DEVELOPMENT OF OPTIMIZED MAINTENANCE SYSTEM FOR VEHICLE FLEET

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ABSTRACT

Vehicle fleet holds a firm ground in both manufacturing and service industry. Fleet management plays a substantial role in an organization's growth. Maintenance of vehicle fleet is critical in terms of cost, availability and customer satisfaction. The major cause for delays is inefficient and ineffective maintenance procedures. To avoid major market losses, an efficient maintenance model is required. This research proposed a maintenance system that integrates the flow of information by incorporating different maintenance strategies. The analysis is carried out on the basis of likelihood of the failures. Five Why Analysis is used to identify the root cause. The model incorporates the inspection method by using checklists and maintenance schedules. The system is capable to provide the basis for an advance system development.

KEYWORDS: *Fleet Management, Fleet Maintenance, Condition-based Maintenance, Corrective Maintenance, and Preventive Maintenance.*

INTRODUCTION

Fleet Management is becoming a substantial element in determining an organization's growth. Among the modules of fleet management, maintenance holds a critical position. Only a properly maintained vehicle is considered to be safer, lasting, and dependable. It gives the customer "What/Where/When they want?". Maintenance of a vehicle fleet should be subjected to the philosophy of continuous improvement. Proper maintenance helps accomplishing the effective and efficient functioning of a vehicle and eliminates the critical problems that may leave the deliverables stranded in the middle of the road.

In contrast to developed countries, fleet in Pakistan is of secondary importance. These fleets are used to facilitate customers not the owners. For example school owners emphasized more on student fees and staff salaries but the cost associated with maintenance of buses and vehicles fleet is considered alien to overall school cost. If maintenance cost is saved the burden on students can be reduced. Additionally the students and staff will get on time transportation at a lower cost.

Depending on the requirement the fleet could be of trucks, buses, cars, vans, heavy earth moving equipment and pickups etc. Table 1 shows types of organization and the fleet they may have. An organization may have more than one fleet. An Oil and Gas Company have a fleet of pickup for officers and workers but also for transporting crude oil and water they have fleet of containers.

LITERATURE REVIEW

Maintenance, Repair and Operation (MRO) is defined as all actions that have the objective of retaining or restoring an item in or to a state in which it can perform

Table 1. Types of Fleet

S.No	Sector	Organization	Fleet of
1	Health Care	Hospital	Ambulances
		Mobile Health Units	Ambulances
		Clinics	Ambulances
2	Education	Schools	Busses
		Colleges	Vans
		Universities	Coasters
3	Production	Cement Industry	Dumpers
		Construction Industry	Tractors
		Oil and Gas Company	Pickups
4	Food	Restaurant	Motorcycles
		Hotel	Cars
		Guest House	Cars
5	Service Provider	AC Repairer	Pickups
		Internet Service Providers	Motorcycles
		Cable Services	Motorcycles

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Table 2. Maintenance Strategies

S.No	Maintenance Strategy
1	Preventive Maintenance
2	Corrective Maintenance
3	Predictive Maintenance
4	Condition Based Maintenance (CBM)
5	Reliability Centered Maintenance (RCM)
6	Computerized Maintenance Management System (CMMS)
7	Industrial Internet

its required function. The actions include the combination of all technical and corresponding administrative, managerial, and supervisory actions[1].

Maintenance refers to the activities required to keep a facility in "as built"condition and continuing to retain its original productive capacity[2]. Maintenance assures that physical assets continue to do what their user wants them to do[3]. Maintenance operation adoption for an organization depends on financial resources and asset management.

Fleet maintenance is a complex phenomenon. Various factors such as number of vehicles, types of vehicle, and maintenance personnel experience are dependent on it. Integration of information flow from different maintenance operation needs to be analyzed systematically. Differentorganization uses different maintenance strategies. Maintenance strategies studied for this research are enlisted in Table 2.

Preventive maintenance includes all actions carried out on a planned, periodic and specific schedule to keep an item/equipment in stated working condition through the process of checking and reconditioning[4]. Corrective maintenance incorporate unscheduled maintenance or repair to return items/equipment to a defined state, carried out because maintenance persons or users perceived deficiencies or failures[4]. Predictive maintenance utilizes the use of modern measurement and signal processing methods to accurately predict and diagnose items/equipment condition during operation[4].

Condition Based Maintenance (CBM) is a management philosophy that performs repair or replacement decisions on the current or future condition of assets. It states clearly that the equipment needs proper monitoring and inspection on component level so that the condition of the equipment can be determined at any time throughout its entire life cycle[5]. Reliability-centered maintenance (RCM) is used to determine the maintenance requirements of any physical asset in context of its functional history[6].

Computerized maintenance management system (CMMS), also known as enterprise asset management and computerized maintenance management information system (CMMIS) is often chosen as a reference to develop maintenance system. It allows the user or in this case organization to keep track of their assets in every possible way.Maintenance optimization is greatly facilitated when companies adopt a World Class Manufacturing/ Maintenance (WCM) philosophy or management strategy in conjunction with CMMS implementation. CMMS software was seen first around 1976[7].

The concept of Industrial Internet is coined by General Electric, which refers to the integration of complex machinery with the help of networking, sensors and software used as a bridge. Industrial internet combines the impacts of machine learning, big data, the working internet concept and machine-to-machine communication to extract machines data, perform analysis (often in real-time), and adjust operations accordingly[8].

Mass transit system community is evolving rapidly. Their need to adapt changes is inevitable. The extent to which transit community evolves depends on IT and implementation of modern techniques[9].

Apart from technologically advance systems, checklists are used to assess the health of a machine or a vehicle. Maintenance checklist is a document enlisting the items that need to be reviewed while performing maintenance operation. Maintenance items will vary depending on the type of maintenance and maintenance item[10].

Vehicle inspection checklists usually consider preventive or scheduled operations. For development of checklist, we analyze the system in consideration. Maintenance schedules provide the initial component list that needs to be reviewed[11].

In addition to the checklist a crunchy data related to likelihood of different failures is also required. Frequent

failures needs to be systematically analyzed. Five Why Analysis is used to analyze frequent failures. It is a great Six Sigma tool that does not involve data segmentation; hypothesis testing, regression or other advanced statistical tools. In many cases it can be completed without a data collection plan[12].

Five Why is a simple approach for exploring root causes and instilling a "Fix the root cause, not the symptom," culture at all levels of a company[13]. Japanese Industrialist Saki chi Toyoda presented the idea to keep asking "Why?" until the root cause is revealed. The number five is not a rule for why's required to reach the root cause level, but merely states that the researcher needs to ask the question until the root case is presented. What matters is that they fix recurring problems by addressing true causes and not symptoms - this is true progress[14]. The general Five Why methodology is explained in Figure 1, where the why question is asked until the symptom is identified.

METHODOLOGY

Objective is to analyze different organization fleet on the basis of maintenance strategies. It is reported that most of the organizations practice corrective maintenance with few exception that uses preventive maintenance. Moreover for maintaining vehicles health, most organizations do not follow manufacturer manuals. Such practices deteriorate vehicle life. A comprehensive maintenance system incorporating all the mentioned flaws will benefit all types of organizations.

First step towards improvement is to analyze the existing system. Current vehicle maintenance system for a gas distribution company and a university is thoroughly assessed. As Toyota vehicles are very common in Pakistan especially in Khyber Pakhtunkhwa province. For this research Toyota Vehicles fleet is selected. The data is available at online complaint center[15].

The data collected is segregated on the basis of likelihood. Microsoft Excel is used to analyze, group and segregate different types of failures. An important parameter in maintenance is Mean Time to Repair (MTTR). A time study is carried out at Toyota Motors Peshawar, Pakistan to calculate the MTTR. MTTR calculation highlights critical components. Scheduled intervals are obtained from manufacturer manual. These intervals are related to the distance travelled by a vehicle.

If the root cause is not resolved, the components failure will keep on recurring. Five Why Analysis is performed on the critical failures and components to identify the root causes.

Use of checklists is an easy way to periodically review machine/vehicle health. Checklists are developed using the analyzed data. Qualitative data such as location of field, operator mood, and improper routes are also considered for checklist development. These checklists acts as an input for predictive and condition based maintenance. Critical components needs inspection more often. Their condition needs to be monitored more frequently and more systematically. Five Why Analysis will not just be helpful in root cause identification but also in maintenance system development.

DATA COLLECTION AND ANALYSIS

For problem identification data is gathered for all types of cars. Complaints data, from Toyota website (Online Complaint Submission) extended over a period of 18 years (1996-2013) is used for this research[15]. Data included the problem category preceded by frequency of failure. The reason for considering all the data is the fact that all car problems database contains the problem data without restriction of make and model. So in case of fleet vehicles, the data can be considered without any reservation of model. It is assumed that the data stands true for personal, as well as commercial vehicles.

Data Segregation On The Basis Of Likelihood

For this research likelihood of the problem is selected as a segregation criteria. Likelihood *(eikos, versimilis)* captures the idea that something is likely to happen or has happened.

Problem categories are branched out to list the number of problems that can be associated with the main category. Engine and engine cooling problem could have been occurring due to numbers of reason, showing a variety of symptoms, so the drop of symptoms were enlisted for each category.

Table 3. Failures likelihood in Toyota Vehicles

S.No	Components	Likelihood
1	Brake Disc Rotor	5488
2	Tire Tread/belt	5333
3	Engine Cooling System	4792
4	Ignition	4497
5	Latches/locks/linkage	4212
6	Manifold/header/muffler/tail Pipe	4090
7	Brake Disc Pads	4016
8	Front Suspension	3980
9	Door Latch	3269
10	Timing Belts	3203
11	Wiring	3134
12	Wheel	2896
13	Brake Hoses, Lines/piping, And Fittings	2778
14	Brake Disc	2261
15	Steering Column	2243
16	Steering Tie Rod Assembly	2183
17	Transmission	2143
18	Rear Suspension	2058
19	Tire Blowout	1934
20	Radiator	1709
21	Clutch	1459

The data in Table 3 enlist 21 components of the vehicle that are more prone to failures.The critical components in terms of likelihood of the vehicle are considered to be the ones with higher frequency of failure over a period of time. Critical components need continuous inspection and monitoring.

Brake disc rotor with a frequency of 5488 failure is the most cirtical component. Followed by Tie rod belt with a likelihood of 5333. Clutch related issues are reported 1459 times. It is the least critical component interms of maintenance frequency.

Mean-Time-to-Repair Chart (MTTR)

MTTR is the average time that it takes to repair something after a failure. Average repair time for all minor and major parts, is calculated via time study at Toyota Service Shop, Peshawar. MTTR is the ratio of total downtime to frequency of failure. Summing up the average maintenance time and dividing it by the sum of repairs required by all the components.

Table 4. Average Maintenance Time

S.No	Critical components	Time (Hours)
1	Clutch plate	322
2	Pressure plate and cover assembly	196
3	Master cylinder	163
4	Clutch release bearing	130
5	Engine Fly wheel	120
6	Clutch disc	112
7	Clutch release fork	110
8	Control arm	110
9	Coil spring	108
10	Carburetor (Air fuel mixer)	99
11	Fan belt	99
12	Electric Power Steering	97
13	Radiator	79
14	Shock absorber	79

The unplanned downtime is generally contributed by the components given in the Table 4. Clutch plate accounts 322 hrs of maintenance per year. The average maintenance time decreases down the table, so does the monitoring level.

As Table 3 shows Clutch frequency on the lower whereas Table 4 indicates maximum maintenance time of 322 hours for Cutch failures. The deviation is because clutch is an integral component of a vehicle. Its quality and proper maintenance requires thorough inspection and minute quality tests. Table 3 indicates 21 components whereas Table 4 indicates 14 components. Few components are rarely inspected in Peshawar, Pakistan. Instead of writing zero, such components are ignored in MTTR calculations.

Scheduled Maintenance Intervals

Maintenance intervals include the manufacturer durations for preventive maintenance (fixed interval operations) that need to be performed on a vehicle in order to restore it, or keep it in working condition. The maintenance intervals data can be extracted from manufacturers manual. The scheduled maintenance intervals are classified on the basis of distance travelled notes

Table 5. Maintaining Vehicle after 10,000 km drive

S.No	Components	Action
1	Brake Line Pipes and Hoses	Inspection
2	Propeller Shaft Bolts	Tightening
3	Front and Rear Suspension	Inspection
4	Bolts/Nuts on Chassis/Body	Tightening
5	Engine Oil	Repair/Replacement

from odometer reading in kilometers. Table 5 shows manufacturer scheduled maintenance suggestion after 10,000 Km of drive.

RESULTS AND CONCLUSIONS

Proposed Solution

The proposed solution addresses the critical problems that are obtained from likelihood, interval classification, average maintenance time calculation and Five Why analysis. The finding regarding major critical components are used to develop checklists and assign strategies to reduce the overall downtime of the vehicle fleet.

Maintenance checklists are developed by on the basis of results obtained from classified maintenance intervals, average maintenance time and five Why analysis.

Classified maintenance intervals; acts as the primary input for checklist. The preventive maintenance operations listed by the manufacturer cannot be delayed, as they are based on component's design life. Average maintenance time chart; acts as secondary input; the repair operations with higher maintenance time is assigned higher priority. Findings from Five Why Analysis are also used in checklist development. As shown in Table 6, a total of 4 checklists are developed.

Daily Inspection Checklist includes the critical components on the basis of Average Maintenance Time. The critical components need to be addressed more often. Daily checklist includes vehicle interior/exterior condition checks, fluid and function checks, before setting the vehicle on road. Daily inspection covers the components that cannot be neglected at any cost. The basic fluid and function checks include minor problems can lead to the major vehicle component failure.

Table 6. Different Checklists

S.No	Checklist
1	Daily Inspection Checklist
2	5000 Km Checklist
3	10000 Km Checklist
4	15000 Km Checklist

5000 Km Maintenance Checklist includes the necessary repair and replacements and inspections of the components. Daily inspected components are thoroughly inspected to check if there is any need of necessary replacements.

10,000 Km Maintenance Checklist includes both daily-inspected components and components inspected at 5000 Km. Same components need monitoring and inspection at 20,000; 40,000 Km.

15,000 Km Maintenance Checklist is roughly estimated to be annual inspection. It will take into account all the mentioned checklists. The thorough inspection will reveal any damages, which will be replaced, lubricated, cleaned or tightened accordingly. 15,000 Km maintenance needs to be repeated at 25,000; 35,000; 45,000 Km.

Proposed Model

The proposed maintenance model incorporated the important attributes of different maintenance strategies that helps the organization to solve problems with record keeping, service log and report generation.

The proposed model is developed keeping in mind the capabilities of corrective, preventive and condition-based maintenance. Corrective maintenance strives to provide information for the failures that occur at random intervals. Preventive maintenance is also referred to as scheduled maintenance and access information at fixed intervals. Condition-based maintenance provides the system with live data from Engine Control Unit. Live data is acquired in form of Parameter-Identifiers (PIDs) by interfacing the online system to Engine Control Unit (ECU) either by wiring or Bluetooth interfaces.

Inspection and monitoring includes record track of all the failures such as sudden failure inspection, interval inspection, and live ECU data. The problems that occur

abruptly are generally subjected to Five Why analysis. But once historical data or service logs, and enough failure data is generated for a specific vehicle problem, sudden failures can be tallied and eliminated easily. Five Why Analysis gives us the root cause for the problem, so by eliminating the root cause, failure can be prevented. Five Why Analysis gives us a clear understanding of critical vehicle components. Same procedure can reveal the causes for an abrupt halt in vehicles. Daily inspection includes the visual checks that are performed before a vehicle is set on route. Daily inspection addresses odometer reading for daily mileage, vehicle interior/ exterior condition monitoring, fluids Check such as brake, engine, clutch fluids and functions check, like MIL, starter, stall, horn etc.

Database serves as the mapping system as it holds the maintenance strategies plus all the data coming from inspection and monitoring module. Vehicle functions are linked to database management system by networking. It provides the maintenance system with the means to prioritize the work order, generate reports, and keep vehicle service logs. With the ability to keep track of all activities of the system, decision-making is more effective and reliable as compared to the traditional system.

Networking is the most important component because the flow of process information cannot be achieved without the help of working Internet. Networking of the system allows machine-to-machine communication, and interaction of database management system with real-time data depends on it.

CONCLUSION

Organizations treat vehicle fleet as a secondary asset. In reality, vehicle maintenance and vehicle capital cost accounts for a huge sum of investment. Maintenance costs are directly reflected in overall project cost. Poor record keeping and systematize maintenance system deteriorate not only vehicle life but also add risk costs. Such risks might become fatal. A simple hybrid system compromising of different maintenance strategies and available technology is proposed in this research. Maintenance activities integrated with electronic control systems will reduce the risk of redundant documentations as well as helps the maintenance official to have better efficiency. The proposed model helps in record keeping and generating periodic and condition based maintenance orders.

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