A Location-Based Device Tree System for Rail Transit

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ABSTRACT
As the Vehicle Branch of Shanghai Metro Maintenance Guarantee Co., Ltd. is making continued progress in refined management, it requires increasing fine data granularity, together with increasing needs for data analysis. Therefore, the existing serial-number-based device trees can no longer meet continuous increasing management requirements, which necessitates a new device tree system. This paper has proposed a new device tree system for rail transit. Based on the physical locations of rail transit devices, the system proposed can associate the location information with property information, equipment serial number, and fault trees. Hence a subway vehicle and fault management system based on device trees was established. Based on the actual situation and management requirements of the Vehicle Branch, this paper has developed a location-based device tree management system and coding scheme, and introduced its advantages in management.

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1. Use of device tree and fault tree at Vehicle Branch

1.1. Use of device tree
The device tree currently used by the Vehicle Branch is called “vehicle serial number tracking”. Based on the serial number of vehicles, it performs life-cycle management of each device. This kind of device tree first generates a unique and exclusive serial number for each device, and then records the disassembly, assembly, and maintenance history of the device through the serial number in the system. The advantage of this management method lies in the fact that the status record of each device tracked by its unique serial number is clear. All repair, maintenance, disassembly/assembly, and scrap operations throughout its entire life cycle are recorded with high clarity. However, the disadvantage is that there are many devices installed on a single vehicle, which makes the serial number tracking of all devices both time-consuming and laborious. Therefore, at the Vehicle Branch, only important devices that are expensive, repairable, and decisive to operational safety, such as bogies, wheel sets, and traction motors, are selected and defined as serial number tracking items.

However, as refined management advances, the Vehicle Branch is seeing increasing demands for statistics and analysis, that is, more and more devices need to be tracked and managed via their serial numbers. The management scope is no longer limited to those that are expensive, repairable, and decisive to operational safety. To track the serial numbers of all equipment means huge labor and high management costs.

1.2. Use of fault tree
The fault tree used by the Vehicle Branch is called “vehicle function structure”. Based on the system functions of a vehicle, the fault tree listed all the potential failure modes of each system or device. Thus, the fault tree is used for fault classification and statistics. In the daily operations of the Vehicle Branch, the fault tree (function structure) is used to record equipment failures. In case of a vehicle failure, a failure work order needs to be issued through the Industrial and Financial System (IFS). When the fault
is eliminated, a corresponding fault tree (function structure) needs to be filled in for classification and statistics. The process in detail is shown in the figure below.

In practices, it is often found that the fault tree (function structure) in the work order is not properly filled in, such as wrong information filled and omission. Operators’ inadequate understanding of the system classification in the Vehicle Branch has also led to the filling mistakes in fault trees (function structure).

2. Management requirements of Vehicle Branch

Upon analysis of its own business and the use status introduced above, the Vehicle Branch hopes to make the following progress in management:

2.1. Finer management granularity

Presently, at the Vehicle Branch, work orders only apply to vehicles or serial number tracking parts. Fault statistics and data analysis can only generate the failure rates of vehicles or serial number tracking parts, which means that the management granularity is not fine enough. A large amount of information on fault locations, fault handling, and fault types is recorded in the Enterprise Asset Management (EAM) system as remarks. These unstructured fields can neither be calculated nor used, resulting in a waste of data resources.

2.2. Establishment of fault models

The EAM system of the Vehicle Branch requires operators to fill in a fault tree (function structure) twice along the work order processing flow, at the time when a fault is reported and the time when the work order is closed. The purpose of filling in the fault tree (function structure) at the time when a fault is reported is to classify the fault while at the time when the work order is closed is to record the cause of the fault and its corresponding failure mode. Such design is intended to establish a correlation between a fault and its failure mode, thus building up a fault model based on increasing data.

Take Figure 2-1 as an example. When an air conditioner in a passenger room fails to heat, the fault is first described in a fault tree (function structure), that is, “failure to heat”. For the second filling, its failure mode shall be provided, that is, “the electric heater fin is damaged”. Then the system can identify that the damage to an electric heater fin may cause heating failure of air conditioners in passenger rooms. As fault data increases, more failure modes will be associated with the heating failure of air conditioners, thereby establishing a model for the failure of air conditioners to heat.

In most cases the fault trees (function structure) are filled in by. However many device operators are not able to properly classify faults and tend to roughly identify most failure modes as “faults”, which is not helpful to statistics. As a result, the fault models generated by such data are far from being accurate, and the system is not made good use of.

2.3. Intelligent O&M support

Vehicle Branch is now actively developing an intelligent operation and maintenance (O&M) system, which consists of a vehicle-to-ground wireless transmission system, a point inspection system, an expert system, a vehicle history system, etc. All these sub-systems require a unified set of device tree to enable data interconnection between systems, and facilitate data collection and statistical analysis in later stages.
Figure 1. Correlation between fault and failure mode.
3. Location-based vehicle device tree coding system

3.1. Reasons for location-based approach

The Vehicle Branch takes location as the basis for the establishment of a device tree for the following reasons:

a) The location of a device is easier for primary staff to understand, as their communication during operations is usually based on equipment location, such as the axle 1 traction motor of “A” end bogie in compartment TC1 of vehicle No. 1701. Therefore, the location-based approach is more similar to the practical operations of employees.

b) It makes location-based statistics easier. In statistical applications, it is often necessary to calculate the failure frequency of equipment of different manufacturers at the same location, or that of equipment of the same manufacturer at different locations.

c) It is conducive to the use of one set of device tree by multiple systems. Despite the fact that the requirements for the device tree vary from systems, most associated data can be mounted based on location.

d) The device based on function classification is not conducive to location description. It is complicated to describe locations. If the device tree is based on function categories, it is also required to design a coding mode for the locations of vehicle devices, which is not feasible.

3.2. Association of device tree with property code, serial number and fault tree

It requires four dimensions to describe a device, namely where the device is, what the device is, which device it is, and what will happen to the device. Where the device is refers to the place where it is installed; what the device is refers to its model, manufacturer, name, unit of measurement and other property information; which device it is refers to its serial number, i.e., the unique ID used to identify the device; and what will happen to the device refers to its potential failure modes.

The device tree is established in this way to associate the locations of vehicle devices with device property codes, serial numbers, and fault trees (function structures). Then the data on the above four dimensions can be collected. Moreover, depending on the importance of devices and the granularity of management, the importance of devices can be managed in four dimensions, i.e., device location, property code, serial number, and fault tree while unimportant ones can be managed in three dimensions, i.e., device location, property code, and fault tree. In this way, diversified management requirements are met, and management resources flexibly configured.

As shown in Fig. 2, after location-based device trees are applied, when a fault is reported, an operator is required to describe the fault as seen, such as damaged cover, black LCD screens across the vehicle, no station broadcasting, or unavailability of intercom in the driver’s cab. When the fault is processed and eliminated, the original fault tree (function structure) is changed to the device tree, that is, the operator selects the location that is repaired, e.g., TC1 (122351) → driver’s cab → access door → emergency unlocking device → device cover. Finally, the operator has to choose the failure mode of the device to be repaired or replaced, such as damage, missing, short circuit, air leakage, etc.
4. Application and benefits of device tree

4.1. Application of work order module in IFS

**Figure 2.** Flowchart of work order after application of device trees.
4.2. Application in point inspection system

The major business of the Vehicle Branch is overhaul. However, the device classification model based on systems is not suitable for the company to dispatch work orders. Take the air-conditioning system as an example. The air-conditioning system refers to a set of equipment including air conditioners, control cabinets, and air ducts in a vehicle. It is difficult to dispatch a work order dedicated to one single top-mounted air-conditioning unit at one end of a carriage to a maintenance technician for inspection and repair.

When it comes to underbody, the overhaul is more complicated. For the underbody of subway vehicles, the daily inspection task covers three work areas: side A, side B and the trench. The inspection of certain undercarriage equipment such as bogies goes across three work areas. For higher work efficiency, the common practice is to have employee A inspect the side A of all bogies, employee B inspect the side B of all bogies, and employee C inspect the trench side of all bogies. In this case, it is necessary to further split and classify devices.

Location-based device trees can well solve this problem. Taking the inspection of the axle boxes of a bogie as an example, the bogie can be split into axle box 1, axle box 2, axle box 3, and axle box 4. The inspection task of axle boxes 1 and 3 can be dispatched to employee A, and that of axle boxes 2 and 4 to employee B. Through device trees, a system or even a large equipment can be flexibly divided into several parts to be inspected and assigned to different maintenance technicians, so as to meet operation needs. Moreover, data on irregularity can be directly linked to corresponding device locations, to serve later statistics.

4.3. Application of intelligent operation and maintenance

In intelligent operation and maintenance of the train-to-ground wireless transmission system, it is necessary to indicate its fault location when a fault is reported. Then the set of device trees with fault codes associated with device locations, can be used to define the connection between the fault code and the location to achieve this function. In addition, statistics on vehicle faults can also be performed from the perspective of locations.

The vehicle history system needs access to the maintenance and replacement of devices. The set of device trees can well define the locations of devices, and record the faults of the same kind of parts at different locations, which means finer data granularity. The expert system is to propose maintenance plans for vehicle failures. Each maintenance suggestion usually involves one or more specific devices, and there are a large number of varied devices at the same position in a vehicle. In this regard, the proposed set of device trees can solve this problem very well.

4.4. Accurate definition by fault tree

This set of device trees can be used to accurately define the categories of devices. With the connection between device locations and fault categories specified in the background, the device trees can turn on-site operators to technicians. As they are required to fill in the repair locations only, the probability of errors is greatly reduced.

5. Conclusion

The establishment of a well-functioning device trees requires a long-term search for problems in application and constant modification to align with operational needs. This paper has proposed a concept of building up vehicle device trees based on location, with an intention to meet the needs of the refined management of the Vehicle Branch. While device trees are rolled out across the company, it is necessary to standardize the names and manufacturers of the same devices for different vehicle models, which is expected to facilitate holistic data collection and statistics.

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