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A User Information System for Diagnosing Faults in Passenger Cars

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ABSTRACT

Transportation plays a vital role in the development of any nation. The density of motor vehicles especially passenger cars and other commercial vehicles is increasing day by day. The vehicle experts may not be available particularly on long express highways in the vicinity of unidentified location where car failure takes place. The purpose of the study is therefore, to identify the root causes which help in car failure diagnosis and evolve a user information system. Eight major causes, forty four sub causes and 142 sub-sub causes have been identified. A cause and effect diagram has been developed through a process of iterative-interactive consensus driven methodology, as advocated by second generation system design paradigm. A user information system was developed which provide support to the car owners, drivers and inexperienced mechanical engineers in case of non-availability of the experts. The system has been tested and gave promising results.

KEYWORDS: Failure, Diagnosis, User information system, Cause and effect diagram.

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1. INTRODUCTION

Today transportation is the prime need for the development and growth of human being. The mode of transport facility provides better accessibility to banks, offices, hospitals, markets etc., with benefits that result in positive multiplier effects such as the socio-economic opportunities and new possibilities in employment and additional investments. Roads are the dominated mode of transportation in India and work as the lifeblood of the Indian economy. They carry almost 90% of the country's passenger traffic and 65% of its freight. The vehicles used for transporting passengers or goods depend upon the distance, weight quantity and volume.

Now a day the vehicles are the subject of status and hobbies rather than necessity for people. The vehicle manufacturers are increasing their production every year. The number of motor vehicle production is increasing gradually every year and expected to rise in forthcoming years too. About 90.78 million motor vehicles were produced globally in the year 2015 out of which India shares about 4.1 million excluding the production of three and two wheelers. In the financial year 2014-2015 the total production of vehicles were 23.4 million including passenger, commercial and three / two wheelers by Indian automobile industries.

As per the increasing demand Indian automobile companies are doing their expansions and the well-known foreign vehicle manufacturers too entering into the Indian market. Further the size of this market is expanding leaps and bounds which is a good signal for the better future of automobile industry. Therefore, automobile industries can be seen as an area of many employment opportunities for automobile and allied engineers particularly in India.

If a car is being compared with a human body it is being observed that there are several similarities as well as dissimilarities exist between them.

There are several systems in a car similar as in a human body, each performing some important role in the proper functioning of the car. For example if accumulation of heat took place in a human body due to problem in circulatory system, it results in an increase in body temperature causing human discomfort and disturbances in the functioning of the internal organs. So attempts are required to reduce the body temperature first by cooling the body and then diagnose the cause and if attention is not paid in time can cause severe damage to internal organs and may tend to death. Similar is the case with the car, if proper dissipation of heat is not taken place through the car engine the average temperature of the car increases and disorder took place in the normal functioning of the engine and if attention is not paid in time it can tend to severe damage to engine components. So proper cooling of a car engine is desired and cannot be neglected. It is clear with this example that the cooling system of a car is analogous to the circulatory system of a human body. There are several

systems of the car which are analogous to the systems in a human body although some of the analogies are as shown in Table 1.

Table 1- Analogies between a human body and a car

System Category	Human Body	Car
Primary	Heart	Engine
	Brain	Software
	Lungs	Air Filters
	Eyes and Ears	Array of advanced safety sensors
Secondary	Digestive system	Fuel system
	Endocrine system	Computer system
	Nervous system	Electrical system
	Respiratory system	Air induction system
	Urinary system	Exhaust system
	Skeletal system	Chassis system
	Muscular System	Power transmission system
Auxiliary	Organs control	ECU
	Knee	U-joint
	Hand	Steering
	Nostrils	Intake and exhaust manifold
	Social Security Number	VIN (Vehicle Identification Number)

Although there exist several similarities between a car and the human body; there are some basic differences exist between a human being and a car. A car is the creation of humans and it was created to make their transport easier and comfortable while cars do not create anything as such. Humans have different organs made of flesh and blood performing different functions while cars do have mechanical parts. Life is just not mechanical unlike cars for humans. Humans have feelings and emotions and can express their happiness, sorrow, pain, love, anger etc. while cars have no feelings and emotions and just work as per the details fed into their mechanical brain or operated by a human being. Humans have the capability to understand situations, and behave according to their consciousness but cars cannot do so. Cars do not have original thoughts unlike humans and in addition have limitations to their performance because they need humans to guide them. The differences between the few activities performed by a human being and a car are shown in Table 2.

Table 2- Differences between the activities of a human body and a car

Activity	Human Being	Car
Intelligence	Natural	Artificial
Age	Appreciated with time	Depreciated with time
Energy Source	Food and Drinks	Fuels

As like our body that needs regular check-up, diagnosis of disease and its treatment by a doctor for a healthy living, a car too need regular check-up, fault detection and remedy of the fault through preventive maintenance by an expert auto mechanic for smooth running and long life of the vehicle and would save money on repairs in future. The analogies between the maintenance of a car

and the treatment of a human body can be categorized in general, preventive and breakdown as shown in Table 3.

It is often frustrating to encounter any form of car-trouble particularly if the car owner is in a hurry or far away from an auto shop. Such type of incidents can be avoided with the regular car check-ups. Regular car repair and maintenance can help preventing the possibility of being stuck in such miserable situations. Maintenance of a car can range from basic car maintenance to an overall. Unfortunately, car maintenance work shops are still using traditional maintenance techniques with insignificant changes for automation.

When a vehicle comes across any fault, the driver would have to call either an automobile engineer or a roadside mechanic simply because he has no technical skill or knowledge to diagnose such faults. Dependence on the expert can be minimized if its expertise can be documented into computer system.

Basically car failure detection is a complicated process and requires high level of expertise. A diagnostic assistance system for car failure proved to be a very useful tool for equipment servicing and further it increases the worker's satisfaction.

Cho et al. initially proposed an expert system using fuzzy relations to deal with uncertainties imposed on a fault section diagnosis of power systems¹. Gelgele et al. developed a prototype named EXEDS [expert engine diagnosis system] for an automotive engine using Knowledge Pro, an expert system development tool². The developed prototype was to assist auto mechanics in fault diagnosis of engines by providing systematic and step-by-step analysis of failure symptoms and offering maintenance and service advice. As the developed model was restricted to engine only would not be useful for other important systems of the vehicle. Al-Taani also presented a knowledge based system for car failure diagnosis using CLIPS expert system language³. He claimed that the developed system can be extremely useful in consistent car failure detection although it is expected to improve it by adding sufficient domain knowledge.

Kim et al. devised a fault detection and diagnosis [FDD] method using decentralized and centralized approaches to enhance the reliability and safety for longitudinal control of an autonomous al-terrain vehicle⁴. Further Kim et al. developed a knowledge based hybrid failure diagnosis system for urban transit consisting of both electrical and mechanical entities for improving the reliability and efficiency of the maintenance process⁵.

Table 3- Analogies between the maintenance of a car and the treatment of a human body

Maintenance / Treatment category	Human Body	Car
General	<ul style="list-style-type: none"> - Check height to weight ratio - Check age - Check eyesight - Check belly fat - Check extra thin - Check breathing - Check insufficient / extra sleeping - Check whether getting tired soon etc. 	<ul style="list-style-type: none"> - Check all lights are working, - Check air pressure in tires - Listen for any strange sound inside and out - Check tires have enough tread - Check different fluid levels like antifreeze solution, power steering fluid, coolant fluid, wiper fluid, gear oil and fuel quantity - Check leakage of any fluid - Check battery leak - Check engine belt, timing belt - Check loose connections, rusting terminals - Check spark plug - Parking in shade etc.
Preventive	<p><i>Scheduled check up by the regular physician:</i></p> <ul style="list-style-type: none"> - Haemogram test - Blood Sugar test - Liver function test - Kidney function test - Lipid profile - Uric acid test - Chest X-ray - ECG Test - Hepatitis-B Test - TSH for thyroid - Abdomen ultrasound - Child / Adult vaccinations - Eye Checking etc. 	<p><i>Scheduled inspection in company workshop:</i></p> <ul style="list-style-type: none"> - Washing and waxing - Changing clutch cables - Changing brake liners - Changing oils - Changing spark plug - Replace engine and cabin air filters - Replace wind shield wipers - Wheel balancing - Alignment check etc.
Breakdown	<ul style="list-style-type: none"> - Brain surgery - Organ transplant - Bypass surgery - Body joints replacement etc. 	<ul style="list-style-type: none"> - Dead battery - Flat tire - Empty fuel tank - Engine belt / Timing belt broken - Coolant pump failure - Transmission failure - Car collision etc.

Apart from vehicle and power systems the computer based expert systems are increasingly used to improve the medical services by the precise diagnosis of human diseases. In this reference P. Patra et al. an analytical model for the diagnosis of common human diseases. In both cases there was a necessity to test the developed model on several more databases although databases are typical proprietary and difficult to obtain⁶.

Sharma et al. presented a car failure fuzzy fault diagnostic system which uses fault tree analysis to represent knowledge of the casual relationships between various components of a car engine and process operation in the whole system⁷. The researchers reported that fault tree analysis is useful for system reliability and fault identification related risk involved in the system, since it illustrates the failure logic of a system and shows combinations and sequences of failure which can lead to a failure condition under consideration.

Jindal et al. developed a prototype model of car failure diagnosis expert system although with very limited utility⁸. Mostafa et al. also presented a Knowledge Based System (KBS) for car failure and malfunction diagnosis⁹. They reported the developed CFMDAS is utilized to assist inexperienced mechanics or drivers who face sudden failure in the car and provide decision support system. They also claimed the CFMDAS is considered as an interactive training tool that can provide expert guidance in car fault detection. Widodo Budiharto developed a model of expert car diagnosis system able to diagnose the failure of the car using Bayesian approach¹⁰.

Moon et al. developed a parallel model based fault detection algorithm for an electronic parking brake [EPB] system which consists of an electronic control unit with built-in current sensor and braking force sensor¹¹. The said algorithm detects severe failures of the force sensor and warns the driver in advance to prevent accidents due to failures.

Olanloye et al. presented an expert system for motorcycle fault diagnosis which serves as a guiding tool to the owner of the rider especially when the automobile or mechanical engineer is not readily available¹².

S. Adsavakulchai presented an expert system for car failure detection using Visual Basic and Microsoft Access as tools to help inexperienced mechanic as the decision support system¹³. The investigators concluded saying that the car detection failure system devised by them is helpful although it might not give complete guide as human expert.

E. Roanes-Lozano et al. developed a friendly graphical user interface in order to ease the communication with the application and its use in remote using any smart device with internet connection¹⁴. In these systems the diagnostic devices provide user centered diagnostic services and prevents accidents caused due to the engine malfunction by providing real-time communication with the use of wired system and Bluetooth module.

2. PROBLEM STATEMENT

A considerable amount of work is being carried out in the development of a decision support system for the diagnosis of faults in a car using knowledge based experts system. Although it is being observed that in reference to the fault diagnosis of a car either the work is being restricted to the engine failure only or if the whole car is being considered a very few system parameters are considered.

With this inference of literature survey it seems that there is a possibility of developing a more versatile user information system using different approach for car failure diagnosis by taking into consideration the maximum variants of car failures.

3. METHODOLOGY

It is evident from the reviewed literature that all the possible failure causes plays a vital role to keep the vehicles in good condition. To know all possible causes the cause and effect diagram has been developed. The synoptic procedure is given in following three steps.

- Step 1: Listing and categorization of general observations during car failures
- Step 2: Listing, categorization of various car failures with their causes and drawing of cause and effect diagram using Normal Group Technique (NGT)
- Step 3: Algorithm and computer programming of user information system for car failure diagnosis

4. DEVELOPMENT OF CAUSE AND EFFECT DIAGRAM USING NGT

For the data collection it is recommended to distribute the questionnaires amongst the experts and recollect the responses from them for further use¹⁵. In view of this a workshop was conducted to know the possible causes of vehicle failure. In this workshop domain expert from automobile sector, eminent persons from academia and the experienced workers of all leading automobile workshops were invited.

Following triggered question was asked to all the domain experts at the beginning of the workshop as shown below.

“What are the causes of vehicle failure? Explain any four common causes in your opinion”.

In all 220 causes were reported by the 55 workshop participants in the first phase of the workshop. After excluding repeated and irrelevant causes a list of 186 causes was finally selected. All causes were coded, merged and key worded.

In the second phase of the workshop a set of 186 causes were distributed to all experts. They were asked collectively to separate and categorized them under main causes as per the relevance. Total 8 main causes of car failures were identified with 44 sub causes and 142 sub-sub causes.

In the third phase of the workshop all the main causes were distributed amongst the participants and suggested to give a weight-age in 10 point scale (10 most and 1 least) with their opinion. In all 55 sets were collected. The average score of each cause was then plotted as shown in Fig. 1.

It is seen that battery and Ignition failure is the most common cause of car failure followed by engine failure. The differential failure is the least occurring failure.

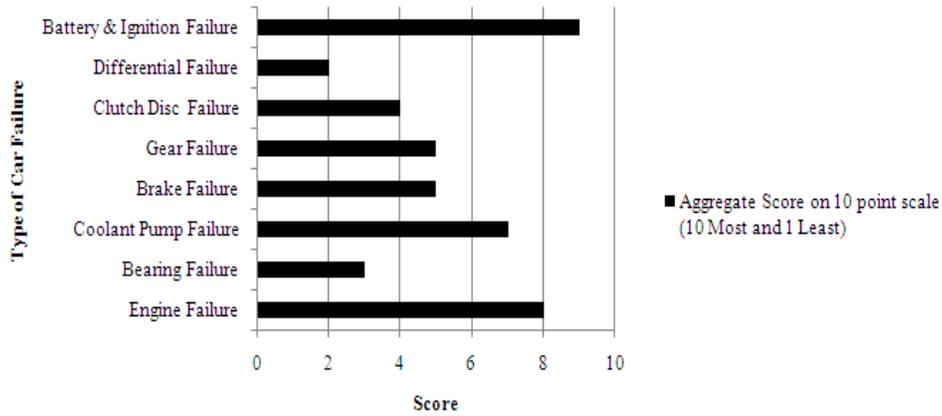


Fig. 1- Average score of each failure by the workshop participants

The enlisted various car failures suggested by the workshop participants are then represented in the form of cause and effect diagram. All the causes of the car failure came out in the exercises carried out in the above described workshop are also presented in the form of Cause and Effect diagram for the thorough and systematic diagnosis of car failures as shown in Figure 2. The cause and effect diagram is useful for system fault identification as it illustrates the failure logic of a system and shows the combinations and sequence of failures. The nomenclatures of the legend used to represent Cause and Effect diagram in Fig. 2 are as shown in Appendix (Refer Table A1).

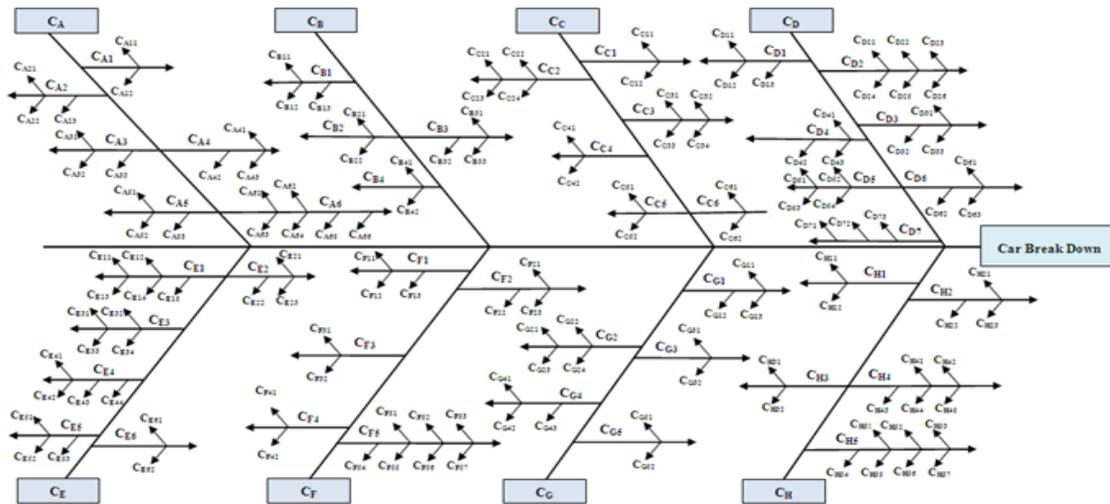


Fig. 2- Cause and effect diagram for car failure diagnosis

5. PROCEDURE OF CAR FAILURE DIAGNOSIS

A computer program is written in C++ to diagnose the fault in a car due to large number of fault parameters. The flow chart of the car failure diagnosis is as shown in Fig. 3.

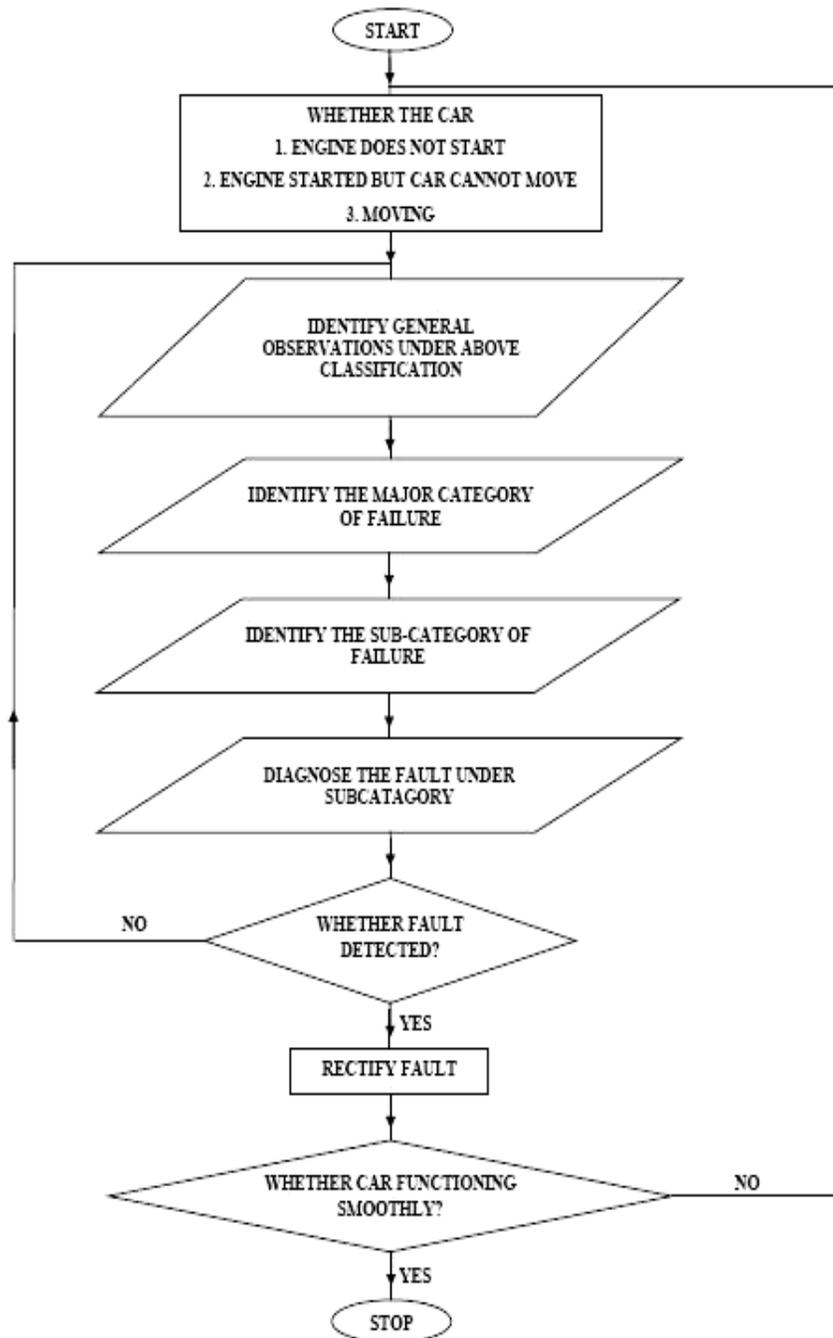


Fig. 3- Flow chart of the car failure diagnosis

The logic is developed by linking the cause and effect diagram with the general observations in case of car failure as shown in Appendix (Refer Table A2). Car failure can be occurred in any one of the situations.

- i) Engine does not start
- ii) Engine started but car does not move from its place
- iii) Car is moving

The user first of all will select the position of the car on the computer display while failure took place. As soon as the user selects the failure position the normal symptoms under that category will display. The user has to select the right symptom which he observed on the failure of a car. On selecting an observation, the relevant possible major causes of car failure/s will display.

The user then can select given single/multiple car failure option by which the sub causes for the given type of failure will display. Further the sub-sub causes can be displayed after the selection of a particular sub cause. Thus user can identify finally the root cause of the failure by following the step by step instruction given by the proposed knowledge based user information system and can take proper remedial action. The display on the computer screen during the execution of user information system is as shown in the Fig. 4.

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DOSBox 0.74, Cpu speed: max 100% cycles, Frameskip 0, Program: TC
*****Car Failure Diagnosis System*****
-----
Are you facing any one of the below problem?
*****
1. When car engine does not start?
2. When engine started although car does not move?
3. When car is in moving condition?
*****

Choose the problem you are facing:3
*****
When car is in moving condition:
*****
1. Whether dash board red light for engine attention is on?
2. Whether strange noises are coming from the engine?
3. Whether engine is overheated?
4. Is there any problem in power transmission system?
5. Whether proper air pressure is being maintained in the tires?
6. Whether brakes don't work effectively?
7. Whether harsh rubbing sound is observed when breakes are applied?
8. Whether car stops instantly while moving?
*****
What you observed from above?

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Fig. 4- Execution of user information system for car failure diagnosis

The developed user information system for car failure diagnosis is found suitable for precise diagnosis of nearly all types of car failures. It gives step-step by step guidance to the user including drivers, mechanics and students for training. The proposed knowledge based user information system for car failure diagnosis is observed to be a dynamic, consistent, unbiased, time saving and economical fault detection technique. It improves the productivity and can work continuously without stopping. It improves the driver's knowledge and can be used as a training tool for inexperienced mechanics and students.

6. DISCUSSION AND CONCLUSION

A user information system for car failure diagnosis using cause and effect diagram is presented in this paper. During the preliminary phase of collecting the data a workshop of vehicle experts and mechanics was conducted. The deliverables of the workshop was used to draw the cause and effect diagram for a car failure diagnosis. Nearly all major types of car failures are considered for its diagnosis in this proposed user information system. It seems as an important and convenient tool for fault finding in cars by the owners, drivers, inexperienced mechanics and for student's training. Due to the dynamic and time saving properties of this system a car mechanic may do more work in less time, thus earning more.

Currently the proposed user information system can carry out the diagnosis in most of the areas of car failure adding sufficient domain knowledge particularly, engine failure, bearing failure, coolant pump failure, brake failure, gear failure, clutch disc failure, differential failure and battery failure. As the system is developed with limited resources and in given time frame there may be chances that some of the facts might be missed. Although it is very clear that the proposed user information system is more reliable in fault diagnosis as nearly all the major causes responsible for the car failure are being considered. It is expected that after refining errors the developed user information system can be used as an efficient tool for car fault diagnosis and may be used for any car.

7. FUTURE SCOPE

Further work can be done to add the rest of the domain knowledge to cover all the car problems and to develop the proposed user information system in the form of mobile app.

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APPENDIX

Table A1- Causes of car failures

Le g.	Meaning	Leg .	Meaning
C _A	Causes of Engine Failure	C _{C5} 1	Worn out shaft, bushes and bearings
C _{A1}	Neglecting oil changes	C _{C5} 2	Damaged impeller blades
C _{A1} 1	Improper oil type	C _{C6}	Seal leakage
C _{A1} 2	Insufficient oil quantity	C _{C6} 1	Seal wear
C _{A2}	Flooding of engine	C _{C6} 2	Faulty bearing
C _{A2} 1	Driving through flood water or water sump	C _D	Causes of brake failure
C _{A2} 2	Heavy rainstorm	C _{D1}	Bad fluid pressure
C _{A2} 3	Water passes through intake manifold	C _{D1} 1	Fluid leak
C _{A3}	No start	C _{D1} 2	Inadequate pressure
C _{A3} 1	Breaking of engine belt / timing belt	C _{D1} 3	Inadequate fluid level in reservoir
C _{A3} 2	Faulty spark plug	C _{D2}	Rusty steel brake lines
C _{A3} 3	Empty fuel tank	C _{D2} 1	Older vehicle
C _{A4}	Overlooking oil leaks	C _{D2} 2	Exposed to road salts and moisture
C _{A4} 1	Deterioration of sealing	C _{D2} 3	Abrasive particles
C _{A4} 2	Wearing of suspension bushes	C _{D2} 4	Inadequate antirust coating
C _{A4} 3	Steering components	C _{D2} 5	Non-replacement of brake liners for a long time
C _{A5}	Disregarding the engine oil light	C _{D2} 6	Excessive use of brakes
C _{A5} 1	Sensor defect	C _{D3}	Bad master brake cylinder
C _{A5} 2	Catalytic converter defect	C _{D3} 1	Seal damage
C _{A5} 3	Less oil pressure	C _{D3} 2	Master piston wear
C _{A6}	Ignoring the cooling system	C _{D3} 3	Low fluid in the reservoir
C _{A6} 1	Avoiding regular flush	C _{D4}	Dirt or rust in the brake system
C _{A6} 2	Avoiding preventive maintenance	C _{D4} 1	Rusted brake disc
C _{A6} 3	Overheating of engine	C _{D4} 2	Chemical break down of oil
C _{A6} 4	Low coolant	C _{D4} 3	Oil impurity
C _{A6} 5	Failing electrical cooling fan	C _{D5}	Brake fluid boiling
C _{A6} 6	Blockage in cooling system	C _{D5} 1	Overheating of brake due to mountain driving
C _B	Causes of bearing failure	C _{D5}	Overheating of brake due to aggressive driving

		2	
C _{B1}	Looking closure	C _{D5}	Overheating of brake in racing cars
C _{B1}	Inadequate lubrication	C _{D5}	Overheating of brake due to riding for a long time
C _{B1}	Faulty installation	C _{D6}	Faulty ABS modulator
C _{B1}	Improper adjustment	C _{D6}	Defective sensors
C _{B2}	Poor adjusting	C _{D6}	Unresponsive brake pedal
C _{B2}	Over tightening	C _{D6}	Sporadic behavior from brake
C _{B2}	Misalignment	C _{D7}	Faulty power brake booster
C _{B3}	Poor metallurgy	C _{D7}	Leakage in vacuum hose
C _{B3}	Material defects	C _{D7}	Brake fluid leakage
C _{B3}	Worn out	C _{D7}	Leakage in diaphragm
C _{B3}	Spalling (Fatigue)	C _E	Causes of gear failure
C _{B4}	Poor quality	C _{E1}	Wear
C _{B4}	Low quality steel	C _{E1}	Metal to metal contact during operation
C _{B4}	Poor heat treatment	C _{E1}	Moderate wear due to inadequate lubrication
C _C	Causes of coolant pump failure	C _{E1}	Excessive wear due to rough running
C _{C1}	Bearing overload	C _{E1}	Abrasion due to foreign particles present in lubrication oil
C _{C1}	Over-tightened belts	C _{E1}	Corrosive wear due to chemicals present in the oil in contact
C _{C1}	Sudden overload due to rapid vibration	C _{E2}	Plastic flow
C _{C2}	Broken water pump housing and shaft	C _{E2}	Cold flow caused by heavy load on gears
C _{C2}	Cracked or broken fan blades	C _{E2}	Ripping due to high contact stresses under cyclic operation
C _{C2}	Cracked or bent pulleys	C _{E2}	Riding due to plastic flow of surface or sub-surface materials
C _{C2}	Overloaded bearing	C _{E3}	Pitting
C _{C2}	Excessive vibration and unbalance	C _{E3}	Initial pitting due to improper fitting of gears
C _{C3}	Cooling system contamination	C _{E3}	Distractive pitting due to surface overload
C _{C3}	Electrolysis	C _{E3}	Spalling due to excessively high contact stresses
C _{C3}	Additive gels	C _{E3}	Case crushing due to very high residual stresses in the gears
C _{C3}	Abrasive particles	C _{E4}	Fracture
C _{C3}	Water with High Mineral Content	C _{E4}	Fatigue breakage occurs due to excessive tooth load
C _{C4}	Thermal Shock	C _{E4}	Overload breakage caused by excessive load
C _{C4}	Adding cold coolant to the overheated engines	C _{E4}	Poor strength of the gear material

C _{C4} 2	Starting engine before adding coolant	C _{E4} 4	Random fracture due to flexure stresses in the gear teeth
C _{C5}	Excessive Vibration	C _{E5}	Scoring
C _{E5} 1	Frosting occurs due to heat in gear mesh	C _{G2} 3	Excessive resistance in the tires
C _{E5} 2	Moderate scoring due to excessive heat in gear mesh	C _{G2} 4	Spinning tires that suddenly catch either off-road or on track
C _{E5} 3	Destructive scoring	C _{G3}	Excessive burned ring and pinion
C _{E6}	Improper lubrication	C _{G3} 1	Excessive heat
C _{E6} 1	Incorrect lubrication viscosity	C _{G3} 2	Lubrication failure
C _{E6} 2	Incorrect lubrication level	C _{G4}	Normal ring and pinion wear
C _F	Causes of clutch disc failure	C _{G4} 1	Wrong lubricant type
C _{F1}	Flywheel damage	C _{G4} 2	Water entering into differential
C _{F1} 1	Gear slippage caused by failing of pilot bearing	C _{G4} 3	Vibrations caused by U-joints
C _{F1} 2	Excessive heat generated by unnecessary clutch driving	C _{G5}	Pitted bearing and race
C _{F1} 3	Vibrations due to spring mount mechanism of flywheel	C _{G5} 1	Excessive preload
C _{F2}	Incorrect driving practices	C _{G5} 2	Insufficient lubrication
C _{F2} 1	Incorrect gear selection while driving	C _H	Causes of battery and ignition failure
C _{F2} 2	Tow-starting or push-starting	C _{H1}	Acid stratification
C _{F2} 3	Repeated harsh clutch engagement at high engine rpm	C _{H1} 1	Battery not in use
C _{F3}	Incorrect clutch installation and adjustments	C _{H1} 2	Car used for travelling only short distances
C _{F3} 1	Dropping clutch disc on the floor during installation	C _{H2}	Accumulation of sulfation
C _{F3} 2	Incorrect alignment of pressure plate	C _{H2} 1	Undercharging of battery
C _{F4}	Premature clutch failure	C _{H2} 2	Irregular charging of battery
C _{F4} 1	Defective pressure pin	C _{H2} 3	Low electrolyte levels
C _{F4} 2	Material defects	C _{H3}	Sludge or mud formation
C _{F5}	Exclusive clutch slippage	C _{H3} 1	Normal expansion and contraction of plate material
C _{F5} 1	Worn down clutch facings to rivet heads	C _{H3} 2	Loss of plate capacity
C _{F5} 2	Heavily contaminated clutch facings with oil or grease	C _{H4}	Hot climate
C _{F5} 3	Burnt or disintegrated clutch facings	C _{H4} 1	Positive grid growth
C _{F5} 4	Clutch facing not in contact with entire surface	C _{H4} 2	Positive grid metal corrosion
C _{F5} 5	Overheated clutch pressure plate	C _{H4} 3	Negative grid shrinkage
C _{F5} 6	Diaphragm spring fractured or worn-out	C _{H4} 4	Buckling of plates
C _{F5}	Wear induced ridges on guide cams	C _{H4}	Loss of water

7		5	
C _G	Causes of differential failure	C _{H5}	Ignition faults
C _{G1}	Burnt ring and pinion	C _{H5}	Fouled spark plug
C _{G1}	Insufficient quantity of oil	1 C _{H5}	Bad plug wire
1 C _{G1}	Improperly set differential	2 C _{H5}	Weak ignition coil
2 C _{G1}	Decomposition of oil at high temperature	3 C _{H5}	Alternator failure
3 C _{G2}	Broken ring and pinion	4 C _{H5}	Bad ignition switch
C _{G2}	Continuous hammering by already broken gear piece	5 C _{H5}	Loose electrical wiring
1 C _{G2}	Excessively applied power	6 C _{H5}	Rusting of battery terminals
2		7	

Table A2- Observations when a car failure takes place

S. No.	Symptoms	Type of Failure/s
	<i>Case-I: When car engine does not start</i>	
1	Whether the battery is dead?	C _H
2	Whether the battery cables are loose or corroded?	C _H
3	Whether the starter relay wiring connections are bad?	C _H
4	Whether the ignition switch is bad?	C _H
5	Are the spark plugs / fuel pumps are faulty?	C _A , C _H
6	Whether the starter drive or teeth on the flywheel damaged?	C _F , C _H
7	Whether the bad alternator is not charging the battery?	C _H
8	Whether the ignition coil is bad?	C _H
9	Whether the fuel tank is empty?	C _A
10	Whether the engine belt / timing belt OK?	C _A
	<i>Case-II: When engine started although car does not move</i>	
11	Whether any one or more tires are flat?	C _M
12	Whether gear shifting mechanism is working properly?	C _E
13	Whether clutch disengagement and engagement is fairly done?	C _F
14	Whether power is transmitted uninterrupted up to differential?	C _G
15	Whether the differential is working fairly?	C _G
	<i>Case-III: When car is in moving condition</i>	
16	Whether dash board red light for engine attention is on?	C _A
17	Whether strange noises are coming from the engine?	C _A , C _B , C _C
18	Whether engine is overheated?	C _A , C _C
19	Is there any problem in power transmission system?	C _E , C _F , C _G
20	Whether proper air pressure is being maintained in the tires?	C _M
21	Whether brakes don't work effectively?	C _D
22	Whether harsh rubbing sound is observed when brakes are applied?	C _D
23	Whether car stops instantly while moving?	C _A , C _H

'C_M' represents miscellaneous faults