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Failure Modes and Effects Analysis (FMEA) in Maintenance and Diagnostics

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ABSTRACT

Failure Modes and Effects Analysis (FMEA) is a tool that has long been used at various stages of the product life cycle but is most commonly used in the engineering design and manufacturing planning stages. Some work has been done on conceptual design stages but very little, if any, research has been conducted to understand how FMEA might be used during the service of the product. Furthermore, the feedback of performance knowledge (in the form of FMEA data) from the in-service product use to conceptual and engineering design is a potentially valuable but un-exploited activity. This can be seen as a possible method of implementing Design for Service. Diagnostic service tools (manuals, computer diagnostics, etc) are usually created as a post-production activity, but reuse of FMEA knowledge generated during design could be used in a concurrent activity. Additional benefits are gained from improved accuracy of the FMEA and the maintenance of up-to-date product knowledge. A system for computerised interactive FMEA generation from FMEA elements has been created from the research. An object-oriented FMEA model has been adopted and expanded to generate the FMEA elements and diagnostic FMEA. The use of an object-oriented FMEA environment and FMEA object libraries promotes the reuse of existing information and has increased data availability for the diagnostic tool development. The Diagnostic Service Tool (DST) is an extended application from the automated FMEA generation. Existing failure mode data is used to determine further characteristics of parts failure. As a result, a tool in the form of diagnostic software is created which is practical for real life use. The prototype software was evaluated in a field service application using four automatic transmission problem cases. The results showed that there was significant difference in repair times between the conventional repair manuals and DST. The research has demonstrated that the prototype software is successful in providing effective field service centered tools to the Field Service and in turn a method of providing feedback to the Designer. Hence, knowledge sharing between Engineering and Field Service can be carried out continuously to provide a significant improvement in product development.

1. INTRODUCTION

There is an increasing tendency for manufacturing companies to provide the services of their products rather than the products themselves. For example Rolls-Royce sell power over a period of years rather than selling an engine [1]. Product serviceability issues are therefore even more strongly influencing product design and manufacture and are perhaps considered very much earlier in the design process than would have traditionally been the case. This in turn drives the need for an integration of the knowledge aspects of design and maintenance and a consequent sharing of knowledge right across the product life-cycle.

Failure Modes and Effects Analysis (FMEA) is a methodology to determine potential failure modes, the effects of these failures and uses severity measures and probability to prioritise the handle the failures. This provides knowledge which could be extremely valuable if reused in downstream diagnostic systems that are designed to use reasoning to determine the reasons of malfunction of products in the field. Diagnosis has been described as a process

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of Fault Detection, Isolation and Recovery [2], and diagnostic tasks may be represented in two parts [3]; detection of symptoms and determination of failure.

Automated FMEA has been used for diagnosis [4], and the reuse of FMEA information in diagnostic systems to integrate design and service information across supply chains has been demonstrated [5]. Recent work [6] has focused on the conceptual design stage and could generate product and process FMEA from sparse knowledge using formal methods of structural modeling, functional modeling and reasoning techniques. It is the deployment of these techniques in creating diagnostics models that span the product life-cycle by knowledge reuse and sharing that forms the central core of the research described here. The method used was to (i) establish an FMEA model (ii) generate diagnostic failure data from automated FMEA software, (iii) build a prototype Diagnostic Service Tool based on the generated diagnostic data and field service information and (iv) evaluate the proposed Diagnostic Service Tool.

The functional model describes the design intent (function) and how the structure achieves the function (behaviour) [7,8]. Hirtz et al [9] developed a comprehensive list of generic functions and Teoh [6] adapted these for the functions required in this kind of work. Table 1 shows an extract from the complete list.

Table 1: Generic Functions [6]

Class	Active	Passive	Description
Branch	separates	separated from	to separate an operand into components in the forms which are distinct from the original
	divides	divided from	to separate an operand into components in the same form as the original operand
	extracts	extracted from	to forcefully pull out
	removes	removed from	to take away a part of operand from the original
	distributes	distributed to	to cause operand to break UP
Channel	inputs	input to	to bring an operand from outside into the system
	outputs	output from	to send an operand from the system out
	transports	transported to	to move a material from one place to another (no fixed path)
	transmits	transmitted to	to move energy or signal from one place to another (no fixed oath)
	guides	guided to	to direct a material with specific path
	conducts	conducted to	to direct signal or energy with specific path
	conveys	conveyed to	to fix the movement in linear direction
Connect	joins	joint to	to bring together two or more operands, but they can still be distinguished from each other
	assembles	assembled to	to join with a predetermined manner
	links	linked to	to couple two or more operands with an intermediate operand
	mixes	mixed with	to combine two operands into a single homogeneous mass
Control Magnitude	actuates		to enable an operand to commence an action based on a control signal
	regulates		to adjust the operand based on a control signal
	increases		to enlarge an operand in response to a control signal
	decreases		to reduce an operand in response to a control signal
	chances		to adjust the operand in a predetermined manner
	amplifies		to enlarge an operand in a predetermined manner
	reduces		to reduce an operand in a predetermined manner
	stops		to cease an action of an operand
Convert	generates	generated to	to change from one form to another
Provision	stores	stored to	to accumulate an operand
	contains	contained in	to keep an operand within limits
	collects	collected to	to bring operands together
	supplies	supplied to	to provide an operand from storage
Signal	senses	sensed by	to become aware of an operand
	recognise	recognised by	to identify an operand
	measures		to determine the magnitude of an operand
	indicates	indicated to	to make known about an operand
	processes		to submit information for a process
Support	stabilizes		to prevent an operand from changing course or location
	secures	secured to	to firmly fix an operand
	positions	positioned to	to hold an operand in a specified location

2. THE FMEA MODEL

The FMEA Model is based on the transformation system [10] where an operand at the input is transformed to a required state at output. This is used as the basis for generating component libraries, function units, functional diagrams and cause and effect propagation. A causal reasoning technique adapted from the "knowledge fragment" reasoning approach of Kato et al [11] is used. The knowledge is divided into precondition and postcondition in the form of "operator failure state" and "operand failure state". The FMEA model forms the framework for knowledge collection and organization in order for FMEA generation to take place.

The modelling is illustrated using an automatic transmission powertrain. Engine torque is transferred to the torque converter through the drive plate, which is attached to the engine crankshaft. Torque, which has been transferred to turbine vanes in the torque converter through the medium of Automatic Transmission Fluid, is then transferred through the input shaft to the rear clutch retainer or the multi-plate clutch. It is then carried through the sun gear (forward and reverse sun gear) and the annulus gear in the planetary gear set to the transfer shaft. It is delivered through the transfer shaft and the differential drive gear to drive the CV-joint by the differential assembly and finally the wheels. Figure 1 shows an automatic transmission system and the power train components. Figure 2 shows the operating configuration in 1st gear and figure 3 shows the corresponding Transformation System.

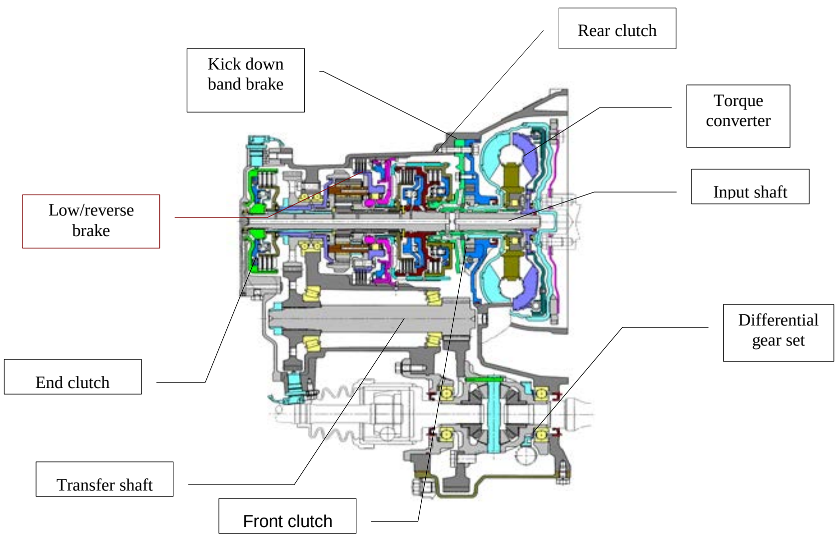

Figure 1: Sectional View of KM series Automatic Transmission.

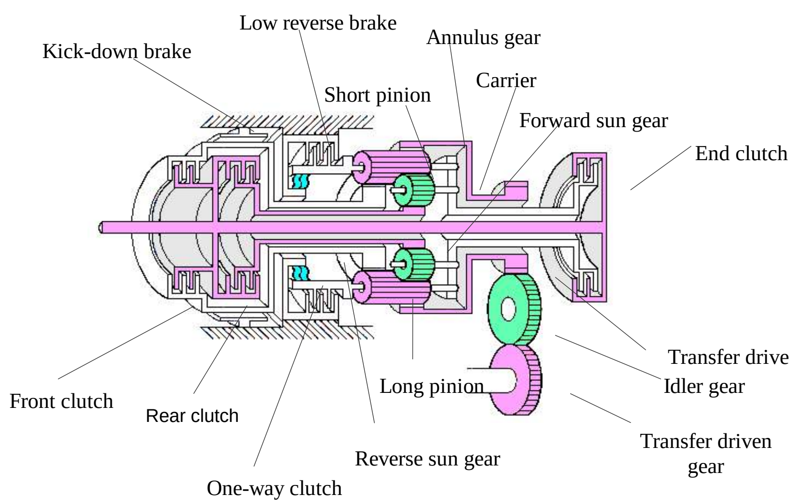

Figure 2: Operating Elements in 1st Gear

A function unit is the relationship of a generic function between an operator and an operand so that in figure 3 the long pinion (operator) interacts with the annulus gear (operand) through the generic function “rotates”. The operator and operand are both sub-classes of a higher level entity, and accordingly an operator in one situation can become an operand in another. The forward sun gear is an operand in the function unit, “input shaft rotates forward sun gear” and is an operator for a different function unit “forward sun gear rotates long pinion”. The remainder of the functional units for the power train system can be derived to form a functional diagram from the transformation system and a functional diagram shown as figure 4.

The FMEA Model proposed by Teoh [6], uses a cause and effect propagation method based on the functional diagram to simulate the actual behaviour. A state change in one entity of a functional model will affect the status of the inter-related entities. The engine torque from the torque converter will be conveyed to the sun gear through the input shaft by the action of the clutches and brakes. The clutches and brakes will have a state change from “not activating” to “activating”. This state of change will trigger a change to the input shaft from “not conveying” to “conveying” and in turn trigger a change to the sun gear from “not conveying” to “conveying” and so forth until the final gear ratio output.

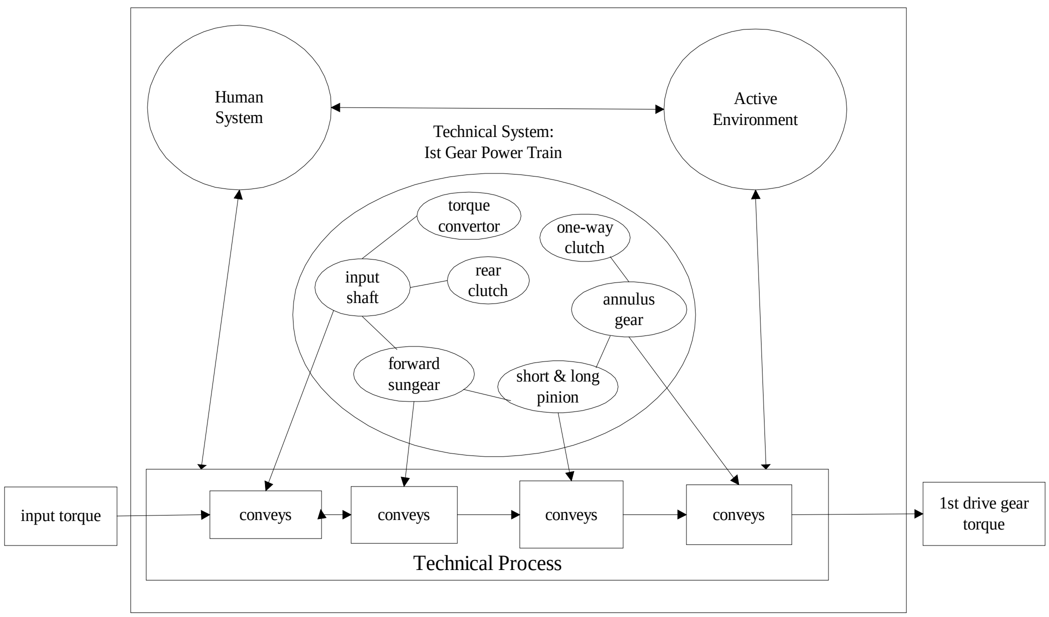

Figure 3: Transformation System for Power Train System in 1st Gear

State changes will propagate until the last boundary of the system. A series of preconditions and postconditions creates a causal change for a particular state change event. The cause and effect propagation created for the power train system is as shown in Figure 5. The precondition and postcondition gain knowledge fragments through historical data extracted from the FMEA. For a particular function unit, the operator state and the behaviour of a failure event form a set of preconditions. The behaviour and the state of the operand form the postcondition of the same event. The failure cause and effect is defined by the operator and operand states of a function unit, while the failure mode is defined by failure behaviour of the generic function. This discussion has been concerned with the development of an FMEA model based knowledge reasoning where static knowledge is confined to the entities and their functions, and not to the function units. During reasoning, new knowledge can be created by matching the precondition and postcondition knowledge with similar failure behaviour, leading to new knowledge synthesis based on minimum information.

3. DIAGNOSTIC FMEA

Diagnostic FMEA Generation (DFMAG) is an extension to the original automatic FMEA generation to generate Diagnostic FMEA (DFMEA) information that is used within the Diagnostic Service Tools (DST). The additional requirements include the creation of diagnostic trees using the information in the FMEA model with the corresponding symptoms and effects from cause and effect chains.

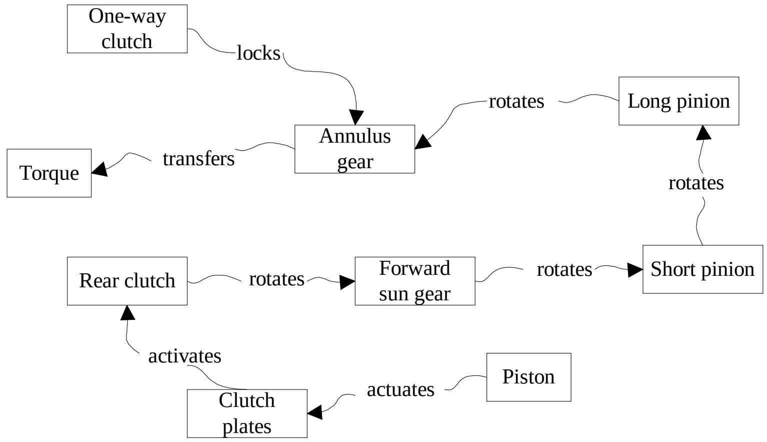

Figure 4: Functional Diagram for 1st Gear

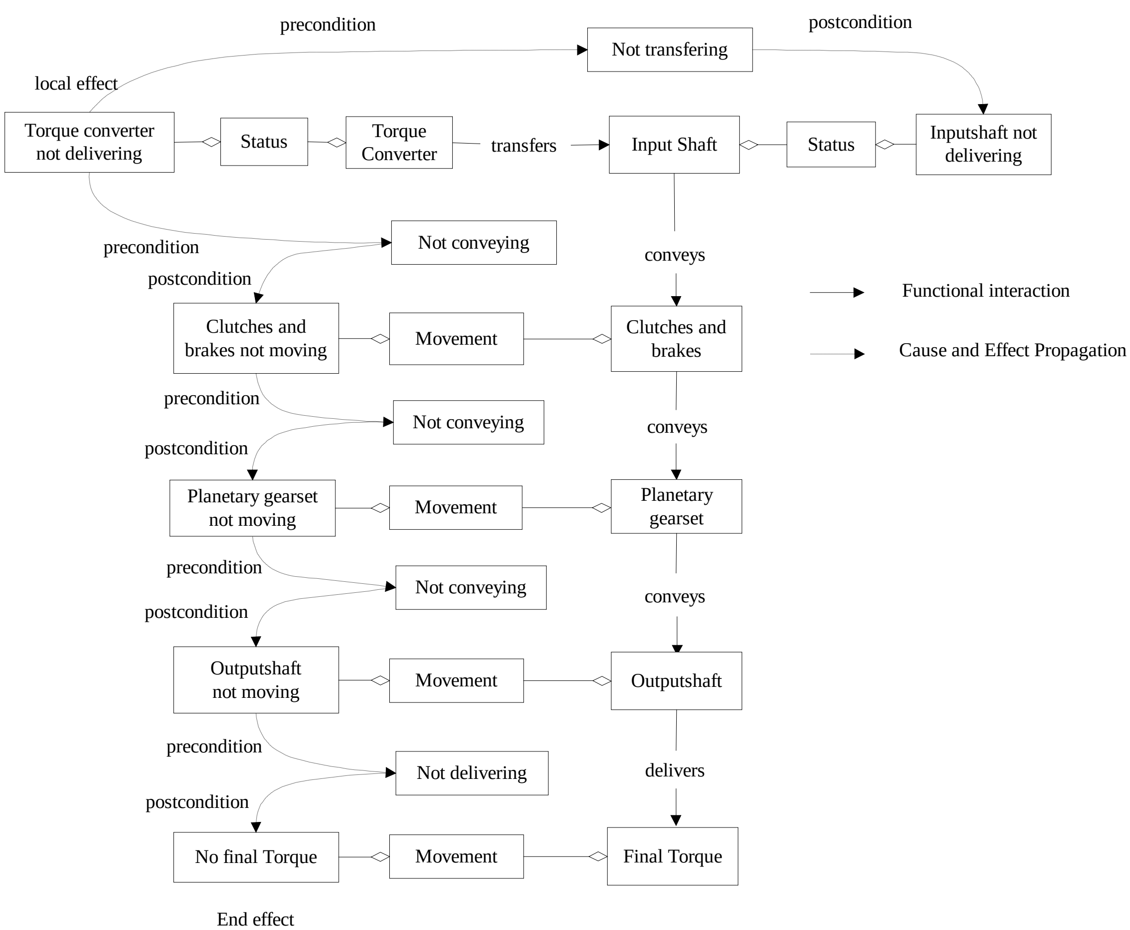

Figure 5: Cause and Effect Propagation for Power Train system

The DFMEA generation process is based on FMAG and functional analysis leads to the IDEF3 functional diagram in Figure 6. In the DFMAG application, the cause and effect building is based on the field failure reports which typically contain the failures, the causes of failure and the solutions to the failures. FMEA generation can either be used just as a conventional report or as the basis for developing the diagnostics (extensions to cause and effect chains). An example of a FMEA item for the end clutch is as shown as table 2.

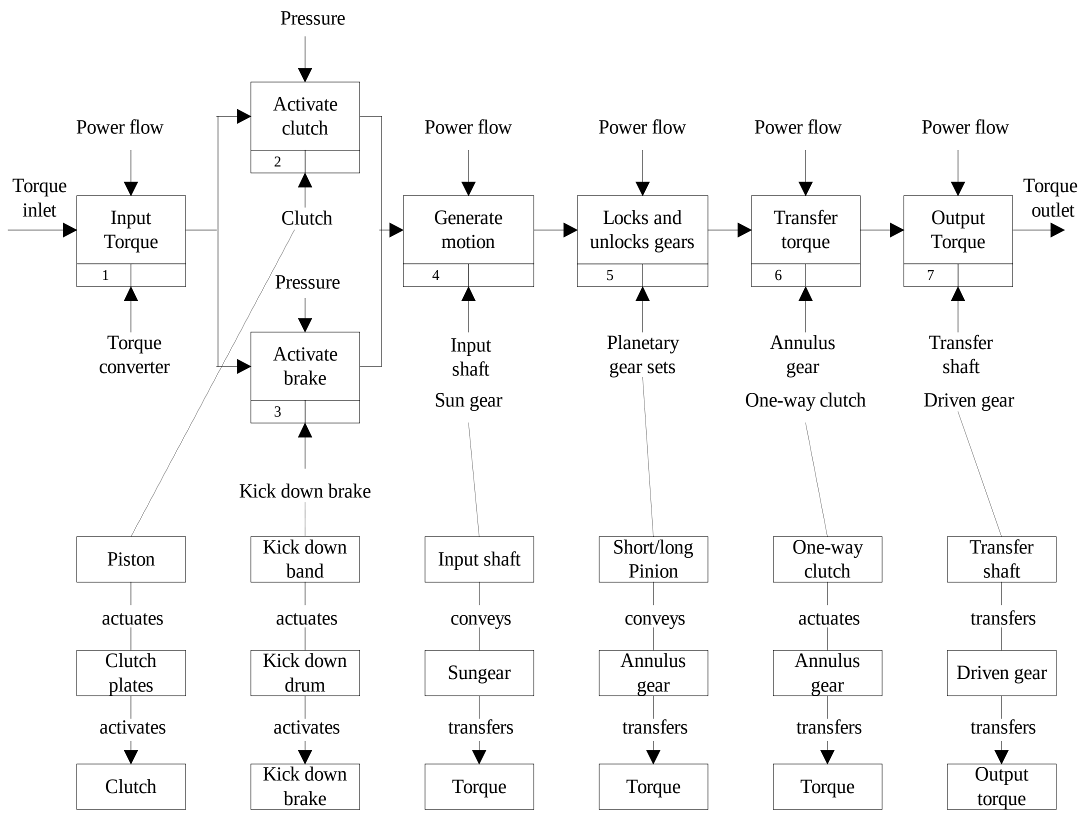

Figure 6: Function and Structure Mapping (Based on FMAG Approach [6])

Table 2: Example of a Generated FMEA for End Clutch

FMEA Report

Part Name	Function	Failure Modes	Potential Causes	Occ	Local Effects	NH Effects	End Effects	Sev	Current Control
Front Clutch	Connects input shaft to reverse sun gear	Not connecting	No Operating Pressure	0	No Reverse gear	No Reverse gear	No Reverse gear	0	Replace front clutch
Front Clutch	Connects input shaft to reverse sun gear	Not connecting	Front Clutch Damage	0	No Reverse gear	No Reverse gear	No Reverse gear	0	Replace front clutch

4. DIAGNOSTIC SERVICE TOOL

The Diagnostic Service Tool (DST) is an extended application of DFMEA that identifies suitable actions for specific part failures. It uses failure mode data from FMEA/DFMEA to determine further characteristics of part failures. Apart from having general limited information on the part failure, the user can also specify extended symptoms. DST acquires information from the FMEA database which is used by both the “Diagnostic Tree Tool” and the “Diagnostic Tree Wizard” module. Before the DST can be used, information on part failures has to be built by using the Diagnostic Tree Tool (DTT) that collects information from the DFMEA database. The user can select any related object to specify the detailed problem. DTT will permit the creation of additional characteristics of the part failure, specify recommended actions and link to the repair procedure. The repair information module enables the creation of repair procedures for specific items having corresponding problems to assist DST users in selecting the proper action on the specified failure. The repair information contains a list of repair procedures that can be linked with the DST. The components in the repair procedure include the symptoms, causes of failure and repair procedures. An example of a repair procedure created for the study from the symptoms of "No Forward Gear" results from the sun gear component (Figure 7). The repair actions suggested come directly from real field service information gathered for this research. All the data on repair information is stored in the Repair Procedure table, and can be retrieved and modified by users.

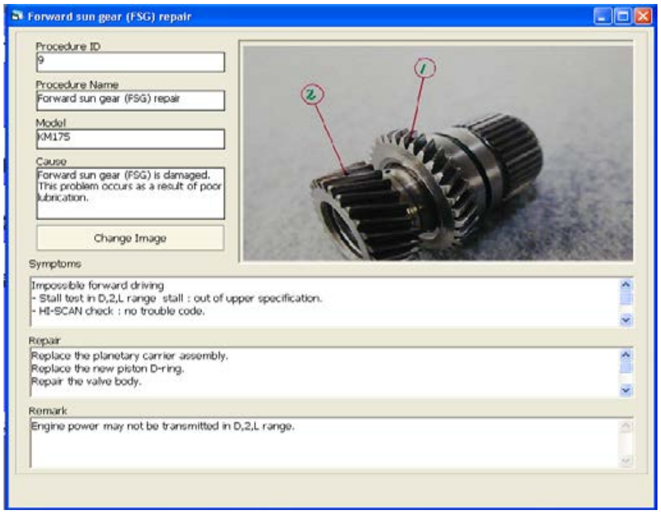

Figure 7: Repair Procedure for Sun Gear

5. EVALUATION

Evaluation was based on real automatic transmission problems from the Proton service centre in Malaysia. The DST methodology was tested theoretically and in practical situations. Sixty-nine students undertaking the Diploma in Automotive Maintenance participated in the evaluation. These students had one year exemption from a three year course due to their working experience and had already passed at least Malaysian Skills Certificate Level 2 and Institute of Motor Industry United Kingdom (IMI) Certificate Level 1. Four major KM series transmission problems were used for the evaluation. The subjects were required to determine the possible causes of each fault, extract the troubleshooting procedure and explain briefly the required rectification, repair or replacement action.

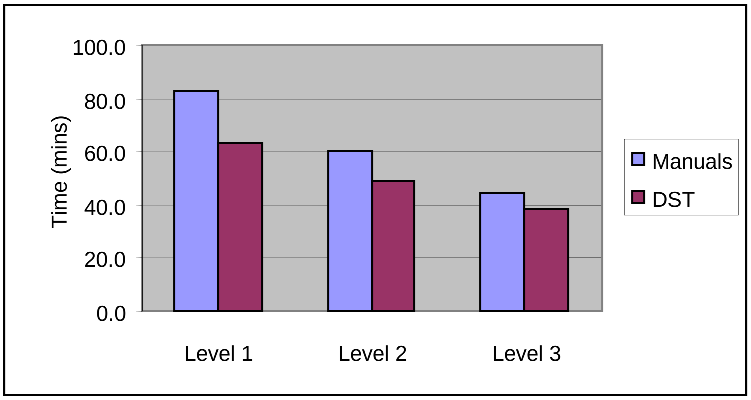

Figure 8: Diagnosis Performance with Manuals and DST

In the first session repair manuals were used and then the same task was performed using the DST only. Details can be found in [12]. The subjects were divided into 3 groups (novices, partly trained and fully trained). For level 1 technicians the hit rate rose from 29.8% when using manuals to 81% when using the DST. Level two figures were 60.5% and 93.4% respectively and level three achieved 84.1% and 97.7%. Average hit rate using the DST was significantly better than using just the technical repair manuals. (Hit Rate is defined as the percentage of correctly diagnosed and repaired problems [13]). DST presented the technician with a focused and precise course of action and also resulted in a reduction in false part replacements. On the other hand, the technicians had to devise a troubleshooting strategy independently by using the repair manuals. In all the evaluations, the time taken decreased as the technician (skill) level increases and the overall repair time improved when using DST (figure 8).

6. CONCLUSION

The evaluations have demonstrated the DST's capability of assisting in diagnosis and have also shown that the repair time has improved. The most noticeable time improvement is the diagnosis time which has shortened by 60.5%. on average for all cases. The parts repair procedure and reported transmission problems database will grow with time. Hence experience from the technician knowledge will be gathered and documented. This precious knowledge can then be use by junior technicians as a reference and for training purposes. Thus it will allow immediate reuse of information not only by the repair technicians but by the designer as well. On a wider front it is believed that designers will be able to directly reuse this actual failure knowledge to improve existing product design or for a new design. A mechanism is provided for sharing knowledge between the two important lifecycle activities of design and maintenance providing a method of practical implementation of design for service.

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