DATA-CENTRIC, TECHNOLOGY-ENABLED ALGORITHMIC FRAMEWORK TO MEASURE AND CLASSIFY DAMAGED ROADS FOR MAINTENANCE IN THE INDIAN CONTEXT

Birendra Bisht and Susmita Pandey
Intello Transpo
birendra.bisht@intello-transpo.com & susmita.pandey@intello-transpo.com

ABSTRACT

It is a day-to-day experience to see roads and highways in poorly maintained conditions. One can observe its manifestations while driving, in the form of shocks and jerks. The biggest challenge to road quality assessment is collection of relevant data and its standardized interpretation.

India has a vast road network (6 million kms). A conservative assumption of 10% poor quality roads, implies data collection over 6 lac kms of roads for the Road Classification & Assessment program. Manual collection of such data can be prohibitively expensive, even if limited to the worst maintained roads. But more importantly, the focus needs to be on defining Road Quality.

Road quality is characterized by usage-led visual defects; these include rough patches, potholes, damaged/uneven speed humps, etc. Road design and engineering also impact road quality, based on design attributes such as gradients, curves, banking angle, etc.

While qualitative interpretations of road quality are widespread, a standard quantitative definition is elusive; also elusive is the relative benchmarking of the parameters impacting road quality metric. The need-of-the-hour is an inexpensive, yet replicable data collection and assessment methodology to measure road quality. Today, a technology solution based on advanced Inertial Measurement sensors, is the best way forward.

Advanced research is currently underway to develop high-reliability algorithms for interpreting severity of road degradations. At the core of these algorithms is the comparative benchmarking of different manifestations of bad roads (potholes, uneven humps, bumps, etc.). Abundant empirical data is now available from sensor devices, and road classification algorithms are being tested.

THE BACKGROUND

Poorly maintained roads are omnipresent in India, throughout the length and breadth of the country. It is a day-to-day experience to see roads and highways in poorly maintained conditions. It is a phenomenon constrained neither by any specific geography nor any observed seasonal patterns (though the monsoon and post-monsoon could be the worst periods). It is not restricted to highways or to cities either. Neither does it stand-out in urban centres, nor in rural areas. It is confined neither to the tough terrains nor to the gentle plains.

Manifestations of Poor Road Maintenance

Poor maintenance of road conditions is best observed through its various manifestations, when one is driving on the roads or taking a ride.

While driving through poorly maintained roads, a driver occasionally negotiates potholes and road bumps, damaged road-patches, sharp speed-bumps, overturned rocks, damaged speed breakers, among other manifestations.

On several unfortunate occasions, bad road conditions get naturally masked and camouflaged due to water-logging, bad lighting conditions, traffic conditions, though such bad road manifestations may suddenly emerge from nowhere at the last moment.

As Figure1. shows, shocks and jerks are the typical manifestations of bad roads. The intensity of shocks and jerks received, while impacted by the vehicle type (quality of shock absorbers?) and the instantaneous driving behaviour, nevertheless is caused by poorly maintained road conditions.

Depending on how a driver negotiates such roads, it may lead to high probability of accident risk. Even for the riders and passengers, the instant jerks and shocks may, at the very least, cause discomfort and poor ride experience, but may occasionally also result in traumatic experiences.

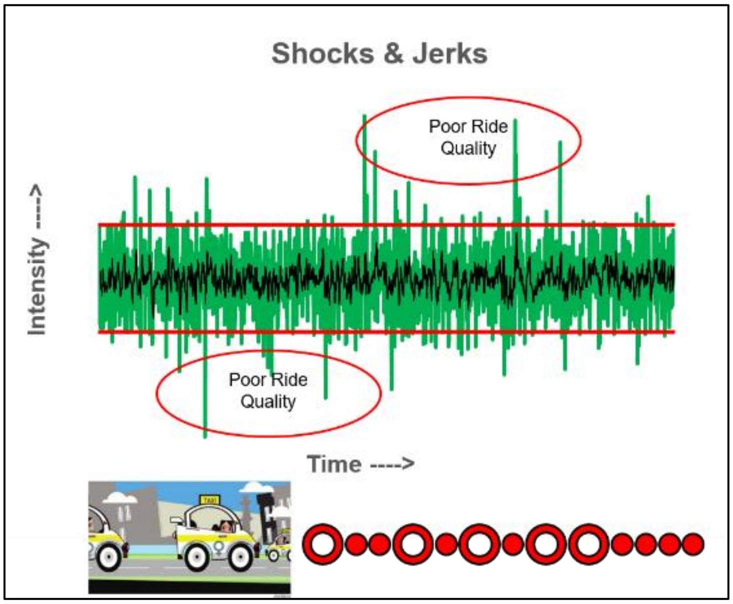

FIGURE 1Intensity of Shocks and Jerks on Poor Quality Roads

Without doubt, poorly maintained roads lead to a much higher risk of road accidents and human fatalities. It goes without saying that preventing or minimizing the deterioration of bad road conditions is the need-of-the-hour for government agencies and road infrastructure developers, who are also responsible for road Operations & Maintenance activities.

The Emerging Context

The Government of India publications have cited the overall impact of road accidents and fatalities on Indian GDP to be around 3%. This implies an annualized loss of approximately Rs. 4 crores per human fatality. As a nation, we have been bearing this economic loss for years now. At the same time, given that the spread of road network in India is around 6 million kms, the economic loss as viewed from a road network perspective, is about Rs.10 lacs per km.

There is an indicated policy shift towards higher funding for road operations and maintenance activities, and perhaps a shift in thinking towards the life cycle cost of road network infrastructure.

Given the current state-of-affairs on road accidents and its strong positive correlation with road quality, there has been an emerging voice towards more effective funds allocation and utilization for better maintenance of road infrastructure.

The issue of funds 'allocation' is, to an extent, being recognized and thereby undertaken by the government. However, the core challenge is towards ensuring an '**effective**' utilization of allocated funds by respective agencies and private firms.

THE CORE CHALLENGE

As we may like to assume, the government has or would be in the process of formalizing on road assessment framework(s); this would lead to s standardized approach of prioritizing, planning, and scheduling of road maintenance activities at a national level. It would beg answers to the following critical questions:

- What data points are required to determine which badly damaged road stretches should be given priority for maintenance funding?
- How will this data be collected in a scientific manner, without human interventions or biases, and within reasonable cost budgets?
- And finally, how should the raw data be standardized, normalized and interpreted, given that there will be huge variations in road characteristics (although all type of roads will be vying for the same funds)?

Food-for-Thought

Let us understand why the data collection on road quality and its correct interpretation is a hard challenge to crack.

Firstly, the road network in India is highly heterogenous:

- Nature of highways → From expressways, to 6-laned highways, to 4-laned highways, to 2-laned, highways, to undivided highways, to state highways, and many others, the contrast is significant.
- Road terrains → Roads passing through mountains and valleys, plateaus, plains, river-beds, forests, deserts, tunnels, etc.
- Nature of traffic flow → With most roads including highways remaining open for all vehicle types, from a bicycle to a heavy commercial vehicle (HCV), the traffic flow is heterogenous.
- Road surface → Asphalt-based, Concrete-based, Stone-based roads are common road surfaces, but there are extensive stretches of roads that are kutcha roads (or mud roads)

We may also include factors such as provision of street lighting, availability of service roads, roads passing through densely populated areas, to further highlight the complexity of Indian road network.

Secondly, responsibility of road development and road upkeep lies with multiple agencies, with every state having its own public works department. This has resulted in adoption of varying road engineering design standards and practices within the country, with limited potential for standardization. For example, the way the roads are designed in response to hilly terrains, say design-for-gradient, is different in different regions. The philosophies behind designing curved roads and their safe negotiation (road banking), are again non-standardized. Even the design of speed humps and speed breakers is different in different regions, though the societal context may be similar (say rural schools).

The third key aspect is the cost of data acquisition, and closely associated is the frequency of data acquisition. Due to seasonal and random 'incidents' that may impact road quality, such as monsoon rains, floods, landslides, major road accidents, etc., it is important that data is acquired at a higher frequency than perhaps every few years or even annually. Since bad road conditions could easily increase the 'statistics' of human fatalities, the earlier the bad road conditions are detected, the higher the chances of preventing road accidents. However, data collection effort, when done manually, could easily become the biggest cost component.

Let's put the above three sources of complexity in the right context:

The Indian road network spans nearly 6 million kms. Broadly assuming that a typical road stretch will require minor repair once in 3 years and major repair every 10^{th} year, it implies that the country will be actively repairing and maintaining almost 600,000 km of roads each year. This is a significant effort, when viewed from the perspective of road quality data collection and certainly prohibitive, if done manually.

Suffice it to say at this stage that the data collection challenge, i.e. what data to collect, how and when, is not a trivial issue. And without data, the bigger picture on effective funds utilization towards road maintenance cannot be achieved.

This sets the context on technology-based interventions; the following sections are focused on it.

TECHNOLOGY AND ITS ROLE

The interesting aspect to researchers and product designers is that despite the high degree of heterogeneity in the Indian road network and conditions, technology and technological solutions could potentially deliver excellent quality of data on road conditions/ damaged road profiles, without the need for large-scale manual effort/ interventions.

There are two key aspects of the data collection challenge:

- Static data of road i.e. road classification: A solid road classification approach requires the entire road network to be divided into smaller (continuous) stretches of road, say 500 metre to 1 km in length, and then assign different characteristics to individual road stretches. These static dataset vector of road characteristics, as assigned to individual road stretches, include road type / number of lanes / divided or undivided / road surface / engineering design parameters (gradient, banking angle, road curvature) / paved / mixed-use traffic / street lighting, etc.
- Real-time data on road conditions: Presence of potholes and their attributes (depth, coverage) / badly damaged road and rough patches (uniform / uneven, severity of damage, length of damaged patch) / poorly designed speed-breakers. Occasionally, the speed bumps also get severely damaged.

While it is the second point above that indicates the intensity of deterioration of road stretches, it is important to retain its perspective around static road characteristics (road classification); this is because any standardization or normalization of a badly damaged road would be observed in the context of its classification attributes (static data). When a relative benchmarking is to be done for prioritizing repair/maintenance activities, then both the intensity of damage and the road static attributes would form the basis for benchmarking.

For example,

- a 6-lane highway having excellent night lighting and having no immediate local population gets **badly damaged** due to flooding and develops deep potholes
- an undivided road in a populated locality with no night lighting, develops a single **rough patch** of road

It may not be an easy response, if it is asked which of the above two need to be prioritized for road maintenance.

EMERGING TECHNOLOGIES FOR DATA COLLECTION

In the remaining part of the research paper, we shall focus on an interesting technological intervention for real-time road-damage data collection. We shall also focus on the cost aspects (data acquisition & data cleaning, model validation, servicing).

Inertial Measurement Unit (IMU) MEMS Sensor Based Automated Data Acquisition

MEMS IMU sensor is an advanced, recently developed technology with a good potential use case for instantaneous profiling of roads. Comprising a 3-axis accelerometer, a 3-axis gyroscope, and a 3-axis magnetometer, the IMU sensor is attached at a strategic position onto a vehicle that tracks a road stretch; it accordingly generates vehicle Orientation Vector (roll, pitch, yaw) and the Acceleration vector (linear, horizontal, vertical) as a function of time. Typical data capture rate in MEMS IMU is 20 Hz, i.e. each data point is generated every 50 milli-second, and thus the orientation/acceleration profile is generated every 50 milli-second.

It is important to recognize that the IMU will directly generate real-time vehicle orientation only. What is finally required is the road profile, and thus there will be a *Transformation Matrix* which would transform the vehicle orientation profile onto the corresponding road profile.

To achieve the best estimates of road profile, four important things are to be considered:

i. Mathematical processing of raw data (accelerometer, gyroscope, magnetometer sensors) is required to develop the time-sensitive road profile. Data processing is based on advanced data filtering algorithms (such as Kalman filter) and statistical approaches (time series smoothening methods). Without the ability to filter out noisy empirical readings, the relative confidence in generated road profile will be low.

ii. The road damage profile will need to isolate the impact of type of vehicle used in data collection activity. It is worth noting that since different vehicles possess varying quality of shock absorption capabilities, there will be a need to consider the shock-absorption behaviour when generating the Transformation Matrix (defined above). In general, the generated road damage profile will be subdued from the actual observation of road profile, and hence the Transformation Matrix will play the role of a scale-up factor acting on orientation profile.

The scale factor is determined using empirical trials, and based on training data set in controlled environment.

iii. Another important consideration in the generation of Transformation Matrix relates to the driving negotiations performed by the vehicle driver, while driving through damaged road stretches. Such negotiation includes speeding, braking and acceleration, and steering behaviour. The role of driving behaviour is to influence the scale-up factor, while generating the Transformation Matrix. Again, the best approach to determine this impact is by conducting empirical trials as training data-set.

iv. The fourth aspect is that of statistical significance of the road profiles generated using the MEMS IMU technology. As indicated, the technology *per se* doesn't capture the dynamic road profiles; however, it captures raw data that can be mathematically transformed into vehicle orientation and subsequently into road profile. As points (ii). and (iii). above indicate, the Transformation Matrix is generated using empirical data collected from training/controlled trials; therefore, more the number of trials conducted, the better is the statistical confidence on road profiles generated.

It is important to mention here that the best results on road profiles are obtained under a classification approach, i.e. when the end objective is to 'classify' road stretches into a limited number of classes, as against computing the exact road profile.

A quick note: Empirical studies are being conducted that suggest the MEMS IMU technology will generate a practically feasible and reasonably accurate classification of damaged road profiles.

PRACTICAL ISSUES IN DATA COLLECTION USING MEMS IMU TECHNOLOGY

Let us now consider two important practical aspects while deploying MEMS IMU: Cost and Scalable Roll-out.

Cost Aspects

Discussing about cost, there are a few relevant dimensions to it:

- **Cost of sensor technology & hardware platform:** The data acquisition technology itself is relatively inexpensive and easily available in the market. The sensor technology is housed in a custom-developed hardware platform, which itself is self-contained in an inexpensive housing. Moreover, it is easily mountable at strategic vehicle position(s), and protects the MEMS IMU sensor from external shocks as well as stringent weather conditions.

- **Real-time Data Acquisition and Embedded Processing:** The complexity in data acquisition and its processing into real-time road profiling is massive. However, once the model is developed and validated, it consumes low processing cost and is highly sustainable over time. Moreover, as the algorithms can be updated over-the-air (OTA), the cost of upgrading the software and adding algorithmic enhancements is quite low. However, it must be pointed out that model validation is at the core of road profiling but is a complex activity; on the time dimension, it takes the maximum time before being put into practical usage.

- **Installation & Servicing Cost:** However, the biggest cost overheads accrue when the road profiling is done at a small scale, in which case the physical activities required to manage the installation, uninstallation, and servicing increases significantly. The cost of maintaining and running a vehicle **ONLY** for collecting and processing road profile data can become overwhelming.

Scalability

In terms of achieving rapid scalability, since the technology is standardized and utilizes the same algorithms uniformly, the technological and commercial challenges are low. The physical aspects in the end-to-end process, in terms of installing and servicing the technology, may require more attention. However, once the device is installed, it can keep collecting data, processing it in real-time, and remotely transferring the road profiles to central server at virtually negligible costs.