utilize DIN rails and terminal blocks, it is suggested to avoid using wall adapters to power ancillary components, and use of low operating temperature DC switching power supplies is encouraged. Solar power could be considered if the candidate site does not have an AC power source in proximity or it is unfeasible to source one. However, the candidate site should have suitable area to accommodate the battery bank and solar panel array if solar power is being considered during the planning and design process.

The telemetry method between the RPU and data center can vary based on site constraints and amount of data to be transmitted. The most convenient and recommended method is wireless by leveraging cellular networks with 5G capabilities given the amount of data to be transmitted. 5G supports broadband communication and is significantly faster than 4G, delivering up to 20 Gbps peak data rates and more than 100 Mbps average data rates. The alternative method recommended is a wired (copper or fiber) broadband connection with suitable throughput to accommodate the volume of data to be transmitted.

3.3. Instruments

Although site properties could vary site to site, the recommended core suite of sensors and minimum specifications to capture minimalistic behaviours of pavement structures in Canada are outline in Table 1.

Success of the instrumentation design relies on understanding of dataloggers voltage requirements, the type of sensors, whether the sensor requires an excitation voltage, and their input and output voltages (i.e. the majority of the sensors have voltage input and output), the sensor measurement range, the sensor’s operating mechanism and response, sensor’s compatibility with the data acquisition system and other limitations related to the surrounding environment and influences.

In addition, the manufacturer’s specifications related to input, output and capacity should be examined and considered in the selection process and respected during installation.

Table 1 Sensors & Minimum Specifications

Class	Sensor	Parameter	Accuracy	Range	
				Operating	Survival
Common Core Sensors					
Atmospherics	Thermistor	Air Temperature	±0.5°C	-40 to +40°C	-40 to +40°C
	Capacitance	Relative Humidity Dew-Point[4]	±2% ±0.5°C	0 to 100% -30 to +30°C	0 to 100% -30 to +30°C
	Anemometer (Ultrasonic or Mechanical)	Wind Speed Wind Gust Wind Direction	±1.0 m/s ±1.0 m/s ±5°	1 to 60 m/s <80 m/s 0 to 360	-40 to +40°C -40 to +40°C -40 to +40°C
Sub-Surface	Vertical Strain Gauge[1]	Vertical Strain	2 mV/V @ 1,500 μstrain	-40 to +50°C	-30 to +200°C
	Horizontal Strain Gauge[1]	Horizontal Strain	2 mV/V @ 1,500 μstrain	-40 to +50°C	-30 to +200°C
	Earth Pressure Cell[1]	Stress	0.15% F.S.	-40 to +50°C	-30 to +50°C
	Capacitance or Time-Domain Reflectometry	Volumetric Water Content Bulk Electrical Conductivity	±0.001 m^3/m^3 ±8% F.S.	0 to 1 m^3/m^3 0 to 20k μS/cm	-30 to +40°C
	Thermistor[3]	Temperature	±0.2°C	-30 to +30°C	-30 to +30°C
Optional Sensors					
Atmospherics	Pyranometer	Incoming Radiation Outgoing Radiation	±3% ±3%	0 to 1,500 W/m^2 0 to 1,500 W/m^2	-40 to +40°C -40 to +40°C
	Precipitation Gauge	Rate	±1%	0 to +40°C	-40 to +40°C
	Network Camera	Visual Images	≥1080p	-40 to +40°C	-40 to +40°C
Sub-Surface	Radiometric Potentiometer[3]	Deformation	<1% F.S.	-40 to +50°C	-40 to +80°C
Pavement	Quartz[2]	Axle Load	±1% F.S.	-40 to +50°C	-40 to +80°C

Notes: [1]*High-speed sampling to capture dynamic response,* [2]*Weigh-in-Motion (WMI) sensor for event-based sampling.* [3]*Multi-depth sensor for subgrade profiling.* [4]*Requires air temperature and relative humidity to derive dew-point or hygristor sensor. An air temperature and humidity probe are commonly used today.*

3.4. Instrumentation Suite Redundancy

Assessing the level of redundancy in the instrumentation suite is an important step in the planning and design process. In fact, significant environmental changes and traffic repetitions can impact the longevity of the installed sensors. Accordingly, one should take into account a certain level of redundancy in the instrumentation plan in order to compensate for these possible sensor failures. It has been frequently found that, replication of sensors at different locations in a test section is considerably helpful dealing with this matter. Thus, it is encouraged to adopt system redundancy specifically for structural sensors to be positioned along the wheel paths of the outer lane (slow lane). Although it is intuitively credible to incorporate a high level of redundancy and replication, increased resources with respect to cost of sensors, installation time and monitoring effort would be required. For this reason, an instrumentation plan should assume a degree of replication through each section.

3.5. Sampling and Reporting Scheme

In general, the sampling and reporting scheme should be tailored to the specific features of the project. For test sites involving the evaluation of dynamic behaviour of asphalt mixtures in a flexible pavement; the following should be considered for two main scenarios:

1. **Non-controlled actual traffic (event-based)** - impact of truck loading immediately after the construction, during extreme operational temperature when surface temperature is as high as the upper temperature of climatic Performance Graded Asphalt Cement (PGAC), or even recommended to consider one grade above upper PGAC, during thawing season and after rainstorm event.
2. **For controlled vehicle testing (one or twice a year)** - impact of truck load level, axle configuration, speed, tire type and inflation pressure.

It should be noted that continuous sampling would likely produce an overwhelming amount of data particularly during peak traffic periods and may be difficult to correlate to a specific event. As a result, event-based sampling (i.e. triggered with one sensor or with Weigh in Motion system, WIM) may seem viable under certain circumstances mentioned above.

For test sites involving the evaluation of static behaviour of asphalt mixtures in a flexible pavement; followings should be considered for two main scenarios:

1) Static data readings which are associated with build-up of permanent deformation over time and under the cumulative action of traffic loading.
2) Diurnal and annual thermally-induced strains at the bottom of the HMA layer.

Apart from evaluating the dynamic behaviour of the HMA, it is encouraged to also investigate how the load and deformation is transferred to the backfill layers of the pavement structure. This process involves measuring temperature and moisture conditions to conduct sensitivity analyses of load response at various moisture states of unbound aggregate and soil materials.

The frequency of sampling will depend on the type of measurement. Sampling rates will be computed and incorporated in the computer programs of the data-logger, taking into account anticipated traffic characteristics and the capacity of the system. Collection of dynamic pavement response involves high-speed data collection rates and if required, the presence of an engineer or qualified personnel at the site. However, static data from sensors may need to be collected over several years at a low-speed sampling rate.

3.6. Instrumentation Layout

A failure rate is recommended to be established for each instrument. This failure rate should be at least a function of winter severity, sensor durability, and traffic loads [4]. Based on the experience of the authors experience with instrumentation and literature search, a failure rate of 50% in a full-scale installation is probable. This requires the layout to be designed with the number of replicates for various gauges and balanced with the cost of each instrument. It is worth noting that the instrumentation layout during the planning and design stages should be customized and tailor-made to each site's properties to ensure they are fit for the purpose. This is done to better capture the influence of different parameters related to the environment, traffic, substrate materials and borrowed backfill materials. Finally, the exact location of each sensor in the road section, and its distance from the data-logger, will determine the length of the required cable. Best practices recommend that each sensor's cable should be labelled accordingly.

Sensors should be installed at the outer lane if the road consists of two lanes or more. The instruments for seasonal parameters should be installed at the inner and outer wheel paths, while the instruments for the structural response should be installed at the outer wheel path. The backfill should be constructed in layers of approximately 150 mm each to allow for the installation of the different sensors.

4. CONSTRUCTION

4.1. Pre-Installation Activities

Prior to installation of instruments, several important planning and preparatory activities should be undertaken for efficient use of available time and resources. It is expected that after completion of these activities, locations for the instrumentation are finalized, and all procured sensors will be ready for installation.

Written installation procedures should be prepared by the consultant to outline a detailed listing of required materials and tools relying on vendor's best practices. Installation record sheets are recommended for documenting factors that may influence the data. In addition, the prepared installation schedule should be consistent with the construction schedule. The location of instruments should be shown on the contract plans, and the exact location of each sensor should be verified using a surveyor and reflecting all changes in the as-built plans. Information collected during the siting assessment should also summarized in the field instrumentation manual. Details including elements within the layout of the right-of-way (ROW) near the instrumentation area (250 meters each side of the excavation) should be drawn into the as-built plans including:

1) Survey maps of the ROW showing
    a. Road layout and profile
    b. Proposed excavation location
    c. Location and type of sensors
    d. Instrumentation box
    e. Proposed location for FWD
    f. Location of collected samples
2) Structural details
    a. Road cross-section and material type in each layer
    b. Soil profile (result from bore holes)
    c. Road history including maintenance history
    d. Cut details based on restoration standard
3) Instrumentation Details
    a. Master plan of the instrumentation system
    b. Distribution of various types of sensors
    c. Wiring diagram involving connections between sensors and data acquisition devices
    d. Accessories including multiplexers and remote link devices (communication)
4) Electrical Details
    a. Power source, grounding, and conduits routing cables to the RPU
5) Proposed Civil Structures
    a. Conduits for running cables from sensors in the cut to data acquisition system
    b. RPU enclosure housing data acquisition system and accessories
    c. Detailed layout of equipment mounted inside the RPU
    d. Pull boxes and stub-outs to roadway for cables from sensors

4.2. Installation of Instruments

By adequately completing all preparatory work needed for implementing the instrumentation plan, installation will take place without interruptions [5]. The following are step-by-step procedures covering the construction period and documentation needed for the project:

1) Video Camera should be set and operated continuously close to the location of the cut without interfering with construction activities. The Survey equipment “Total Station” should also be set prior to construction.
2) Cutting of the asphalt surface (if it is not new construction) should be documented including:
    a. Type of equipment (Saw, Jackhammer, etc.)
    b. Cutting depth

c. Configuration (single or double cut on each side)

3) Excavation:
    a. Equipment type
    b. Process (layer by layer, random, etc.)
    c. Samples representing existing layers should be collected following *AASHTO R 58, entitled "Standard Practice for Dry Preparation of Disturbed Soil and Soil–Aggregate Samples for Test".* A minimum of 100 lb. of each material type should be collected. Caution should be exercised to avoid sample contamination (mixing material from different layers). Field moisture content for every material type should be determined using a minimum of two replicate samples following AASHTO Specifications – T265, entitled *"Laboratory Determination of Moisture Content of Soils"*.
4) Examine condition of the cut and document;
    a. Dimensions (width and depth), slopes or any other special features (cutback)
    b. Signs of sloughing
    c. Material in the cut and depth of layers
    d. Services including their size, condition and orientation with respect to the cut.
    e. Survey work should be carried out to document all details needed for establishing as-built-plans.
    f. Evaluate sensor distributions plan in view of the observed cut condition and recommend necessary changes without jeopardizing the usefulness of installed sensors. Inform the survey crew of these modifications to adjust sensor coordinates included in the Instrumentation Plan.
5) Initiate sensor installation and backfill process. Sensors must be protected with fine material (sand) before applying granular material on top.
6) Compaction of backfill should only commence when the level specified in the contract is reached. Survey work should continue to accurately establish coordinates of each sensor and layer thickness where compaction is applied.
7) Compaction equipment type (steel roller, vibrating plate, tamper, etc.) and their specification should be documented. Achieved density, measured by the nuclear gauge should be recorded (AASHTO Specification - T 310, entitled "Standard Method of Test for In-Place Density and Moisture Content of Soil and Soil–Aggregate by Nuclear Methods (Shallow Depth)"). Moisture content samples should be collected from each backfill lift and tested in the laboratory following AASHTO Specifications - T 265, entitled "Standard Method of Test for Laboratory Determination of Moisture Content of Soils"
8) Document any other tests conducted by the personnel and obtain results and reference specifications followed.
9) Document asphalt concrete layers applied to the surface of the backfill and up to the road surface including thickness, compaction type, density and construction joint treatment.
10) Establish timeline followed for applying the backfill and asphalt concrete layers with respect to the time when the road is opened to traffic.

11) Conduct survey work to establish road profile, including reinstated cut, before opening the road for traffic. This profile should be considered as the base for future measurement and should be considered as a reference for potential future settlements or surface deformations. Any damage associated with construction should be recorded.
12) Before opening the road for traffic, or immediately following that, a test vehicle with known axle weight distribution should be driven over the instrument section at a minimum of two speed levels (45 and 15 km/hr), during which asphalt concrete field temperature and sensor readings are acquired. The collected sensor readings are needed as a baseline data source for tracing future changes such as those associated with material densification, wetness, freezing and thawing cycles or damage. The second source of baseline data is the FWD test, which must be conducted within the first two weeks after opening the road for traffic.

Scheduling should be tied closely with the roadway construction schedule since the pavement monitoring system does have dependencies related to the roadway construction schedule. A high-level overview of key milestones is shown in Figure 2 Key Milestones & Dependencies. It should be noted that SP 25.0, 19.0 and 12.5FC2 type of asphalt mixtures are used as an example of asphalt bound layers used for the case of flexible pavement. Figure 2 milestones can be still used for rigid pavements or composite pavements by simply considering differently bound layers used in lieu of SP type mixtures.

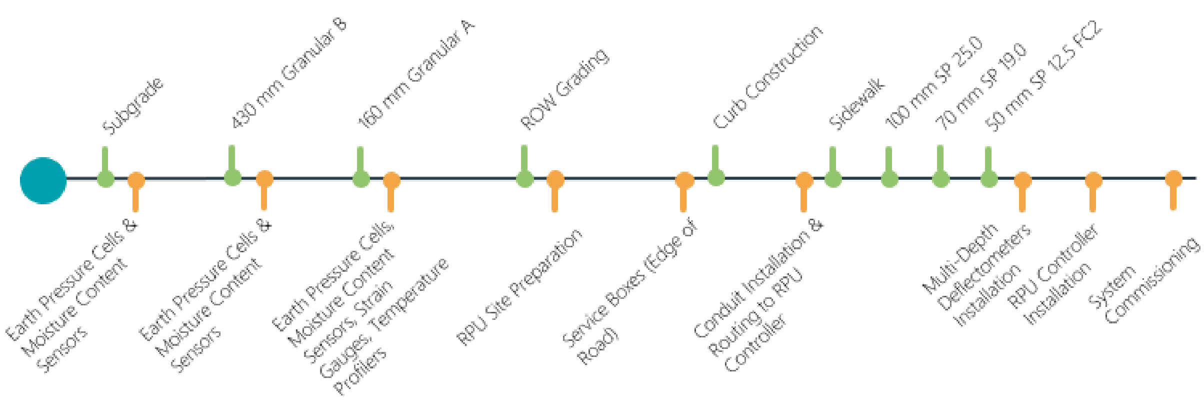

Figure 2 Key Milestones & Dependencies

Safety is an important consideration while performing the instruments installations. Below are some safety considerations pertaining to the work:

1) The Region-issued safety regulations are required for personnel working in the Right-Of-Way (ROW) during road construction and maintenance activities. It is important for fieldwork personnel to inquire about these safety regulations and adhere to them. Collapse of cuts is common, which motivated mandating work inside steel cage below a certain cut depth. Almost all construction sites require hard hats, safety boots and reflective vests, which must be worn all the time during excavation and restoration of a road section.

2) It is important that the instrumentation crew approaches power supply connections cautiously and tests supply feed lines before connecting sensors and data acquisition systems.
3) Maneuvering of heavy equipment during construction may require moving personnel from the cut location. Instructions from the Forman supervising cut restoration must be followed to avoid accidents

5. SYSTEM COMMISSIONING

5.1. Factory Acceptance Testing (FAT)

This process helps to achieve independent proof of functionality and quality of incoming products (sensors and data acquisition components), and is intended to verify all important documents, such as manuals and instructions. At minimum, the main pieces of the system should be put together with temporary wiring and communication in order to make sure that associated datalogger program operates according to the requirements and the calibration of the sensors are correct against the calibration charts provided by the manufacturer. All accessories of the data acquisition system including multiplexers, data loggers, batteries, and terminal blocks must be mounted and the entire network pre-wired on instrumentation trays prior to moving to the experimental site.

5.2. Site Acceptance Testing (SAT)

Site Acceptance Testing (SAT) provides a final confirmation that the performance experienced during the Factory Acceptance Testing (FAT) is achieved after the systems are installed onsite. In other words, this process is done to ensure that hardware system has not been changed or damaged during shipment and installation. To do so, a full functional testing of the system is carried out after installation and integration with support systems. Preferably, the same team of engineers and technicians who designed the systems and performed the FAT, should also lead the SAT to certify continuity and completeness. As a fundamental step in SAT, controlled tests will be done on each sensor to evaluate responses recorded by the data acquisition system. This step ensures that the whole network is connected properly, and the program is free of errors and in conformance with the established parameters.

5.3. Baseline Data Performance Reporting

Baseline data is the first set of data to be collected from the instrumented site and it is therefore important to document the initial state of the pavement (immediately after construction) before opening the road to traffic. The future data sets will be compared with reference to the baseline data to capture changes in the state of the pavement response with time. The collection of baseline data will be performed during the operation of a test truck and/or under the load action of a FWD device.

5.4. System Burn-In

Once the system is installed, SAT is completed, and baseline data is recorded, the system should undergo a burn-in process. The duration of the burn-in is usually 30-days to validate end to end operation of the system to ensure the system is operating in accordance with established requirements and specifications.

5.5. As-Built Plans

Survey work should be carried out to document all of the construction steps including the exact location of the different sensors and different material structural layers, and as-built-plans should be prepared.

6. DATA MANAGEMENT AND ANALYTICS

As described earlier, data will be remotely retrieved and stored on the data centre's case processing units or computers during and after completion of the construction. Data collected by each data logger(s), according to programmed schedule, will be downloaded by interrogating each RPU over internet. Data from the field is stored in files, for each field experiment having a dedicated folder. The suggested folder organization is represented in Figure 3, that shows an example of a repository structure for different applications of collected data: such as manual reporting, info graphic reporting of pavement structural adequacy status, as well as any items needed for further R&D. Raw data should be converted to engineering units (i.e. processed data) according with the calibration sheets provided by the manufacturer. Before the final storage, weekly data should be tested and evaluated for any reading errors like instrument malfunction, lower bound exceeded, upper bound exceeded, etc. These issues should be reported to the Instrumentation team accordingly based on their contractual obligations.

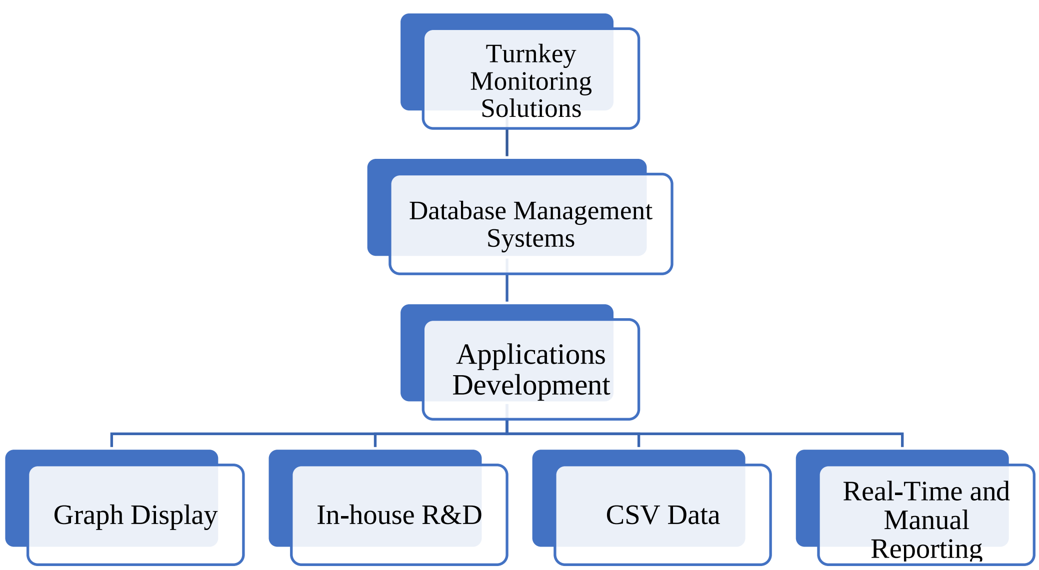

Figure 3 Overview of Data Management and Analytics

7. DATA ANALYSIS & REPORTING

Some of the performance indicators that should be considered are given below:

1) Load and deformation distribution is assessed using the pressure and rutting gradients at different asphalt concrete temperature that will be generated from pressure and deformation sensors
2) Resistance to freeze/thaw cycles is determined using freeze and thaw diagrams that will be generated from thermocouple measurements
3) Impact on the moisture regime is evaluated using profiles that will be generated from water content reflectometer measurements.
4) Performance should be assessed visually and using deformation sensors to capture distresses such as rutting of road different structural layers.

Distress survey in accordance to a format accepted to the project jurisdiction should be conducted before and after each season to trace accumulation of various distress types. Survey documentation form should be used to record crack initiation and propagation with time and traffic. Most importantly, rut depth should be recorded using results of the survey work conducted to establish the road profile immediately after construction as a reference for determining potential future road profile changes associated with shear flow or volume changes in the pavement. Potential opening of construction joints should also be monitored during site visits (4 times a year).

Data collected over the life of the field experiment will allow evaluating the performance of the instrumented sections under environmental and structural effects [6]. The total (i.e. cumulative of all layers) rutting on the experimental sections can be determined using surface measurements produced from profile surveys. However, the contribution of individual material layers to the observed total rutting will be determined from deformation sensors.

8. CONCLUSIONS

Steps and synthesis provided in this paper showed that special efforts and considerations are required to develop a systematic approach to plan for a pavement instrumentation project in light of new environmental and urban challenges facing road infrastructures. This paper provides major steps and key tasks involved in planning the monitoring program, procurement, factory calibrations, installations, maintenance and regular calibrations, data collection and interoperation of results. In summary, this paper showed that there is an overall lack of guidelines and detailed pertaining to instrument installation services, regular calibration and maintenance, data collection, processing, presentation, interpretation and reporting.

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