Benefit cost analysis of Automated Road Construction Monitoring.

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Abstract - The communication consumes approximately 7 to 90 percent ofa Construction Manager's (CM) time tocollect current and available information on demand. Field verification is an important part of a CM's responsibility, but administrative task consumes time which would otherwise be spent on road construction site. In order to overcome these shortcomings, there is a necessity to use advanced technologies in road construction which gathers the information efficiently, monitoring project and also helps in proper quality control. SCADA (Supervisory Control and Data Acquisition) is one of the modern day's information technology tools which can be used for monitoring roads construction activity in real time, which lead to better project performance control and optimize project performance indicator such as cost, time productivity. This paper mainly explores the cost effectiveness of conventional vs. automated, by comparing the monitoring of asphalt compaction activity and collecting the cost data of compaction for conventional and intelligent compaction for one km of road construction. This benefit-cost analysis demonstrates that use of IC reduces compaction costs by as much as 33.45 percent and results in a Rs.6,33847 annual savings per lane –km throughout the roadway's life.

Key word: **Automated monitoring, Cost, Intelligent compaction, SCADA etc.**

1. INTRODUCTION

The construction industry lags behind other manufacturing industries in project performance control. The current practice of manual amassment of monitoring requires massive data collection, more labor intensive, hence the cost of collecting the data and generating the information is high and the quality integrity and real time availability are low. Hence the focus of our construction automation (CA) research has shifted towards the area of Automated Project Performance Control (APPC) which is deals with automated Data collection (ADC) technologies to optimize the cost, progress, productivity. i.e. project performance indicator (PPI). To monitor the road construction activity in real time the continuous data collection regarding quality time cost is necessary to measure the project performance. The role of the control system is to identify the discrepancies the construction manager then identifies the causes for the deviations and accordingly decides about appropriate corrective measures. Accurate data is needed not only to control current projects but also to update the historic database. Such updates enable better planning of future projects is terms of costs, schedules, labor allocation, etc. The may help to comparing actual project performance vs. planned one.

This paper mainly explores the benefit cost analysis of conventional data collection, monitoring and control method vs. new emerging automated methods, of project performance control. For this the researcher has consider the asphalt compaction activity of road construction. i.e. the cost required for compaction of asphalt for 1 km road through conventional and intelligent compaction i.e. based on SCADA control.

2. Objective

The impacts of automation in road construction especially utilization of SCADA based monitoring and control system on cost are not well documented. Therefore, earthwork contractors have only anecdotal information on which to base estimates when considering using these technologies. This paper presents an initial step to address that need through the analysis of specific compaction operations. The primary objective was to demonstrate the Cost effectiveness of automation in road construction activity monitoring. Insight and information were gained through consultation with vendors and contractors. Two construction sites were observed, and their cost scenarios of compaction activity were analyzed.

3. Research Methodology

As this research topic was being formulated, the opportunity presented itself to work with road construction contractorsV.M.Matare Infrastructure Pvt.Lt (karad city).The study utilized three important research methods, First, the literature review was conducted to find the manual method of monitoring and controlling project performance, and their limitation. Second to understand the technology i.e. SCADA, system developed by PWD department. Third observations by researcher at road construction site where Benefit cost analysis of asphalt compaction activity through conventional method of compaction and intelligent compaction. The researcher spends two days on construction site. This help to understand the working procedures of each component of SCADA system, and study the working of intelligent compactor system. In this two days' researcher will collecting the cost details and necessary information of asphalt compaction activity with intelligent compaction and conventional compaction methods and also conducted expert interviews to gain insight of the system, with PWD engineers Er. ShrikantGulkotwar. The in short details of SCADA system and intelligent compactor system explain in further section

3.1 SCADA System:

SCADA system is an assemblage of computer and communications equipment designed to work together for the purpose of controlling a commercial process. Data acquisition refers to the procedure used to access and manage information or data from the equipment being controlled and monitored. The information accessed is then forwarded onto a telemetry system prepared for transfer to the various sites. They can be analog and digital information gathered by sensors, like temperature, compaction, location of equipment etc. It is a technique used in transmitting and receiving information or data over a medium. SCADA system comprises of following components.

i. CMS (Central Monitoring Station or Master Station
ii. PLC (Programmable Logic Controller):
iii. RTU (Remote Terminal Units):
iv. HMI (Human Machine Interface):
v. Communication System:

3.2 Intelligent Compactors system (ICS):

As an observation made on field monitoring of asphalt compaction activity using SCADA. The rollers used for compaction are of type HAMMHD-90. Which is shown in the fig. 1 On the field interviewing with project manager Mr. Manoj Deshpande sir give details about component and working of SCADA system. The further section determines the details about the ICS.

Fig: 1 Intelligent compactor of type, HAMMHD-90.

Fig: 2 Intelligent compactors with all details.

Compaction is a process of densification of various layers of a pavement. The serviceability of roads depends on the level of compaction it undergoes during the construction process. Intelligent Compactors is a technology used to achieve the required compaction using sensors, GPS and other devices. The main features of IC are enlisted below.

(1) Integrated measurement system which determines the extent of compaction and surface temperature of the underlying pavement in real-time.

(2) A GPS based documentation system for continuous recording of roller position and corresponding compaction level data for the complete road.
(3) On board display system to display the real-time operation parameters like compaction level, temperature of pavement, roller pass, direction of roller, GPS location of the roller, and a colour coded mapping of compaction level at each location. Fig. 2 shows the display screen of roller.
(4) A feedback control system that can change the operational parameters of the roller such as frequency, amplitude, speed, direction to vary the compactive effort on the pavement according to the compaction level. Color coded display maps are an important feature of Intelligent Compactor.

4. Benefit- cost analysis

The framework for a benefit-cost analysis was developed based on costs for construction of a roadway and savings from improved compaction uniformity over the pavement lifecycle. The framework is illustrated using one case study on single lane 1km road section, a thick 50 to 100 mm (2- to 4-inch) asphalt overlay. The methodology to obtain cost data includes two specific cost cycles: construction and roadway life. The summation of the cycle costs is to be compared between two compaction methods: conventional compaction and testing versus IC compaction.

4.1 Methodology

The methodology used for analysis takes into account construction costs and roadway lifecycle costs as two separate time periods. Definitions for the time periods and compaction types are presented first. The framework for analysing the differences between the conventional and intelligent compaction types is then presented for each time period.

I] Definitions:

The definitions below provide an outline for types of costs that would be defined within each time period and type of compaction. Construction Cycle Cost: The construction cycle includes the time period that begins with the preparations for conducting roadway compaction. This encompasses the costs for rollers, labor to operate the rollers, and conducting QC/QA testing. Roadway Lifecycle Cost: The roadway lifecycle means the expected service life of the roadway. The costs per year for conventional compaction and IC are calculated based on the capital cost of the roadway improvement divided by the service life of the roadway in years. Pavement maintenance costs are not considered because the type of maintenance is highly dependent on the transportation agency and roadway characteristics.
Conventional Compaction and Testing: Conventional compaction means any method of compaction used by contractors to perform roadway compaction and subsequent QC/QA methods that do not use a roller equipped with on-board stiffness or density measuring devices. QC/QA data are obtained by in-situ field tests.

IC compaction means the compaction of a roadway section by use of a device. Generally, this includes the use of an accelerometer, GPS unit, and onboard computer to aid roller operators in compaction efforts. QC/QA data are obtained from the roller and is analysed by SCADA software.

4.2 Framework

The comparison between the two compaction methods comprises a summation of the costs from the two cost cycles over similar construction lengths and roadway lifecycles. The summed costs for each time period are compared to each other independently. In order to illustrate the framework, a project type and size must be chosen. The first case study, described a project with a thick, one-lane km asphalt overlay.This framework not only can be applied to new road construction but also can be applied to different types of roadway improvements, including reconstructions, so long as the data for each type of improvement are gathered and used accordingly.

A] Construction Cycle:

Construction costs regarding roller equipment and labor for conventional compaction are gathered using pricing data from contractors. The costs are set as an hourly rate so that they can be used for different types of projects if necessary. A rate of compaction for construction crews can also be obtained from the contractors. The rate should yield an area per unit time period, for example, 6,000 square feet per hour. This allows for calculation of the amount of time that it would take a construction crew to complete the type of work that is being analysed. This amount of time is then multiplied by the roller equipment and labor costs for each type of compaction. For conventional compaction.

Construction Cost = (Compaction Time in Hours) × [(Roller Cost per Hour) + (Roller Operator Cost per Hour) + (GPS Cost per Hour)] + [(QC/QA Cost per Area) × (Area)] …1

= (10) x [(690 + 385] +N/A + [10 x 4482]

= Rs. 55,570/- only.

Construction costs for IC were calculated based on a reduced amount of time to perform roller operations and the cost of an IC roller. The IC roller cost may be available from contractors. The roller manufacturer chosen for a specific analysis should be based on similarities to the conventional roller used, such as setup (drum roller number and type), weight, and vibratory characteristics. In order to calculate the number of hours for compaction using IC, a 30 percent reduction in the number of hours it would take a conventional roller is applied, which is given by Equation 2. The reduction was based on the number of roller passes from IC rollers compared with conventional rollers to perform similar compaction work as observed by Briaud and Seo (Briaud&Seo, 2003). The test section area, used for QC/QA purposes, must be added into the amount of time needed for compaction using the IC roller. The total time required for compaction of the test area and the roadway section is then multiplied by the hourly rates for labor and equipment to obtain the cost as demonstrated in Equation 3.

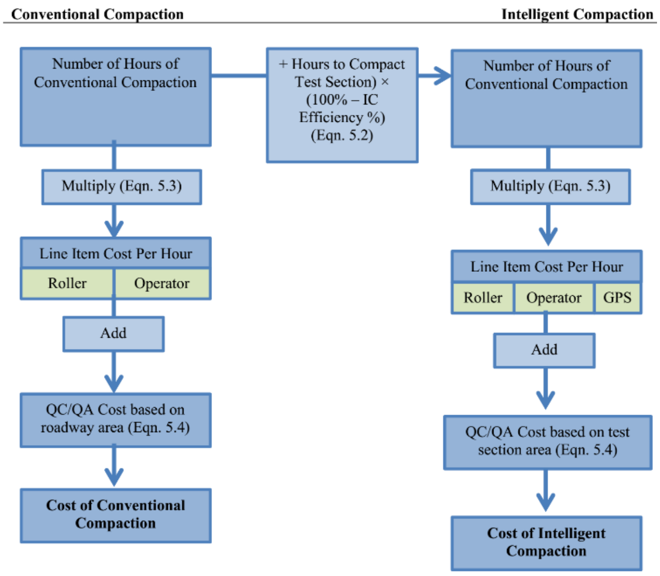
IC Hours = (Conventional Compaction Hours for Roadway Section + Conventional Compaction Hours for Test Section) × (100 percent – IC Efficiency percent) ….2

Cost per Line Item = (Hourly Rate of Line Item Cost) × (Hours)….3

The QC/QA program costs are also part of the total construction cost. The information for conventional compaction and testing can be obtained by surveying contractors on their costs related to QC/QA. Contractors may provide this information with equipment and labor costs separated or combined. The costs will be in either an hourly or unit area rate, such as square feet. In order to calculate the QC/QA program costs from hours, the rate of QC/QA performance must be converted using a time per unit volume or area as given by Equation 4. The calculated unit volume or unit area can then be converted into a total cost based on the size of the roadway being analysed. The cost for the QC/QA program for intelligent compaction is then multiplied by the test section area divided by the total project area.

QC/QA is provided on the test section area in order to correlate MVs with conventional testing methods, such as nuclear gauge or core sampling. The area used can vary depending on the project but is often between 300 to 600 feet (Mooney, et al., 2010) and several DOT IC specifications (The Transtec Group, Inc, 2014).

Figure 3 is a flow chart for calculating the cost of each type of compaction based on the equations and description of calculations.



QC/QA Cost = (Area of QC/QA per hour) × (Cost QC/QA per area) ….4

= [10] x [4482]

= Rs. 44820/- only.

B] Roadway Lifecycle:

One of the largest benefits provided by IC is that it provides a more uniform compaction. Uniformity translates into an extended pavement life. In order to calculate the benefit from using IC, the cost per lane km for a thick asphalt overlay was divided by the remainingservice life improvement to the roadway as noted in Equation 5. The average cost per lane km and remaining service life improvement should be obtained from contractor. The increase in remaining service life from IC is 2.6 times (260 percent) the conventional compaction method based on Chang, et al. (Chang, et al., 2012). This is due to an increase in fatigue life, where pavement fatigue from loading is assumed to be the cause of most roadway failures.

Cost per lane-km per year = (Cost of Roadway per Lane-km) / (Service Life in Years) ...5

C] Pavement Analysis:

The cost comparison between the two compaction methods comprises a summation of the costs from the two cost cycles over similar construction lengths and roadway lifecycles. To illustrate the application of proposed benefit-cost analysis framework, a case study of a thick, one lane-km overlay asphalt pavement was presented. Table 1 contains the data inputs used for the analysis, which are discussed in more details in the subsections.

Table: 1 Input Data for Benefit-Cost Analysis

Item	Unit cost /Quantity	Source
Construction cost		
QC/QA per square yard	Rs.10	Simon Contractors,
IC Reduction in compaction cost	30 percent	Briaud&seo (2003)
Lane width, feet	12.3	Assumption
IC to conventional QC/QA cost	10 percent	NCHRP 676 (Mooney,et al.2010)
Conventional roller cost / hour	Rs.690	DSR PWD
IC pavement roller cost /hour	Rs.1235	DSR PWD
Roller operator per hour(same for both)	Rs. 385	DSR PWD
Conventional compaction hours/lane-km	10	High Country Construction, 2014.
Compaction cost per square meter	Rs.10	DSR PWD
GPS System rental per hr	Rs.60	Trimble Navigation Limited
Work hours per week	40	Assumption
Lifecycle costs		
Test Section Length, feet	500	Mooney, et al., 2010)
Increased service life with IC, multiplier	2.6	Chang, et.al, 2012
Average asphalt life, years	10	Average overlay service life
Cost per lane-km	1.03 cr.	Road contractor.

D] Construction Cycle Data:

The construction cycle costs for conventional compaction were gathered from a survey ofcontractors. The data used were the cost of a roller, roller operator, and GPS system per hour. These data were obtained from roller manufacturers, a phone survey of contractors, and GPS system providers (Jones, 2014; Bastian, 2014; Newman, 2014; Trimble Navigation Limited, 2014). Also, QC/QA data were based on local contractor information. The summation of these data was used to create a cost per lane km for the construction of a 2- to 4-inch thick asphalt overlay as given in Equation 1. Where data were given in ranges, a value within the range was assumed in order to create comparable data between the two compaction types. Also, the hourly rate for the roller operator was assumed to be the same for each type of roller. The cost of intelligent compaction was then calculated using a 30 percent reduction in the number of hours it would take a conventional roller. The reduction was based on the number of roller passes from IC rollers compared with conventional rollers as observed by Briaud and Seo (2003). The time to compact the 500-foot by 12-foot test section area for establishing MV correlation to conventional compaction testing was added. QC/QA costs for IC were reduced to the area of the test section required to calibrate conventional testing methods with the IC's measurement values. The cost of QC/QA testing was then multiplied by lineal feet of the test section, 500 feet, divided by the lineal feet in a km, 3280 feet, which resulted in a multiplier of 0.152. Equation 6 is the cost of QC/QA for IC based on the conventional compaction QC/QA cost.

This can also be described as the test section being 0.152 times the lineal length of one km. 'SCADA' a software program developed by the PWD Maharashtra allows for instantaneous determination whether data comply with QC/QA standards, real time monitoring and control on project performance. An initial expense to program QC/QA compliance into the software and train QC/QA engineers to use the software are required; however, it would not be a significant contributor to cost to a single project when averaged over several compaction projects.

QC/QA Cost for IC = (QC/QA Cost of Conventional Compaction) × (Test Section Lineal Length / Length of Roadway Section) 6

= [44820] x [500/3280]
= Rs.6832/- only.

E] Roadway Lifecycle Data:

The benefit from increased uniformity was calculated for the thick asphalt overlay using the increased fatiguelife multiplier. The average cost per lane km for thickasphalt overlay is approximately Rs.1.03 Cr. based on estimates (Contractor). Also, the average remaining service life improvement of a thick asphalt overlay is assumed to be 10 years under conventional compaction methods. Under greater uniformity from IC, a thick asphalt overlay has been calculated to have a service life of 2.6 times greater, or 26 years, due to the increased fatigue life (Chang, Gallivan, Horan, & Xu, 2012).

4.3 Results of Pavement Case Study:

The results for the construction cycle and the roadway lifecycle are presented separately in the following subsections. Calculations for the cost per unit and number of units are described in each subsection.

4.3.1 Construction Cycle:

The unit costs for the roller, operator, and QC/QA for conventional compaction are listed in Table 1. The unit cost for the IC roller was based on the cost per hour of the roller (i.e., Rs.1235 taken from DSR. This yielded an hourly rate of for the IC roller. The hourly cost of the GPS is Rs.60 (Trimble navigation limited).The number of units in hours or per square meter was calculated using a combination of the rate of construction and the areas of the road section and test section. The rate of construction is 10 hours per lane-km for conventional compaction as noted in Table 1 the distance of the test section was added to the one-km distance of the road section and then divided by the rate of construction. This result was then reduced by 30 percent to account for the reduction in time using an IC roller as given by Equation 2 (Briaud&Seo, 2003). The result of the reduction yielded an equivalent of 7 hours to perform IC. The number of units for QC/QA was calculated as the unit cost of Rs.10 per square meter to perform QC/QA from Table 1 multiplied by the number of square meter that QC/QA was performed on. For conventional compaction, the QC/QA was performed on the area of the road section, which is 3280 feet multiplied by 12.30 feet and divided by 9 square feet per square yard. The area of the test section, which is 500 feet by 12 feet, was the square meter for QC/QA for IC. The remaining QC/QA is performed based on readings from the IC roller. The data can be downloaded from the roller and inputted into the SCADA software in a limited amount of time to check for compliance on the road section. The costs were yielded by summing the cost of each line item as shown in Table2. Conventional compaction yields a cost of Rs.55570 per lane-km and IC yields a cost of Rs.18592 per lane-km, which is a 33.45percent reduction compared with conventional compaction. The 33.45 percent reduction was mainly a result of the 30 percent reduction in compaction time and also the reduction in QC/QA costs. The increase in cost from the GPS system was marginal. The GPS cost was calculated by using the annual rental cost and dividing it by the ratio of hours that it was used during compaction.(Trimble navigation pvt.lt) The number of hours to complete compaction of a roadway was 23 percent less using IC. This was calculated using the 30 percent reduction in compaction time using IC and increasedby the additional 500-feet long by 12-feet wide area for the test section. Line-itemed calculations are contained in Table 2.

Table: 2Cost of Construction Cycle per Lane-km.

Conventional compaction					Intelligent compaction				
Item	Cost/ unit Rs	Unit	Number of unit	Total cost	Item	Cost/ unit Rs	Unit	Number of unit	Total cost
Roller	690	Hr.	10	6900	Roller	1235	Hr.	7	8645
Operator	385	Hr	10	3850	Operator	385	Hr	7	2695
GPS	N/A	N/A	N/A	N/A	GPS	60	Hr.	7	420
QC/QA	10	Sq.m	4482	44820	QC/QA	10	Sq.m	683.2	6832
Total				Rs 55,570					Rs.18592

4.3.2 Roadway Lifecycle:

The total cost of performing a thick, one lane-km asphalt overlay was divided by the service life increase from the improvement. The service life improvement using conventional compaction was noted as 10 years in Table 1. The total cost per lane-km Rs.1.03 cr. was divided by 10 years to yield the annual cost for conventional compaction. The total cost was then divided by 26 years for IC, reflecting the 2.6 times of improved service life (Chang,

Gallivan, Horan, & Xu, 2012). The annual costs were then multiplied by 26 years for each conventional compaction and IC to demonstrate comparable costs during the lifecycle of a one lane-mile road section using IC.
Table: 3 contain the data used for each of the compaction types. Conventional compaction yielded 16 years less service life compared with IC. The cost savings for IC compared with conventional compaction is Rs.6,33,874 per year, or Rs. 51,5,0000 when spread over the lifetime of an IC road section. The cost savings using IC resulted from increased material uniformity.

Table: 3 Roadway Lifecycle Costs per Lane-km for One Year and 26 Years

Compaction Type	Service Life(yr)	Cost per year	Cost over 26 year
Conventional	10	Rs. 10,30000	Rs.1,54,50000
Intelligent	26	Rs. 3,96,153	Rs.1,03,00000
Difference	-16	**Rs. 6,33,847**	**Rs.51,5,0000**

5. Conclusion

The aim of this research work is to understand the need of implementing the automated monitoring system, creating awareness and interest about learning and implementing the rapid developing monitoring system in the road construction project. From the result of benefit-cost analysis of asphalt compaction monitoring it should be clear that utilization of new system or automated technology in road construction project is cost effectively, up to 33.45 percent and Annual savings on a lane-km is approximately Rs.6,33,847.which enhance the ability of construction manager to take a decision, lead to better project performance control and operation could be significantly improve daily performance, project management activities i.e. achieve the goal of automation in road construction.
Additional research is currently being carried out in order to develop the databases and methods required to fully realize it. Eventually, this framework could facilitate the establishment of a database that can be used to analyze, and also this research work is helpful to those who are recently work in the automated monitoring system in construction of road project.

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