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Maintenance processes modelling and optimisation

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ABSTRACT

A Maintenance Procedure is conducted in order to prevent the failure of a system or to restore the functionality of a failed system. Such a procedure consists of a series of tasks, each of which has a distribution of times to complete and a probability of being performed incorrectly. The inclusion of tests can be used to identify any maintenance errors which have occurred. When an error is identified it can be addressed through a corresponding correction sequence which will have associated costs and add to the maintenance process completion time. A modified FMEA approach has been used to identify the possible tests. By incorporating any selection of tests into the maintenance process it can then analysed using a discrete-event simulation to predict the expected completion time distribution. The choice of tests to perform and when to do them is then made to successfully complete the maintenance objective in the shortest possible time using a genetic algorithm. The methodology is demonstrated by applying it to the repair process for a car braking system. The developed method is suitable for application in abroad range of industries.

1. Introduction

In order to repair hardware failures and restore functionality of hardware, a maintenance procedure (MP) is performed by a sequence of tasks [1]. It may be possible to perform a task incorrectly or for a task to take too long to complete. Since there is frequently a time limit on the window of opportunity to conduct the repair, both of the undesirable outcomes can be considered as failures of the MP. The objective of this research is to develop a means by which any task failure occurring during performance of an MP can be identified and subsequently rectified to restore the hardware functionality in as short a time as possible.

To achieve this objective a modelling approach is introduced in this paper which is conducted in three phases. The first phase identifies all of the errors that can occur in carrying out the process, along with tests which can be performed, and when they can be performed them, in order to identify these mistakes. For each test there is a correction process defined which describes the list of tasks which must be performed in order to correct the error identified. These tasks will also have associated time distributions indicating their duration to completion. Since the tests themselves need extra time to be conducted excessive testing could slow down the MP execution [2]. The full description of any maintenance process will then be constructed of the tasks required to conduct the maintenance along with the selected tests and corrective actions embedded in it. The effectiveness of any such process is evaluated through a simulation which predicts the time distribution to successfully complete the maintenance. This simulation capability is phase 2 of the framework. The final phase is the optimisation of the test selection. This will identify those tests whose inclusion will enable the correct maintenance to be completed within the shortest possible time. For complex processes where there are large numbers of possible tests combinations, methods such as Genetic Algorithms are needed to find a good solution within a reasonable time and computational effort [3]. An optimal combination of tests is required, which can then be integrated within the process design to achieve its objective in the shortest time.

The modelling framework developed is appropriate for application in any industry since minimising the maintenance activity time will increase the availability of the system. Recently there has been a trend towards functional products [4], or power by the hour type contractual arrangements where a capability is sold rather than a product. The responsibility for the maintenance within such contracts rests with the supplier rather than the purchaser and a major factor influencing the financial success of this arrangement will be the effectiveness and efficiency with which the repairs can be carried out. The modelling approach developed has the potential to make a significant impact in such industries.

In order to illustrate the methodology established to develop a test selection strategy, a car braking system repair process is considered. The layout of the paper is as follows: Section 2 gives a detailed

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description of the braking system repair process example. In Section 3, a modified FMEA technique is described which identifies faults or failures introduced during the braking system repair process. By applying this, a full set of potential testing options is established. The simulation method used to predict the expected MP execution time and an optimisation strategy, in which the analysis model is embedded with the testing options selected is then described in the next section. The analysis results are then shown in Section 5 and conclusions are drawn in Section 6.

2. Car braking system maintenance process

A car braking system is used to slow or stop a moving vehicle, which is usually accomplished by means of friction [5]. The front brakes of a car are more significant than the rear brakes when stopping the car, since the braking process transfers the car's weight onto the front wheels and increases the available grip. In the event that the braking system needs maintenance due to worn-out brake-pads and rotor located on the front left wheel of a car. The objective of the motor mechanic is to replace the worn-out brake pads and rotor so that the braking system is restored to its functional state. At the end of the process, a driving test is performed to ensure the braking system is fully functioning. Theoretically, an MP can always achieve its objective to restore system functionality, assuming the presence of sufficient and reliable tests, and the variable is the time in which this will be achieved. Therefore, the expected time taken to accomplish the maintenance objective is the performance measure by which the efficiency of the MP will be evaluated.

2.1. The hardware

For the braking system parts shown in Fig. 1, the hardware is considered to be comprised of the front wheel, wheel bolts, caliper, caliper pins, rotor, and braking pads. The rotor turns with the front wheel and is straddled by a caliper with pistons installed in it. The pistons, which are powered by the hydraulic system of the vehicle (not considered in the maintenance example), press on brake pads that clamp against the rotor from each side to slow it down.

2.2. The resources

There are three factors that contribute to the length of downtime of any failed hardware item: the preparation time for arranging the maintenance technicians; the actual MP performance time and the logistic time required to obtain any necessary maintenance resources [7]. The MP requires resources, either equipment or spares, at different stages of the repair process. In the example, there are two tools: a wrench and a jack, and four consumable spares: grease, new brake-pads, a new rotor and new wheel bolts. These resources are acquired before the MP starts (except the new wheel bolts, since they are not compulsory) and are ready to use when needed. One mechanic is required and is on-site when the repair starts.

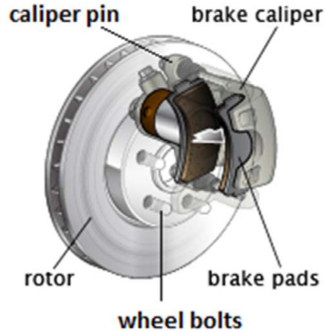

Fig. 1. The parts of a car braking system considered in the MP (Source: RepairPal.com [6]).

Table 1
Basic tasks involved in the braking system repair process.

Indicator	Task
1	LoosenWheelBolts
2	RiaseJack
3	RemoveWheelBolts
4	RemoveWheel
5	RemoveCaliperPin
6	SeperateCaliperFromRotor
7	LubriateCaliperPins
8	LubriacateNewBrakePadRear
9	RemoveBrakePads
10	RemoveRotor
11	InstallNewRotor
12	FitNewBreakPads
13	RefitCaliper
14	RefitCaliperPin
15	RefitWheel
16	RefitWheelBolts
17	LowerRemoveJack
18	TightenWheelbolts
19	CleanBrakePads
20	GetNewWheelbolts

2.3. The required maintenance procedure tasks

The braking system repair process has 20 standard process tasks, which, when required, are performed in sequence by the mechanic. The process tasks together with their indicator numbers are shown in Table 1.

The process flow diagram that shows the sequence of tasks is given in Fig. 2. Parallel sections indicate where there are several possibilities which can be performed depending upon the circumstances. For example, after the performance of task 6, any of the three tasks: 7, 8 and 9, can be performed and the sequence in which they are conducted will not affect the progress of the overall MP. After the performance of task 8, a checking task C8 is perform to reveal if the new brake pads have been greased correctly and thus determine which task to perform next. If the brake pads are not greased, then task 8 is repeated; or if the brake pads are incorrectly greased (the front part rather than the rear parts are greased), then task 19 is performed. A similar checking task is conducted after the performance of task 18 to show the state of the wheel bolts. The actions which follow correspond to the different wheel bolts states. If both task 8 and task 11 is completed correctly, then the mechanic can progress to task 12.

Before the end of the MP, a driving test (as described in Section 3.3) will be performed prior to discover any deviations from the correct states of the hardware for normal functionality of the system. If any deviation is detected, the appropriate rectification actions will be carried out to correct the problem, or alternatively the entire repair process needs to be repeated. The overall process ends when the driving test shows that the process has been completed correctly. The three checking tasks in the MP shown in Fig. 2 are compulsory in order to ensure the progress of the MP and success of the MP objective.

3. Using the modified FMEA technique to identify faults

A Failure Mode and Effects Analysis (FMEA) is a methodology for systematically identifying ways in which the failure of components in a process or product can affect the functionality of the system. It indicates the symptoms that would be observed should any of the components failure modes occurs. It is presented in form of a table, and in the application to an MP is used as a means to identify the symptoms which result from failures that can occur during the performance