Urban transport scenario test design with modelling works

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Abstract

Scenario based testing is a test methodology widely used in integration test and trial operation of urban transport. By setting a scenario which reflects a particular status of urban transport in normal, degraded, or emergency operations, a scenario test is used to demonstrate the function performance of certain systems involved so as to verify if the function performance can meet the operation requirements. With the engineering implementation of scenario tests in Mecca Light Rail, this paper provides an in-depth study about scenario test design with modelling works. A serial of models like the interface matrix, the function flow diagram, and the test flow diagram are used to determine all key elements of a scenario. Test scenarios designed in this way can be qualified to meet the integration, typicality and completeness requirements and implemented for overall metro system function verification.
Keywords: scenario testing, systems integration test, Mecca light rail.

1 Introduction

1.1 Scenario testing in systems integration test

Urban transport is a macro system consisting of a large number of equipments and facilities. Each individual system assumes various design functions with the availability of complex interfaces among them. In order to verify the overall performance of a new urban transport line before it is put to passenger operation, a systematic, multi-disciplinary, and integrated testing and commissioning (called *Systems Integration Tests* or Comprehensive Tests [1–3]) is needed to be deployed. Following the completion of various equipment systems'

WIT Transactions on The Built Environment, Vol 128,
www.witpress.com, ISSN 1743-3509 (on-line)
doi:10.2495/UT120341

commissioning works, Systems Integration Tests (SIT) conduct a serial of tests to demonstrate the performance of linkage functions among major systems and verify the match degree of all major interfaces, so as to ensure the overall system can coordinate in the passenger operation [1, 3].

Scenario testing is one major test methodology used in SIT. This methodology carries out the verification of system functions by means of scenario demonstration [4, 5]. Using scenarios developed from urban transport's daily operation practices, this methodology can effectively evaluate the system functions against the operational requirements in every possible operating status.

1.2 The difference between SIT test and trial operation scenarios

The concept of operation scenario is first used in trial operation exercises and trainings [6]. Although both SIT and trial operation use scenarios in their tests/exercises, and the two even have a large overlap on their scenario settings, they have different emphases in their design and implementation. Scenario testing in SIT is designed for equipment functionality verification. With demonstrating a pre-designed scenario, testers observe the realization of system functions and their realization sequence and verify if the demonstration result is different from system design and operation requirements. However scenario exercises in trial operation is to examine the proficiency of the operator participants in accordance with operation and management rules and specifications, and the availability of operational regulations, crowd control regulations, and safety regulations. For example, when the typical scenario *Train Operation in Station* is taken as a testing scenario, it is used to verify if urban transport systems like rolling stock, signalling, platform screen door, communication, power supply, can work properly so as to arrange an operational train to access a station and enable passenger getting on/off on schedule. However when the scenario becomes a trial operation exercise, it is used to evaluate the operation of dispatchers, train drivers, security and maintenance staff against their responsibilities, and the efficiency of regulations in passenger organization and train operation on schedule. Although the system function verification in SIT cannot be separated from personnel operations, and the evaluation of staff fulfilment also involve the support of equipments, scenario testing and scenario exercises cannot be confused.

1.3 Contribution and organization

Scenario testing, as a highly targeted, widely coverage, and low cost test methodology, has been widely used in the comprehensive testing and commissioning work for many urban transport lines. However its implementation involves the realization of complex interactive functions among various systems, its execution needs cooperation work from many participants in different positions. How to design a test scenario based on systematic analysis, so as to avoid design oversights and better achieve the verification effects, is the most important part of scenario testing methodology. However there are still no articles devoted for scenario design and verification so far.

In 2010–2011, China Academy of Railway Sciences conducted Systems Integration Tests for the *Al Mashaaer Al Mugaddassah Metro Project- Southern Line* (called Mecca Light Rail thereafter) in the Kingdom of Saudi Arabia. Altogether 20 scenarios are designed and implemented, which provided a comprehensive verification of all major system functions of the metro line. The implementation of scenario testing and other SIT works contributes to the on-schedule passenger operation of Mecca Light Rail (which has the largest designed traffic capacity, highest outdoor operation temperature and shortest construction period to date) and realization of designed capacity. Based on the implementation of scenario testing in Mecca Light Rail, this paper provides a detail introduction of test scenario design with modelling work.

The remaining of this paper is organized as follows: Section 2 discusses the component elements of a test scenario based on the introduction of urban transport operation status. The modelling of interface matrix is introduced in Section 3 for the overall design of test scenarios and necessity evaluation. The modelling of each particular test scenario is provided in Section 4 in the form of function flow diagram and test flow diagram. Discussion and future work plan in Section 5 will conclude this paper.

2 Operation scenarios

2.1 Operation status

According to the train running and passenger organization situation, the daily operation of an urban transport line can be generally divided into three operational statuses [7], namely the *normal*, *degraded* and *emergency* operation status.

Urban transport in the normal operation status generally refers to the status when urban transport equipment systems work properly, passenger traffic is organized properly and train running can be arranged in accordance with a pre-designed operation diagram. When some minor incidents happen, a urban transport line turns to the degraded operation status. The overall line still maintains the operation since these incidents have no influence on the safety of train running and passenger movements; however the efficiency of train running or passenger movements is visibly impacted. Urban transport is forced to move to the emergency operation status when an accident happens which may seriously affect the safety of train running or passenger movements, and some stations or even the entire line will be closed and exit the operation.

The equipment systems of urban transport are designed to provide different functions so as to ensure the safety of train running and passenger movements in different operation statuses. Therefore as to verify system functionality, each scenario should be designed in accordance with a particular operation status.

2.2 Component elements of SIT test scenarios

A so-called "*scenario*" refers to a serial of events happened in a particular place under a particular circumstance. In the context of urban transport, a particular place refers to the typical sites involving train running and passengers, such as stations, OCC (Operation Control Centre), depot, sections with various structures (such as viaduct, tunnel and steep slope). A particular circumstance refers to the operation status of urban transport while events refer to the major train running and passenger movement activities happened in the place.

A typical test scenario of SIT should include the following elements:

- *Name*
- *Status*, which is used to clarify the corresponding operation status.
- *Place*, which refers to the region where the scenario happens.
- *Events*, the remarkable train running or/and passenger movement activities.
- *Systems*, the ingredient systems of urban transport whose component equipments make corresponding actions when some event happens.
- *Functions*, the designed actions of an equipment or a facility whose realization enable train movement and/or traffic control.
- *Allocation*, the necessary personnel used in the demonstration progress of a scenario and their responsibilities.

The process of test scenario design is the process to determine and clarify those elements mentioned above. In the beginning stage of scenario design, test designers should take full consideration of the requirements of various operation statuses, and break down daily operations of urban transport into various typical operation scenarios, and scenario events can be developed from the daily operation activities.

The scenario *Train Operation in Station*, as one basic scenario of urban transport, refers to the process when an operation train approaches, stops at, and then departures from a station platform. Therefore this scenario can be broken into five events: *Train Start* (from the initial place), *Train Approach* (the test platform), *Train Stop* (at the test platform), *Train Departure* (from the test platform) and *Train Moveout* (from the test platform).

In the scenario designing process, the *operation scenario matrix* is often used to avoid gaps and overlaps in scenario setting. In the matrix, all scenarios are listed according to their places and status characteristics. Any blank in the matrix reminds the designer to find new scenarios to cover the gap. For all scenarios in the same grid of the matrix, the designers should pay more attention to delete possible overlaps among those scenarios. A typical scenario matrix is shown in Table 1. With the scenario matrix, the place and status elements of a scenario are classified. In next section, we will classify the system elements of a scenario, and evaluate the necessity of each scenario.

Table 1: Typical operation scenario.

Operation Status	Station	Section				Depot	OCC
		Viaduct	Tunnel	Steep Slope	General		
Normal	1.Train Operation in Station 2.Station Open 3.Station Close	1.Normal Operation	1.Normal Operation	1.Normal Brake 2.Normal Start	1.Normal Operation	1.Depot Entry/Exit	1.Normal OCC Operation
Degraded	1.Train Hold 2.Train Skip 3.PED Failure 4.Ticket Machine Failure	1.Signalling Fallback Operation 2.Train Ground Communication	1.Red Signal in the Tunnel End 2.Train Ground Communication lost	1.Red Signal in the Slope End 2.Brake Release	1.Emegerncy Brake 2.Temporary Speed Restriction 3.Abnormal Door	1.Transfer Rail Failure	1.OCC Degraded Control
Emergency	1.Station on Fire 2.Station Power Cutoff	1.Onboard Fire 2.Lightning Hit	1.Onboard Fire 2.Tunnel On Fire	1.Onboard Fire			1.Emergency Power Cutoff 2.All Trains Emergency Brake

3 System interface analysis

3.1 The necessity standards of SIT scenarios

A test scenario is designed to evaluate the realization of system functions in the scenario against the design and operation requirements. Therefore system functions are the essential and distinguish characteristics of a scenario.

Although there can be many scenarios listed in the scenario matrix, they may not all be suitable for scenario testing implemented in SIT stage. In this case, we need to determine which scenario is indispensible in SIT, for the purpose of evaluation of the overall functionality of an urban transport line.

Based on the practice of SIT in Mecca Light Rail, we believe there are three necessity requirements for a test scenario in SIT stage. First of all, the integration. SIT will be implemented after individual systems have been commissioned. Therefore a test scenario in SIT stage should involve the function realization of *at least* 3 systems. Any scenarios which only involve the function of 2 or less systems cannot serve as test scenarios. Secondly, the typicality. Each test scenario is designed to evaluate the reality of *different* system functions of the urban transport line. The system functions involved in any two test scenarios should have a clear distinction. Thirdly, the completeness. The evaluation of all major system functions should be achieved when all test scenarios have been implemented.

3.2 System interface analysis

For a particular scenario, system interface analysis is to determine systems whose function realization is involved. And these systems are called the *interface systems* of the scenario. A system interface matrix is used for this analysis. All scenarios designed in the operation scenario matrix will be listed in the left side of the system interface matrix. For each scenario, an interface mark "X" is given for each of its interface systems. Table 2 gives a system interface matrix fragment in which all interface systems for three scenarios are presented.

When the interface systems for each scenario have been marked, the interface matrix can be used in the necessity analysis of test scenarios. We first carry out the integration analysis. For all scenarios which have only two or less interface systems (like the scenario *ticket machine failure* in Table 2) cannot be implemented in SIT and will be deleted from the matrix.

Table 2: Interface matrix fragment.

Operation Scenario	RSK	Comm	SIG	SCADA	PED	ACS	PSS	L&E	BMS	FAS
Train Operation in Station	X	X	X	X	X					
Ticket Machine Failure				X		X				
Station on fire	X	X	X	X	X	X	X	X	X	X

Typicality analysis is carried out when the integrity of all scenarios have been analyzed. If two scenarios have almost the same interface systems distribution, it means the coincidence of these two scenarios is high. The similarity should be removed by deleting one scenario or merging two scenarios into one.

After typicality analysis, the interface matrix model can intuitively reflect the completeness characteristics of the current set of scenarios. If a particular system of urban transport does not serve as the interface system for any scenario, it means the current set of scenarios does not fully cover the content of daily operation. Therefore some supplementary scenarios should be designed which should focus on the function realization of the system which is not interfaced with any other scenarios.

3.3 The interface matrix of Mecca Light Rail

The Mecca Light Rail lies in the suburb area of the holy city of Mecca, with the full length of 18.25km. 14km of the metro line uses the viaduct structure and the remaining 4km section is constructed with cutting/embankment structure. No tunnel structure is involved. This metro line is mainly used to alleviate the traffic pressure in each Muslim pilgrim season. In order to increase the transport capacity, this line does not have any fare collection facilities, and is freely ridded for all passengers entitled [8]. Considering these characteristics of this metro line, SIT designed 19 test scenarios with the reference to the test scenarios of Dubai Subway in United Arab Emirates [9]. All test scenarios are in line with the integration, typicality and completeness requirements. The corresponding interface matrix is shown in Table 3.

4 Test scenario diagram models

In the previous sections, both scenario matrix and interface matrix are used for test scenario design as a whole, without clarifying the detail functions and personnel allocation for each scenario. These scenario elements will be analyzed with the flow diagram models introduced in this section.

Table 3: System interface matrix of Mecca Light Rail.

Interface System Matrix of Mecca Light Rail

No	Test Scenario: Scenario Name	Operation Status: Normal	Degraded	Emergency	RSK: RSK	Power Supply System: OHL	HV	MV	LV	Communication: Wire	PA	PIS	Wireless	ACS	CCTV	SCADA: VCP	SCADA	SIG: SIG	PED: PED	L&E: L&E	MEP: BMS	LIG	FAS	HAVC	Depot: Depot
1	Train Operation in Station (Normal Direction)	X			X			X			X	X	X		X	X	X	X	X						
2	Train Operation in Station (Abnormal Direction)	X			X			X					X		X	X	X	X	X						
3	Train Reaction to Failure Status of PED			X	X												X	X	X			X			
4	Train Reaction to Activation of PESB			X	X										X		X	X							
5	System Reaction to LV Power Outage/ Restoration		X						X	X	X	X	X	X	X		X	X	X	X	X	X	X	X	
6	Station Open/Close Operation	X							X	X	X	X	X	X	X		X	X	X	X	X	X	X	X	
7	System Reaction to Station Fire Alarm			X				X	X	X	X	X	X	X	X		X	X	X	X	X	X	X	X	
8	Train Hold	X			X					X	X	X	X		X	X	X	X	X						
9	Train Stop Skip	X			X					X	X	X	X		X	X	X	X	X						
10	Emergency Cutoff			X	X	X	X	X	X				X			X	X								
11	Signaling Fallback Operation		X		X						X	X				X	X	X	X						
12	Control and Monitoring of Train Operation from OCC	X			X					X	X	X	X			X	X	X	X						
13	Control and Monitoring of Power Supply System from OCC	X				X	X	X					X			X	X	X							
14	Depot Entry/Exit	X			X								X			X	X	X							X
15	Normal Train Operation in Section	X			X	X							X			X	X	X							
16	System Reaction to Train Fire Alarm in Section			X	X	X					X		X		X		X	X		X	X	X			
17	System Reaction to Abnormal Train Door Status			X	X								X				X	X							
18	System Reaction to Safety Function of Train Operation			X	X								X				X	X							
19	System Reaction to Train Degraded Operation in Depot		X		X												X	X							X

Abbreviations and Acronyms

RSK: Rolling Stock **OHL:** Overhead Line **HV:** High Voltage Power Supply **MV:** Middle Voltage Power Supply **LV:** Low Voltage Power Supply **SIG:** Signalling
PA: Public Address **PIS:** Passenger Information System **ACS:** Access Control System **CCTV:** Closed Circuit Television **VCP:** Virtual Control Pannel
L&E: Lift&Elevator **BMS:** Building Management System **FAS:** Fire Alarm System **HAVC:** Heating, Ventilation and Air-Conditioning **LIG:** Lighting
PED: Platform Edge Door

4.1 Function flow diagram model design

The completion of daily operation for any urban transport line requires more than all relative systems with correct functions. Various interface functions between these systems should also achieve correct performance orders. Take the broadcasting function of Public Address System as an example. If the train approaching next station information is not broadcasted before the train parking, the information is out of date. Therefore, the function realization and its realization order of all involved systems are key to the scenario testing.

In this section, we take the test scenario *Train Operation in Station* for Mecca light rail as an example, to introduce the method of using function flow diagram to establish a test scenario model. The scenario model is shown in Figure 1.

All events of a test scenario are listed at the top of the diagram in their execution sequences. Then according to the interface matrix, the designers choose one interface system each time and display all relative system functions triggered by the events listed above. All functions belonging to the same system will be displayed horizontally while functions belonging to different systems will be displayed vertically in different colours.

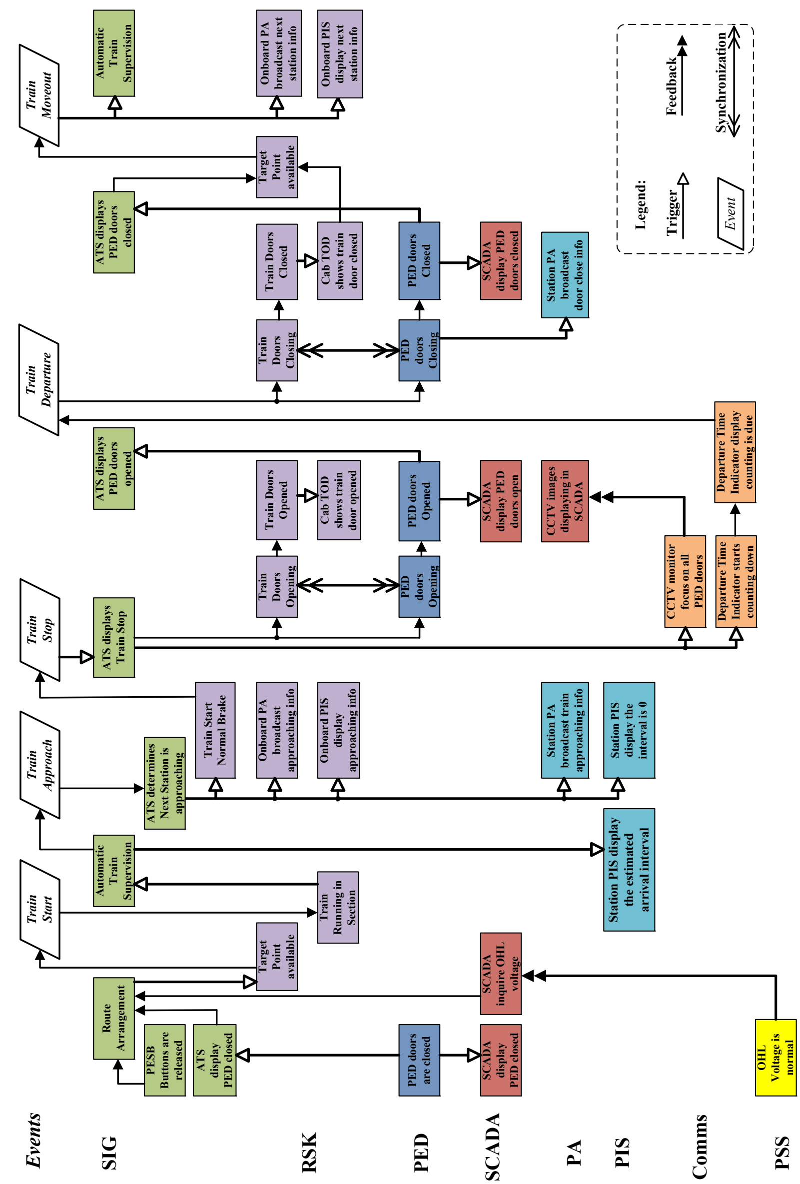

Figure 1: Function flow model for train operation in station scenario.

After relative functions of all interface systems marked in the interface matrix have been added to the diagram, their linage relationship will be studied next and sort out in detail. A scenario model focuses on the following three kinds of linage functions. The first is *synchronization*. Synchronization happens when two functions are carried out simultaneously. A typical synchronization example is the synchronization in train doors/Platform Edge Doors open and close. The second one is *trigger*. Trigger happens when one function begins its execution after the completion of its linage function. A typical trigger example is SCADA display of PED door status in real time. *Feedback* is the third linage relationship. A feedback happens when a function is realized according to the requirement of its linage function. The inquiry of OHL (Overhead Line) voltage and current values by SCADA is the typical feedback example. All these relationships are key to the correct execution of events in a scenario and are marked in different shapes of arrow in the function flow diagram.

4.2 Test flow diagram model design

Scenario testing is primarily used to demonstrate system function realization against design requirements, but the implementation of any scenario test cannot be separated from the participation of personnel. On the one hand, the system function realization result should be observed by the test personnel. On the other hand, the realization of non-linkage system functions can only be achieved by staff operation. Scenario designers should determine all key allocation requirements, such as the number of test staff and operation staff needed, their responsibilities and distribution location. The correct allocation planning plays fundamental role for the successful execution of any scenario.

Although the key elements like the events, systems, functions have been clearly displayed in the function flow diagram, the model can give no information about personnel allocation. Therefore another scenario model, named Test Flow Diagram is needed to present this element. The test flow diagram for the *Train Operation in Station* is given in Figure 2.

Similar as the function flow diagram, all events are displayed at the top of the test flow diagram in their execution sequence. Each line below gives the action and responsibility of each position. Because the test flow diagram focuses on personnel distribution, all personnel are grouped in the diagram according to their location. For example, from the test flow of *Train Operation in Station*, one can easily tell that all test personnel locate in four possible places: OCC, test train, test station platform or station control room.

The formulation of test flow diagram can be taken as the feasibility analysis of a test scenario. With the availability of test flow diagram, test organizer can know the human resource requirements so as to give reasonable allocation for the scenario. Besides, the diagram can also help all participants to be familiar with their locations and responsibilities.

The completion of test flow diagram formulation marks the completion of test scenario design. With a serial of models like scenario matrix, interface matrix,

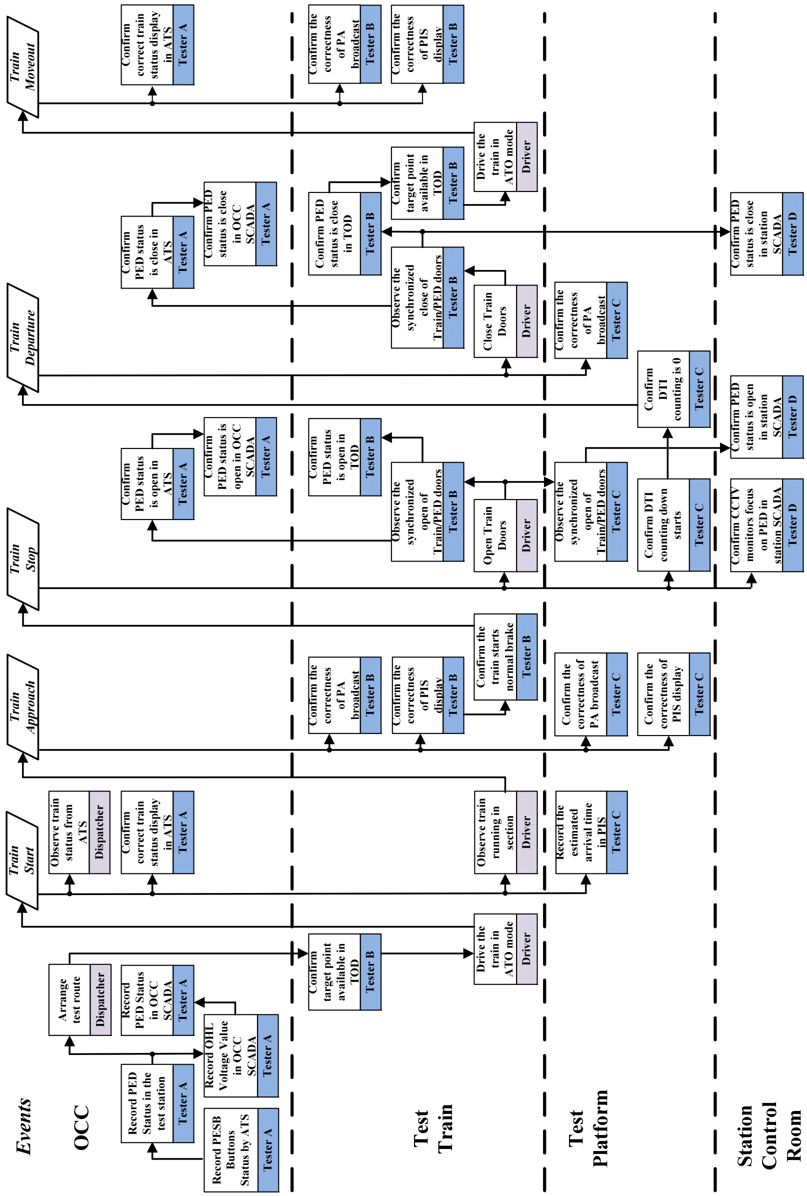

Figure 2: Test flow model for train operation in station scenario.

function flow diagram, and test flow diagram, the design process clarifies all key elements of a test scenario. Necessity analysis is also provided in this progress with all unnecessary scenarios have been omitted. The carrying out of the modelling-work in this paper plays fundamental role to ensure the quality of test scenarios, to effectively realize the test purpose and finally to give the proper verification for the function realization of the entire urban transport system.

5 Discussion and future work

Scenario testing is an important test methodology for SIT of urban transportation. In this paper, we introduced the test scenario design method with modelling works like scenario matrix, interface matrix, function flow diagram, test flow diagram. All test scenarios designed in this way can satisfy the integrity, typicality and completeness requirements, and ultimately to evaluate the overall function of urban transport.

In the future, Coloured Petri Nets [10, 11] will be used for test scenario modelling and simulation, in which *Places* are used to describe various statuses of systems of urban transport, *Transitions* describe the (coordinated) function realization of systems and their interfaces, and *Tokens* variation express the flow of testing process in the scenario. The simulation of the Coloured Petri Nets model can effectively describe the full details of the test scenario, and it can be used for on-site resource allocation and test personnel training so as to improve the efficiency of the test.

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www.witpress.com, ISSN 1743-3509 (on-line)