4th Construction Specialty Conference
4e Conférence spécialisée sur la construction

Montréal, Québec
May 29 to June 1, 2013 / *29 mai au 1 juin 2013*

Modeling the Trend of Maintenance Cost for Road Construction Equipment

Sharif Mohammad Bayzid[1], Maria Al-Hussein[1], Yasser Mohamed[1]
[1]Department of Civil Engineering, University of Alberta, Canada

Abstract: Large road construction companies usually own a large fleet of heavy equipment. The maintenance of this road construction equipment contributes significantly to their operating costs, and consequently, overall construction costs. Therefore, it is necessary to track these costs to develop realistic estimates and equipment replacement plans for upcoming years. These costs emanate mainly from running repairs, and different type of maintenance work. The research work described in this paper aims to develop a data-driven approach for modeling the trend of equipment maintenance costs for a major road construction company. Database records of actual maintenance activities spanning several years of company operations are used in this study to develop models for different equipment classes. Labor and parts costs data is associated with equipment meter readings and is consolidated from ten different sections in the database to find consistent maintenance-cost-per-hour values for each equipment class, to visualize their trend, and eventually to fit proper models to that trend. The paper focuses on the initial results observed from analyzing the maintenance costs of several equipment classes in the database. In addition, it discusses the challenges faced during data gathering and preprocessing phases of the study, which represent significant time- and effort-consuming steps. Finally by second order polynomial equation a methodology to predict maintenance cost per hour has been proposed in this paper.

1. Introduction

Any kind of road construction project involves major capital investment for equipment. Equipment management has become a major concern for today's equipment-intensive road construction systems. Equipment productivity depends on weather, operator efficiency, and operating site conditions and is a main concern in regards to profitability, but equipment managers cannot control these factors all the time; the main factor that equipment managers can control is the availability of equipment (Asfahl et al., 2006). Therefore, equipment acquisition and replacement decisions play a major role in the profitability of a project (Halpin and Senior 2011). Equipment managers face different decision-making issues such as budgeting operating and replacement costs for a fleet and for individual machines, determining the viable economic lives of machines in their fleets, etc. (Mitchell et al., 2011.). It is equipment manager responsibilities to select the most economical equipment combination in a way that maximum production can be achieved at the optimum cost (Halpin and Senior, 2011).

Equipment costs are composed of two cost types: namely equipment owning cost and equipment operating cost. Equipment owning cost is fixed cost and incurs regardless of the fact a piece of equipment is in use or stored. Equipment operating costs are variable costs and include all cost directly associated with equipment use on a project. They consist of fuel costs, operator's wages, maintenance costs and tire costs. Maintenance cost, make up a major portion of operating costs, include running repairs, preventative maintenance and predictive maintenance. These different components of maintenance cost vary with respect to different types of equipment. Also within the same category of equipment trend of maintenance cost could be different for different units.

Equipment managers use computerized Equipment Management Systems to monitor and track of equipment inventory, record daily equipment operations, and maintenance schedules and costs. Although these systems provided pre-canned reports and record daily equipment data, analysis of the data for decision making such as replacement of equipment, trends analysis is still non-trivial and readily available.
The partner of this research is Standard General Inc.; a major construction contractor in Alberta that owns a large fleet or heavy construction equipment. The company utilizes an Equipment Management System developed (MTrack) in collaboration with NSERC/Alberta Construction Research Chair. The system has been in place since 1997 and has captured tremendous volumes of equipment maintenance data. The system is a client –server application as data is stored in MS SQL server. Some of the main features of the system include: equipment parts purchasing and receiving management, inventory tracking and control, shop labour timesheets, equipment services such as running repairs and maintenances. Equipment services costs are captured in terms of labour cost and parts costs. While the system tracks daily operation and stores large volumes of data successfully, it lacks comparison and trend data analysis to support decision that equipment managers face on daily basis. It cannot provide sufficient data to answer "should a piece of equipment be replaced or keep servicing, what is the optimum life for an equipment, forecast future maintenance cost based on the historical equipment performance".

In current practice, the equipment manager usually takes decision for budgeting maintenance cost on the basis of last one or two year's budget with or without any statistical analysis but not in a systematic way, which may not quite enough to make proper prediction. For this reason a research work has been initiated to find out proper methodology or systematic approach to predict maintenance cost, so that equipment manager can do budget more precisely for upcoming years and can make proper decision about replacement of equipment. This paper focuses on the analysis of construction equipment maintenance costs, discuss some of the issues imposed by the data collected and then tried to propose a methodology to predict maintenance cost by regression analysis.

2. Literature Review

Calculating or predicting maintenance costs for upcoming years is a critical task. Prediction of maintenance cost could be done on the basis of cumulative cost that is summing up of the cost from the beginning of an equipment, or cost per hour basis. Mitchell, Hildreth and Vorster (2011) suggested cumulative cost model (CCM) which can help construction managers to better understand the nature of maintenance costs as they relate to production fleets. Figure 1 (Vorster, 1980) shows geometric representation of the CCM where the abscissa of the CCM is age and the ordinate of the CCM is cumulative cost. Optimum economic life, L, is the tangent to the cumulative cost curve drawn from the origin and optimum average cost; T*, is the slope of that tangent line (Mitchell et al., 2011).

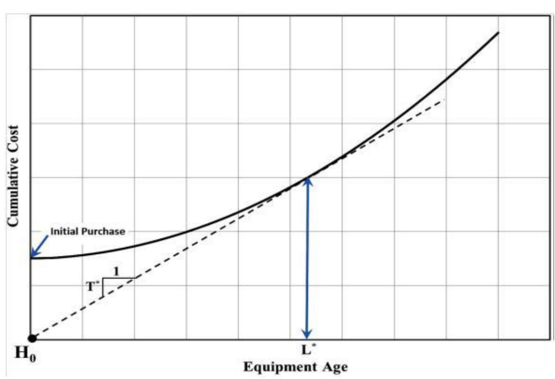

Figure 1: Cumulative cost model [adapted from Vorster (1980)]

Clutts (2010) suggested Construction Equipment Profitability Optimization Model (CEPOM), which is a decision-support model to determine the best fit acquisition method among rent-lease-buy where maintenance cost of equipment is a vital decision-making factor. Maintenance and operation of the fleet on the basis of optimum costs will pave the way of significant savings, and to achieve this goal, timely replacement of equipment is required. Chien and Chen (2007) considered an age-replacement model with minimal repair based on a cumulative repair cost limit where a cost model is developed for the average cost per unit time based on the stochastic behavior of the assumed system. Rashidi and Ranjbar (2010) tried to predict accumulated repair and maintenance cost of John Deere 4955 tractors by power regression model. Bakht, Ahmadi, Akram and Karimi (2009) investigated mean accumulated repair and maintenance costs through five different models of regression analysis and found that power model gave better cost prediction with higher confidence and less variation than the other models.

Apart from the usual equipment, in nuclear power plants, two types of maintenance work are required: planned and corrective. Popova, Yub, Kee, Sunc, Richards and Grantom (2006) have demonstrated the failure rate of nuclear plant equipment, and Bayesian model had been used in their research work. They have found that a combination of principle components analysis and factor regression provides the best model for explaining most of the variability of the maintenance costs and has very reasonable statistical characteristics. Gillespie and Hyde (2004) suggested three methods, logarithmic model of variable cost as a function of fuel expense, ratio between the average labor and parts cost per dollar of fuel (or per mile) year to date and the average labor and parts cost per dollar of fuel (or per mile) life to date. These statistical methods would allow an estimate of the probable unit cost for the subsequent year. It is imperative to have the capability to make effective decisions for maintaining equipment, as well as for estimating maintenance cost. Therefore, the manufacturer has to figure out the minimum maintenance cost. Industry is interested in adopting methods of reduced maintenance costs because of the overwhelming demand and complex structure of the marketplace (Hall, 1997). Pascuala and Ortega (2006) offered a cost minimization model for a product sold with warranty to determine the optimal levels of maintenance costs, which emphasizes some crucial factors such as overhauling, repairs and replacement.

From the above earlier studies it has been found that maintenance cost of equipment has been analyzed by cumulative cost model or by cost per hour model. They tried to analyze these models by different algorithms or numerical approaches and proposed some models, algorithms or approaches that were suitable for their database. Almost all of them had the intension of minimizing waste on maintenance of equipment and predicting maintenance cost for proper budgeting. In the section four the advantages of cost per hour model over CCM will be elucidated. Also comparison among different numerical approaches, mentioned in this literature review section and some additional, will be done to know which ones are suitable for the given database.

3. Data Collection and Preprocessing

Data collection is crucial, and proper data assists in making pertinent decisions in solving critical problems. In most cases, the data that can be obtained for research work mainly remains in raw format, so rearrangement or pre-treatment of the database is required before use in any decision-making research work.

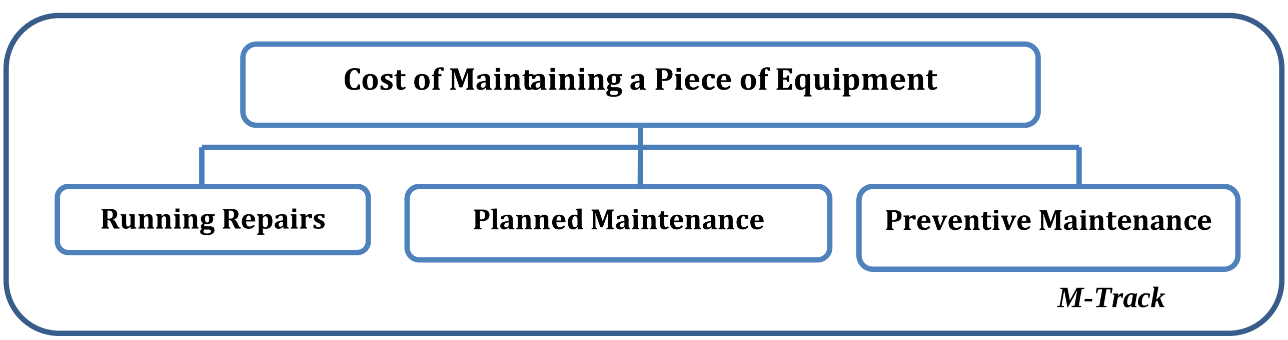

Figure 2: Main sources of maintenance cost for any equipment in M-Track

Figure 2 depicts the main source of data to determine equipment cost of maintaining in M-Track;

- Running repairs – a repair completed due to breakdown of equipment.
- Planned maintenance- equipment inspections performed on annual basis can capture mechanical deficiencies that if not repaired can lead to an equipment breakdown
- Preventative maintenance – a routine and periodic maintenance suggested by manufactures to keep equipment in the best possible operating condition (Nunnally, 2000)

These sources of maintenance cost mainly come from labour costs (running repair (RR), planned maintenance (PL) and preventive maintenance (PM)), and parts costs (purchase order (PO), internal transfer (IT), cash purchase (CP) and preventive maintenance (PM)). Purchase order, internal transfer and cash purchases are done for both running repair (RR) and planned maintenance (PL). In Table 1 all these components of maintenance cost have been shown. In the database, each piece of equipment is identified as a six-digit unit no and all the equipment pieces of same category are grouped into classes.

These maintenance cost data was stored in M-Track database as per requirement of Standard General Inc. But that approach was not always convenient for this research work. For this trend analysis of maintenance cost, odometer or hour meter reading should always be available with respect to maintenance cost data. But for the running repair, cost data was not available with respect to odometer or hour meter reading. The same problem was observed for planned maintenance. But both of the maintenance cost data were available with respect to timestamps. Only for preventative maintenance, hour-meter reading and timestamp were stored properly for each of the maintenance cost data. So by comparing the timestamps of preventative maintenance with that of other maintenances, a common database can be formed where all the maintenance cost data would be available with respect to odometer or hour meter reading. Sample of this database is shown in Table 1.

Table 1: Sample data of different components of equipment maintenance cost

Unit No	Time Stamps	Hour Meter Reading	Labour Cost			Parts Cost						
			RR	PL	PM	PO_ RR	PO_ PL	IT_ RR	IT_ PL	CP_ RR	CP_ PL	PM
217-401	9/17/2001	2091	717.5	0	70	366.37	0	23.9	0	0	0	36.82
217-401	4/22/2002	2224	3272.5	0	280	2126.2	0	302.4	0	0	0	343.11
217-401	9/16/2002	2406	1265	0	70	30.64	0	0	0	0	0	25.68
217-401	5/9/2003	2487	612.5	0	210	0	0	42.3	0	0	0	208.10
217-401	10/14/2003	2671	1102.5	0	70	4658.0	0	18.4	0	0	0	29.78
217-401	5/18/2004	2698	1575	0	210	503.13	0	538.4	0	0	0	354.29
217-401	4/7/2005	2827	1347.5	0	280	1526.7	0	39.5	0	0	0	392.58
217-401	10/4/2005	3130	525	0	70	24	0	0	0	0	0	34.99
217-401	4/19/2006	3078	140	0	140	297.3	0	5.1	0	0	0	67.66

Some problematic data or outliers were encountered during data accumulation such as misleading hour-meter readings, starting of hour-meter reading from zero when hour-meter is replaced etc., which is illustrated in Table 2. First highlighted row in Table 2 shows the problem regarding replacement of hour-meter, which was solved by adding new meter readings with the last previous hour-meter reading. Second highlighted row shows problem regarding misleading hour-meter reading, which was solved by taking average of previous and next hour meter readings. Although these approaches do not give the exact values of hour meter reading, it is approximate to the actual values.

Table 2: Illustration for hour-meter reading correction

Unit No	Event Id	Time Stamp	Hour-meter Reading	Hour-Meter Reading Corrected
205-404	114123	28/03/2008	288	288
205-404	117148	20/03/2009	520	520
205-404	119452	03/02/2010	547	547
205-404	**121987**	**16/02/2011**	**2**	**549**
205-404	123530	12/01/2012	108	655
230-405	108686	10/04/2006	6783	6783
230-405	**109934**	**16/10/2006**	**255**	**7046.5**
230-405	111093	09/04/2007	7310	7310
230-405	111758	27/06/2007	7382	7382
230-405	115029	14/07/2008	7702	7702
230-405	118424	31/08/2009	7952	7952
230-405	121026	17/09/2010	8250	8250

4. Trend Analysis of Maintenance Cost

A large road construction company like Standard General Inc. store huge amount of maintenance related data. But having this huge amount of data do not help any equipment manager if that cannot be utilized or analyzed in proper way. From M-Track database enormous maintenance cost data for previous couple of years could be extracted, but by using M-Track an equipment manager may not forecast maintenance cost of equipment pieces for coming years. A proper systematic approach has been tried to propose in this paper to make proper prediction of maintenance cost. The total systematic process of this trend analysis with some of the items that already discussed in the previous section have been shown in the following flow chart (Figure 03).

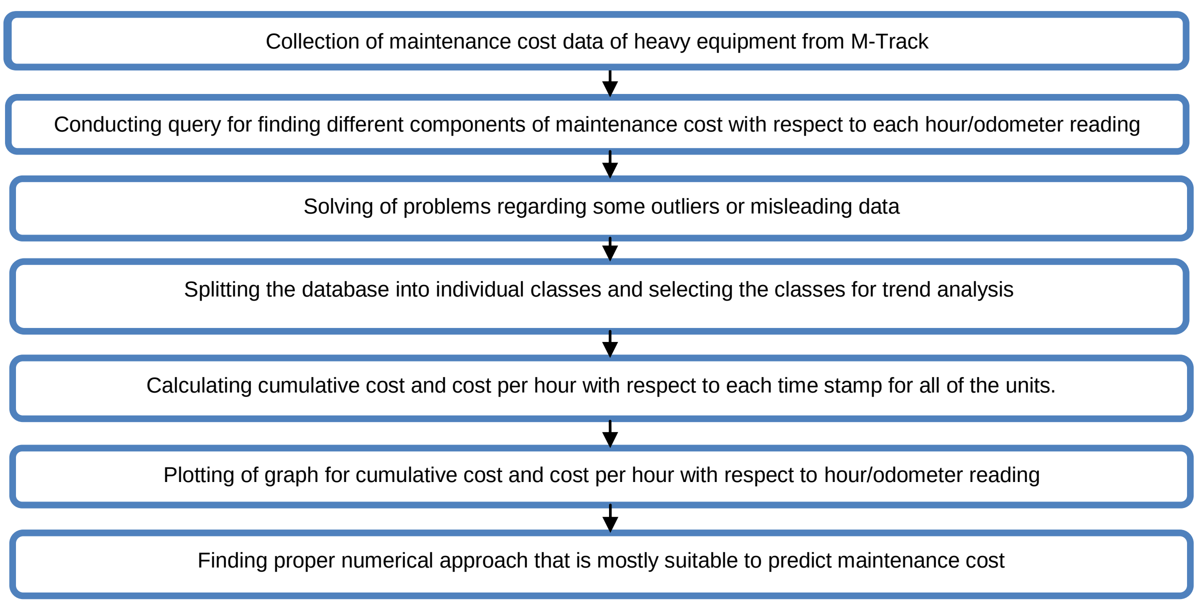

Figure 3: Flow chart of the systematic procedures for generating trend of maintenance cost from the given database

The M-Track database for equipment maintenance cost is available for more than hundred of classes. But the main focus was given within couple of classes as per the requirement of the industrial partner. From the pre-processed database, discussed in the previous section, cumulative maintenance cost and maintenance cost per hour for each of the equipment pieces was calculated to build a proper methodology for prediction of maintenance cost. From the Cumulative Maintenance Cost vs. Hour-meter Reading graphs, which were plotted for all required classes for industrial partner, it was observed that all the equipment pieces of the same class do not start from the same hour-meter reading as shown in the left graph of Figure 3. Therefore, it is difficult to draw a common trend of a class from this cumulative cost data. If the cumulative cost data can be transformed to maintenance cost per hour, then the problem can be solved, because in that case, the cost data always represents average cost per hour (right graph in Figure 3). Also it is convenient to use cost data for any budgeting estimation or any other calculation by maintenance cost per hour.

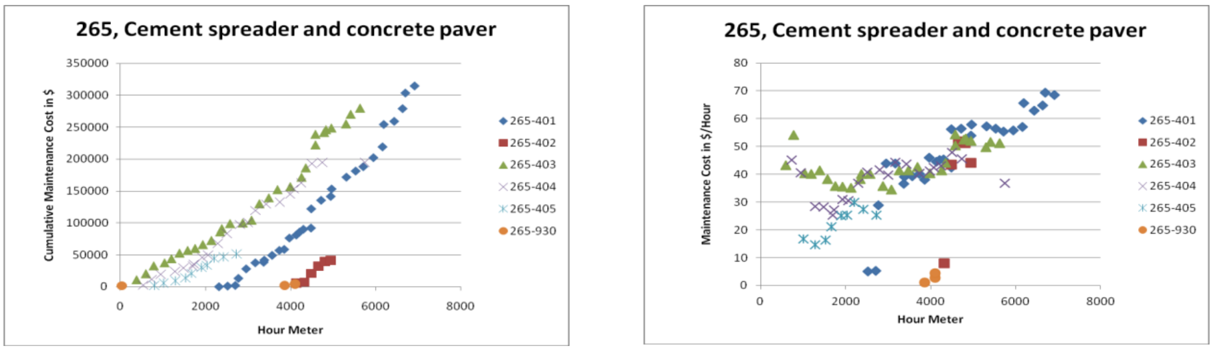

Figure 4: Trend of maintenance cost for Class 265

After plotting the graphs, different trends are shown. In each of the figure of 5, 6 and 7 there are two graphs- left graph shows the trend of each individual unit of a class where the right graph shows the trend of all the units of a class together. Also in the right graph a regression analysis by second order polynomial equation was done to predict maintenance cost per hour. Second order polynomial equation was selected because the value of coefficient of determination (R^2) is higher for this equation than exponential, logarithmic or power equations (Table 3); on the other hand for 3rd or 4th order polynomial equations R^2 values do not increase significantly but those are more complicated to implement practically.

Table 3: Sample of comparison of different numerical approach

Class No	Coefficient of determination (R^2)				
	Exponential	Linear	Logarithmic	2nd order Polynomial	Power
205	0.34	0.4	0.32	0.43	0.28
223	0.57	0.61	0.46	0.65	0.52
256	0.26	0.29	0.31	0.31	0.31
265	0.26	0.47	0.31	0.54	0.17

There was typically an upward trend for maintenance cost per hour, but in a few cases, there are downward as well as fluctuating upward and downward trends. Figure 5 is illustrating an upward trend or a trend of increasing maintenance cost per hour for tandem rollers (less than 5 ton). Figure 6 is also showing the same trend for cement spreader and concrete paver. But in figure 7 a decreasing maintenance cost per hour with respect to hour meter reading is visualized for Vibratory rollers (double) drum of 80+ which is unusual. The main reason behind this could be high initial maintenance cost. Initial high maintenance cost could occur due to early large preventative maintenance or planned maintenance work. These explanations were taken from the specialists of Standard General Inc.

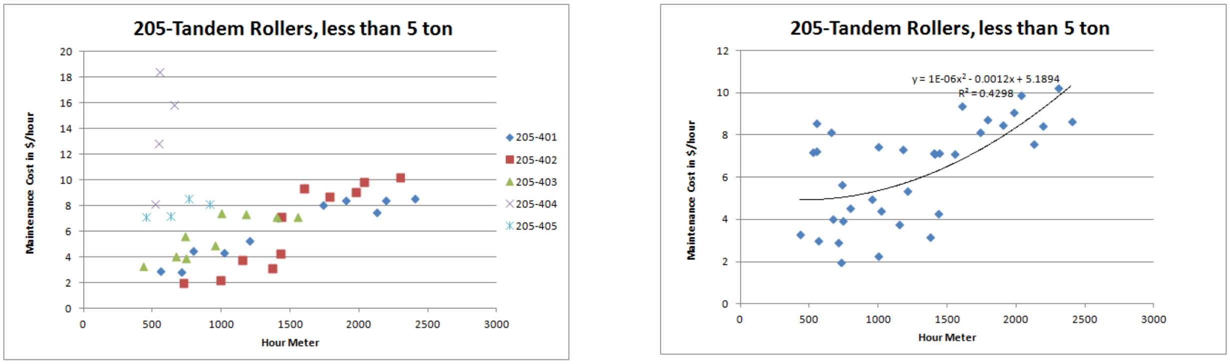

Figure 5: Maintenance cost trend analysis for class 205

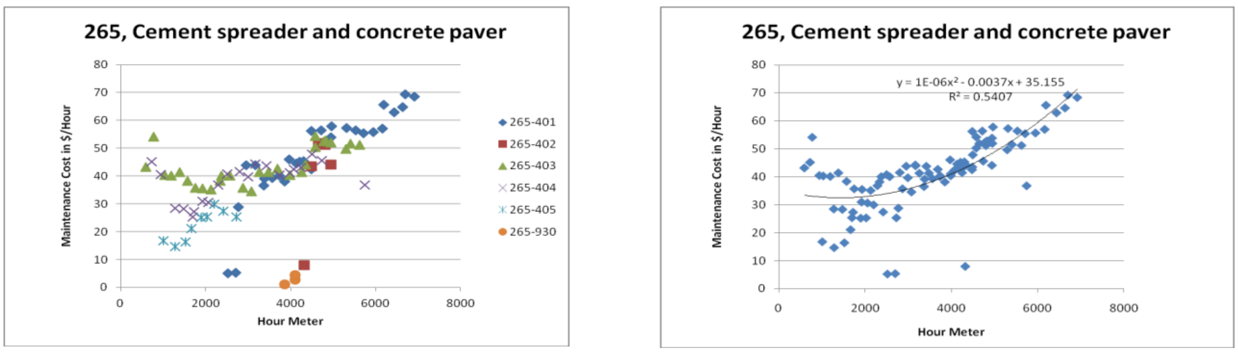

Figure 6: Maintenance cost trend analysis for class 265

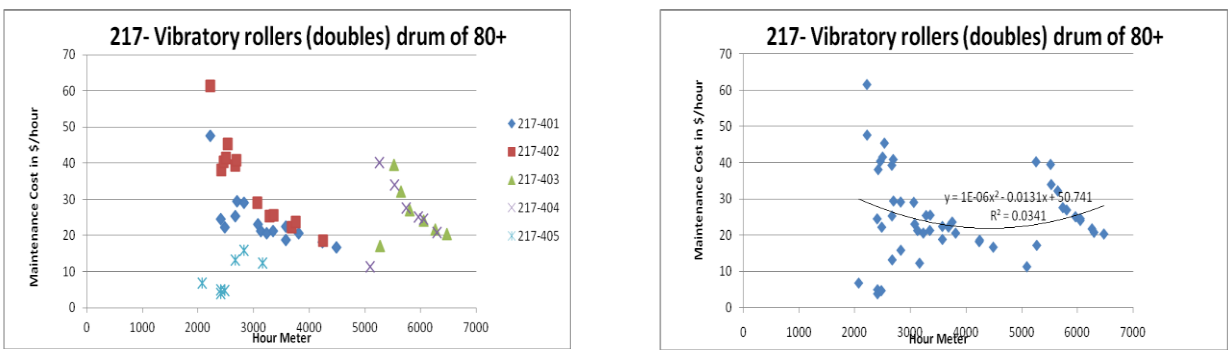

Figure 7: Maintenance cost trend analysis for class 217

For most of the cases R^2 value for regression analysis remains within the range of 0.4 to 0.6. So in further research, it will be tried to find out more accurate algorithm to predict maintenance cost for this given database.

5. Conclusion and Summary

Since the task of maintaining heavy equipment is an enormous job, that’s why it is important for today’s industrial sector to predict maintenance costs accurately. Proper operation of all equipment is not the only concerning factor for an equipment manager, but also he/she has to take decision regarding upcoming year’s budget, replacement of equipment etc. If the prediction of maintenance cost could be formulated, that will also help to take decision regarding replacement of equipment. Both of these analyses are essential for running a fleet at optimum operation cost.

In this research paper trend analysis and prediction of maintenance cost have been discussed. Moreover, this paper has presented the challenges that were faced during data collection and preparations. It was found that maintenance cost per hour is more convenient to use in this research work than cumulative maintenance cost. In this paper, different trends of maintenance cost have been analyzed and usual and unusual maintenance cost per hour trends have been shown and described. The usual trend of maintenance cost is upward, but for some classes it can become downward due to high initial maintenance cost. Lastly it has also been elucidated that for predicting maintenance cost per hour from the given database second order polynomial equation is most suitable than any other numerical approaches.

Some areas of improvement and extended research work could be-

- Application of different data mining algorithms to enable more accurate prediction of the maintenance costs.
- Formulation of a proper methodology for replacement of heavy equipment.
- Incorporation of proper data collection method into the software M-Track. Whenever any data about any equipment is being stored, the corresponding hour meter or odometer reading should be taken for future research work.

6. References

Asfahl, D.R., Moore, C.S., Brown, R.R., Santarelli, D.F., Santarelli, C.F., and Santarelli, R.F.(2006). “Construction Equipment Management for Engineers, Estimators, and Owners.” CRC Press.

Bakht, G.M. K., Ahmad,H., Akram, A.and Karimi, M.(2009). “Repair and Maintenance Cost Models for Mf285 Tractor: A Case Study in Central Region of Iran.” Advances in Biological Research 3 (1-2): 19-23.

Clutts, C. A.(2010)., May, 2010. “Profitability versus Construction Equipment Maintenance.” MSE thesis, Purdue University, West lafayette, Indiana, US.

Chien, Y.H.; Chen, J.A.; , "Optimal age-replacement model with minimal repair based on cumulative repair cost limit and random lead time." Industrial Engineering and Engineering Management, 2007 IEEE International Conference on , vol., no., pp.636-639, 2-4 Dec. 2007.

Gillespie, J. S. and Hyde, A.S. (2004). “The Replace/Repair Decision for Heavy Equipment.” Virginia Transportation Research Council, Charlottesville, Virginia.

Hall, R. (1997). “Analysis of Mobile Equipment Maintenance Data In an Underground Mine”. M. Sc. thesis, Queen's University, Kingston, Ontario.

Halpin, D.W. and Senior, B.A. (2010) Construction Management. John Wiley and Sons. Inc.NJ.

Mitchell, Z., Hildreth, J, and Vorster M.(2011). “Using the Cumulative Cost Model to Forecast Equipment Repair Costs: Two Different Methodologies.” J. Constr. Eng. Manage., 137(10), 817-822.

Nunnally, S. (2000). Managing construction equipment, Prentice-Hall, Upper Saddle River, NJ.

Pascuala, R. and Ortegab, J.H. (2006). “Optimal replacement and overhaul decisions with imperfect maintenance and warranty contracts”. Reliability Engineering & System Safety, 91(2), 241–248

Popova, E., Yub, W., Kee, E., Sunc, A., Richards, D., Grantom, R., (2006) “Basic factors to forecast maintenance cost and failure processes for nuclear power plants.” Nuclear Engineering and Design, 236(14–16),1641–1647.

Rashidi, M. and Ranjbar, I. (2010). “Modeling of Repair and Maintenance Costs of John Deere 4955 Tractors in Iran.” American-Eurasian J. Agric. & Environ. Sci., 9 (6): 605-609.

Vorster, M. (1980). “A systems approach to the management of civil engineering construction equipment.” Ph.D. thesis, Univ. of Stellenbosch, Stellenbosch, South Africa