Chapter 123
Modeling of Shipboard Aircraft Operational Support Process Based on Hierarchical Timed Colored Petri-Net

Ting Wang, Bo-ping Xiao, Lin Ma and Yan-kun Tian

Abstract The operational support of shipboard aircraft is a complicated process, reasonable planning of aviation support resources and reduce the operational support time plays a vital role of the tasks persistent of the aviation support system. The paper introduces the basic principles of Petri nets, points out the defects of the basic Petri net in the operational support process modeling and puts forward a simulation model of shipboard aircraft operational support process based on Hierarchical Timed Colored Petri-Net. The approach simplifies the hierarchical modeling, make up for the lack of a Petri net time performance analysis, and distinguish the different operational support resources. The operational support process of shipboard aircraft and the modeling method based on HTCPN has been given in this paper. It shows the application of Petri net in the analysis and evaluation of the shipboard aircraft and is important to optimize the shipboard aircraft operational support process.

Keywords Aviation support system · HTCPN · Petri-Net · Operational support · Shipboard aircraft

123.1 Introduction

The aircraft carrier is the combat platform at sea with the most powerful combat effectiveness in the world now. It plays a significant role due to its unique characteristics like integrating the sea and air routes, combining ships and planes, controlling the air and sea and rapid deployment. The main reason for aircraft carrier becomes an important force in naval battle and land combat is its unique

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weapon equipment—shipboard aircraft. The shipboard aircraft is the power of the aircraft carrier. The operation and management of aircraft carrier is very complex, starting and recycling need a series of procedures like the lifting, guiding, arranging, refueling, loading ammunition, landing, catapulting, and blocking, which are implemented by the aviation security system. Therefore, the rational planning of aviation security resources and reducing the security time of using aircraft carrier play vital roles in the sustainability of the aviation security system task.

The security process of using the carrier aircraft is the typical discrete system. The process modeling methods commonly used for simulation modeling in discrete system are: CPM/PERT methods, IDEF3 method, Petri network method, activity-based random network method. The concepts of the place, transition and arc in the Petri network correspond to the activities, states, and rules in the security process of equipment. Applying Petri network can better show the use and maintenance process of the equipment. But the basic Petri network is difficult to describe a variety of security resources, unable to model the security task execution time, moreover, the system is complex, the model is large, hence it is easy to become chaotic. As the air security system have more security resources, higher requirements of the task duration, and complex and variable security tasks, the Timed Colored Petri network concept is introduced, which models the security process of applying shipboard aircraft, and lays foundation for building comprehensive security model of complex equipment and systematic analysis.

123.2 Basic Principle of Petri-Net Modeling

Petri network is put forward by German scholar C. A. Petri in 1962 as a process modeling and analysis tool. It is a tool for describing the graphical and mathematical processes, which provides a powerful means for studying complex systems with parallel, asynchronous, distributed and stochastic characteristics. After four decades' development, the Petri network has been widely used in various fields to simulate, analysis and control of the system such as the design, artificial neural networks, network performance analysis in parallel program and so on.

123.2.1 Basic Elements of Petri Network

The basic elements of the PDM workflow model include Store house, Transition, Token and directional arc (Sun et al. 2011).

(1) Store house: Represents the conditions that is, promoting factors of processes, and is shown by a circle "○". When the conditions are met, the corresponding end nodes of directional arc with this store house as the starting point will be

activated. The introduction of store house is used to strictly distinguish the abilities and the real implementation of the activities.

(2) Transition: represents the tasks, which is the activities in the PDM workflow, and is shown by a box "□". For example, document countersignature and the design change. However, when an activity is not completed within the set time, the system will deliver the timeout warning to the operating users, and the process will be suspended. In order to better describe the PDM workflow, transition of zero delay-instantaneous transition as auxiliary structure is added in the model. To make the model easy to be understood, this paper will apply "□" to represent the transition of zero delay.

(3) Token: represents the resources and data that can be used, which is a sign that a certain condition is met, and is shown by the black spots in the circle. When the process is moving forward, the token will transfer from one store house to another.

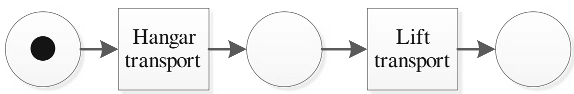
(4) The directional arc: it is used to connect store house and transition, representing the order of the implementation of activities. When the starting node of the directional arc is finished, the system will conduct process navigation according to the definition of the directional arc and the follow-up activities will be activated.

(5) Routing: routing means the sequencing description of activities and connection through the process of business implementation, and the various activities are associated through routing. There are four basic routing structures in PDM workflow: sequential routing, parallel routing, conditional routing, and cycle route. In order to describe some basic routings in the workflow model, several corresponding structured components are constructed in a functional network, i.e.: serial component, parallel component, condition selecting component and cycle component.

(a) Serial component
Serial relationships define the activities performed in a fixed order. For example, in the shipboard aircraft transporting process, the carrier aircraft must be transported from the hangar to a lift, and then transported by the lift to the deck, which is just as shown in Fig. 123.1.

(b) Parallel component
If several tasks can be executed simultaneously or in any order, it can be called as the parallel relationship. It mainly applies two basic workflow primitives: And-Split and And-Join. For instance, in the deck support process, when the shipboard aircraft gets to the support point, a variety of deck support activities, such as refueling and charging. If these activities have no relations, they can be seen as different branches of the whole process. The implementation of the

Fig. 123.1 Serial component



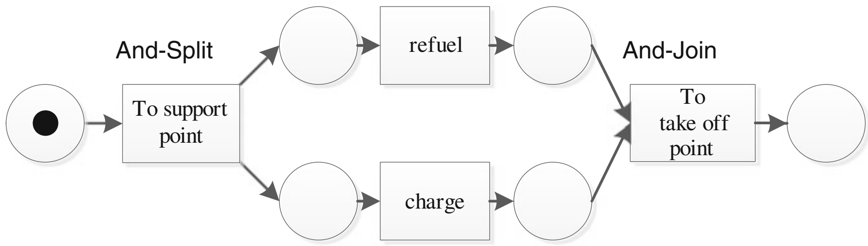


Fig. 123.2 Parallel component

two activities is not in chronological order, the "take off" activity will not be triggered only when the two activities are completed. It is just shown as in Fig. 123.2.

(c) Condition selecting component
Corresponding to conditional routing, it is used to define the split activities with mutual restraint and exclusive relations between each other. This kind of split activity often conducts the "single choice" or "multiple choices" based on the specific implementation situation. The condition selecting component also requires two basic work-flow primitives: OR-Split and OR-Join. The relationships of condition selection can be divided into two kinds: one is the implicit or split selection, that is, it is not known in advance that the trigger order of the activities determines which split is triggered; and the other is the explicit or split selection, that is, determine which branch is triggered according to the activity property before split. The operational support process mainly adopts explicit or split selection logic. In the refueling process, do pressure refueling or gravity refueling will be determined according to the aircraft model. After refueling is completed, move to the next step as shown in Fig. 123.3.

(d) Cycle component
Cycle component is used to characterize the repeated execution of a task. In this component, an explicit or OR-Split is used. For example, in the tractor repair process, if the repair is successful, go to the next step, that is used for aircraft transporting. If the repair is unsuccessful, continue to repair, until

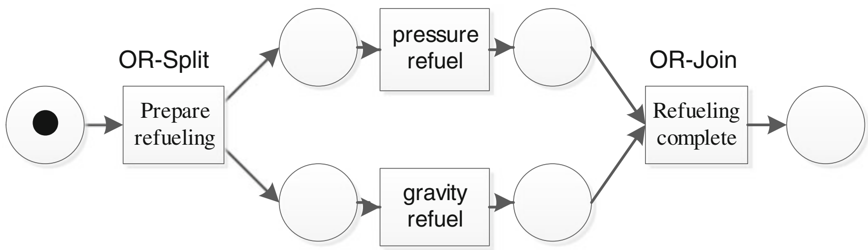
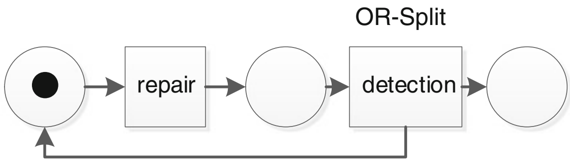


Fig. 123.3 Condition selecting component

Fig. 123.4 Cycle component



available. Here does not consider the tractor maintenance grading and repair strategies, only discuss the maintenance activities as a unity. It is shown as in Fig. 123.4.

123.2.2 HTCPN Model

Hierarchical timed colored Petri net (HTCPN) not only extends the color of the model and the execution time of activities, but also hierarchical modeling operational support processes, which combine data structures and hierarchical decomposition (Zheng et al. 2011).

Aviation support system is very complicated; the model created with traditional Petri net will be a huge scale and have a large amount of notes. This will not only make the process of modeling complex, but also make the analysis of the model characteristics difficult. Therefore the hierarchy Petri network models can be introduced, that is, use corresponding subnet in a large model to replace the transition needs to refine. The transition that contains the subnet is represented by the double box ‘⧈’. The design process of hierarchy Petri network model can be divided into two stages. First: define tasks at the top of the entire workflow structure; second: to determine the details of tasks description in the lower level (Zhao et al. 2009).

In the basic Petri network model, the transition is only with the feature of “transient”, which means its trigger is not time-consuming. When studying the operational support process, time is the parameter must be considered, as many analysis quantitative indicators like maintainability and support are described in time value, such as MTTR. HTCPN brings in the concept of time and the modeling task execution time, hence they can be simulated to obtain the time performance of shipboard aircraft using the support HTCPN model, and estimate the support time of aviation support system and the utilization rate of the support resources so as to provide the basis for the optimization of applying the support process.

In the work of the equipment support, contents like support equipment and support personnel must be considered. HTCPN defines the color of the places and enhance the arc expression ability so as to uniformly model different support resources and avoid utilizing the large and complex support models (Yang et al. 2010; He et al. 2010).

123.3 The Support Process Analysis of Shipboard Aircraft's Aviation Support System

Aviation support system is constituted by a variety of subsystems, components, parts and equipment assembly, and it is designed to provide the overall of carrying, taking off and landing, maintenance and supplies for shipboard aircraft. It includes lifts, catapults, tractors, jet bias board, the Fresnel lens, arresting wires, island-type superstructure, flight deck and hangar, etc. The system can be divided into command, transporting, deck support, landing, catapult, and other subsystems (Yao et al. 2009; Wang et al. 2005).

The aviation support system studied in this paper is composed of the transportation system, deck support system, taking off system and landing system (Zhang 2010) (Fig. 123.5).

The transportation system includes shipboard aircraft's tractors and lifts as well as weapons' tractors and lifts. To guarantee the plane transportation of shipboard aircraft on the hangar deck, the hangar is equipped with the tractors of the shipboard aircraft. To guarantee the shipboard aircraft's lifting transportation between the hangar and flight deck, the shipboard aircraft's lifts are set. To guarantee the plane transportation of weapons between the hangar deck and flight deck, the weapons' tractors and lifts are set.

The deck support system is mainly for the detection and maintenance services of shipboard aircraft, including preparation before start, inspection after the task, and preparation for another start. The main equipment contains supply facilities of air power, compressed air, nitrogen, air oil and fuel and weapons mounting equipment.

Landing system mainly ensures the safe landing of the shipboard aircraft. In order to complete the safe landing of the shipboard aircraft, the landing system is equipped with facilities like optical landing aid device, arresting wires and arresting nets.

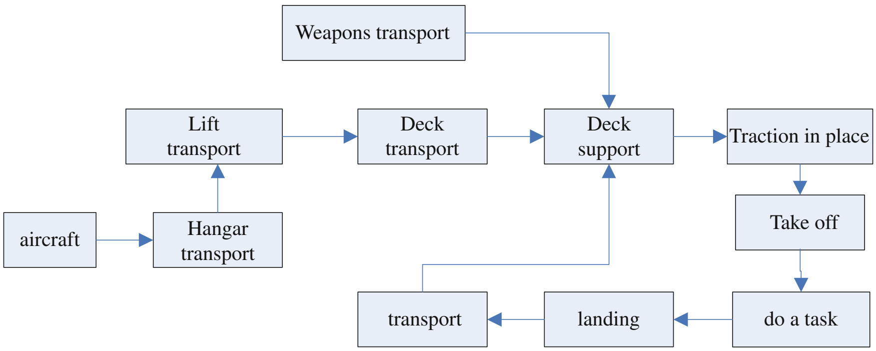


Fig. 123.5 The operational support process of shipboard aircraft

Take-off system mainly includes the facilities such as catapults, jet bias boards. The main task is to provide sufficient power to make the shipboard aircraft take off smoothly in a shorter distance.

The task of the aviation support system is triggered by the shipboard aircraft's task, and the number of shipboard aircrafts can be flexibly set according to the task.

123.4 Petri Network Modeling for the Aviation Support System

HTCPN modeling is used to establish support modeling for applying shipboard aircraft as shown in Fig. 123.6. This model fully reflects the characteristics of hierarchical modeling, simply and clearly shows that working processes of aviation support system, and lays the foundation for further analysis and evaluation of the operational support processes (Song 2008).

123.4.1 The Top-level Model of the Aviation Support System

The operational support process of shipboard aircraft from the hangar to the take-off point first needs to transport shipboard aircraft from hangar to deck support point, meanwhile, the ammunition must be transported from ammunition depot to the deck support point, and then conduct deck support for the shipboard aircraft so as to complete deck support and tract the shipboard aircraft to take-off point. This process can be divided into four relatively independent modules, and the operational support process is sub-divided according to hierarchical Petri network theory (Fig. 123.7).

In the figure, the black token means shipboard aircraft, and the red token represents ammunition. It should be noted that the token in the figure is only for more vividly expressing the relationship between support resources and major equipment, not for showing the number of tokens. During the actual modeling process, the amount of preset resources can be simulated and the allocation of resources can be balanced through analyzing the simulation results.

123.4.2 Transportation Process Modeling

The transportation of shipboard aircraft can be divided into three stages. The first stage is the transportation of shipboard aircraft in the hangar, which is the time transporting shipboard aircraft from the hangar to the lift; the second stage is the time transporting shipboard aircraft from the hangar to the deck, that is, the transportation process of the lifts; the third stage is the transporting time of the deck 1.

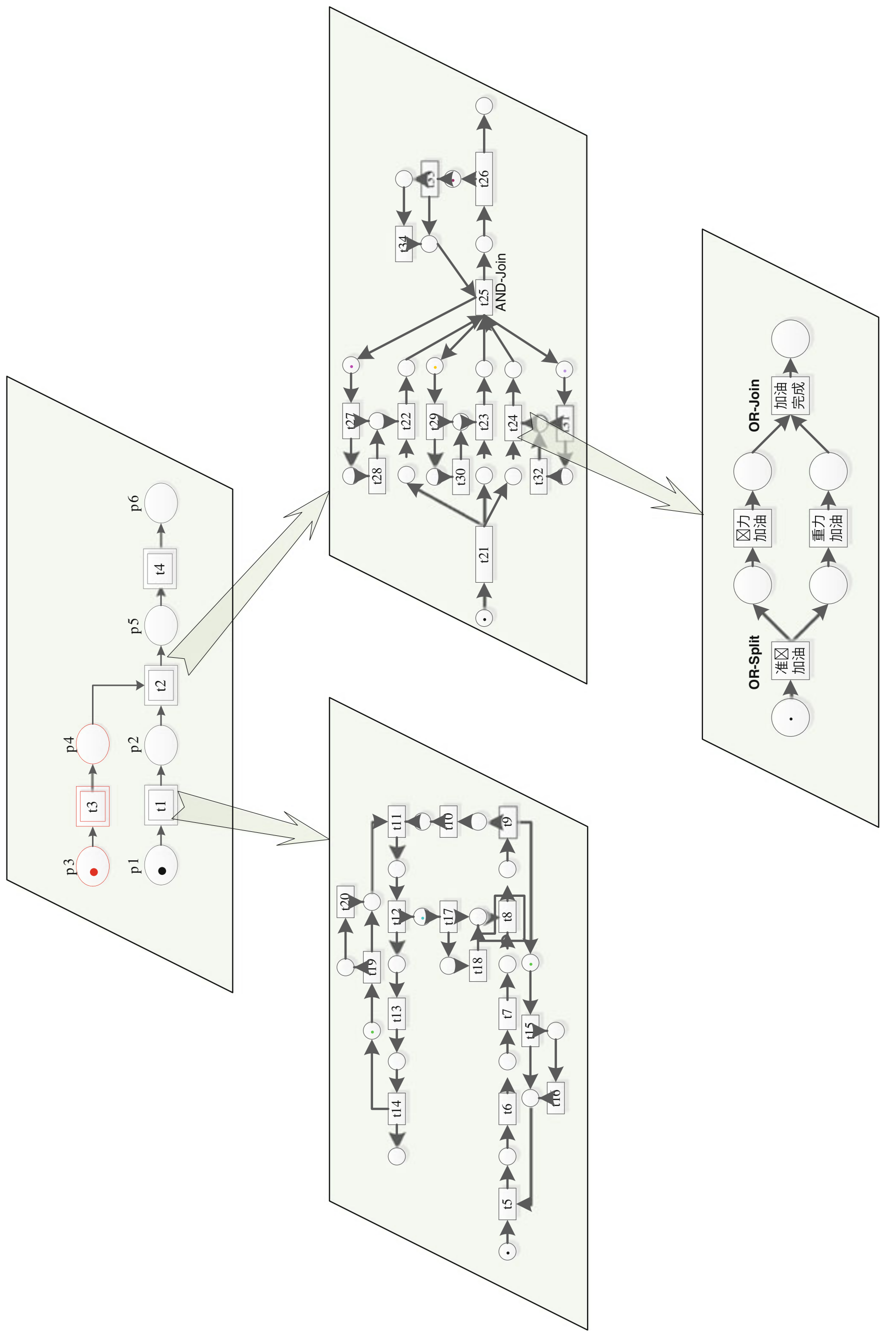


Fig. 123.6 The petri-net model of aviation support system

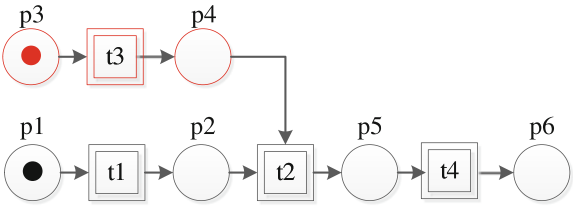


Fig. 123.7 The top-level model of the aviation support system. *t1*: transport shipboard aircraft from hangar to shipboard support point. *t2*: shipboard support. *t3*: Weapons transport. *t4*: tract the shipboard aircraft to take-off point

The transporting time here means the time from the lift to the protection time to time, excluding from the protection point to the take-off time, and to protect the support point excluding the time from the support point to the landing point and from the landing point to the support point. The number of shipboard aircraft's tractors in hangar, the number of lifts, the number of shipboard aircraft's lifts on the deck and the number of shipboard aircrafts need transporting directly affect the transporting time. The more the tractors and lifts are, the less time needed is. However, due to space and weight constraints, unlimited increase in the number of tractors and lifts is impossible. Considering from the other aspect, it will also cause a waste of resources. Therefore, in order to meet the conditions required, a reasonable number must be determined.

The model of transportation process is shown as Fig. 123.8.

The model also takes the failure of support equipment into account, and incorporates the support equipment maintenance activities into the shipboard aircraft's transporting sub-module in dominant or branch ways. The green token in the figure means the hangar tractor and deck tractor while the blue token represents lift. It should be noted that in order to more clearly show the utilization of support resources, this paper only uses a token to show the support device, but in the actual situation there should be more standby support equipment.

Ammunition transporting process is similar to transporting process of shipboard aircraft, and hence it will not be repeated here. It should be noted that the quantity of the weapons delivery should be measured by weight, which can be split. The transporting of the shipboard aircraft is as a whole, which cannot be split. This should be considered when conducting simulation.

123.4.3 Deck Support Process Modeling

The deck support system includes jet fuel system, aviation power system, air supply system, and deck support facilities. The major functions include pressure refueling and gravity refueling for shipboard aircraft; responsible for the support of the preparation before deck and shipboard aircraft flight, and aviation power

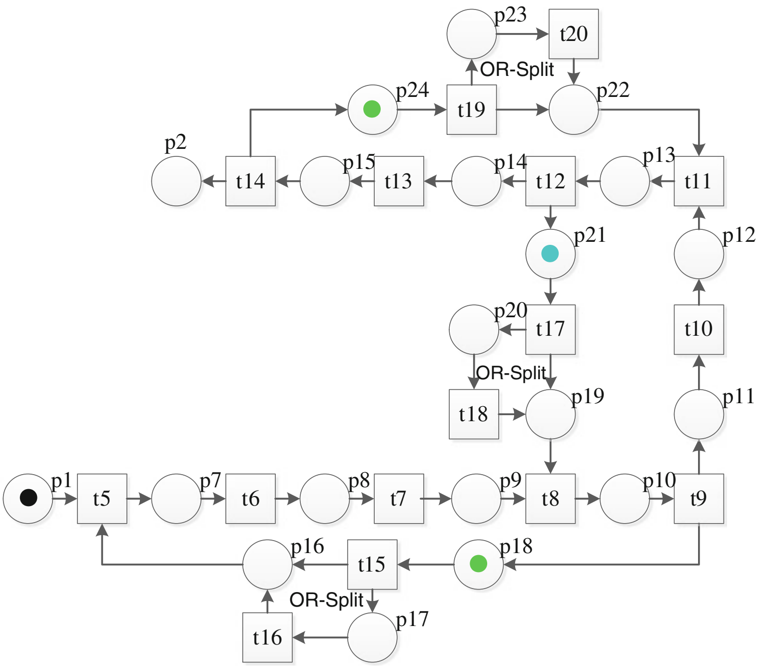


Fig. 123.8 The model of transportation process. *t5*: tie the aircraft to the hangar tractor. *t6*: untie the aircraft from the hangar. *t7*: transport by the tractor. *t8*: tie to the lift. *t9*: untie the hangar tractor. *t10*: transport by the lift. *t11*: tie to the deck tractor. *t12*: untie the lift. *t13*: transport by the deck tractor. *t14*: untie the deck tractor. *t15*: check the hangar tractor. *t16*: repair the hangar tractor. *t17*: check the lift. *t18*: repair the lift. *t19*: check the deck tractor. *t20*: repair the deck tractor

supply before the second start; power supply for the maintenance of flight deck and shipboard aircraft in the hangar; aviation power supply for guaranteeing the ship aviation maintenance, and related cabin maintenance; guaranteeing the flight deck utilizes aviation power to start the shipboard aircraft; guaranteeing the centralized storage, management and charge/discharge maintenance for aviation batteries,. In addition, it is also responsible for preparation before flight, maintenance of the required gas including filling oxygen and nitrogen to the shipboard aircraft, guaranteeing the gas filling for the shipboard aircraft's wheels and making sure the cooling of electronic equipment in shipboard aircraft when the power is on. Guarantee the routine maintenance of the deck support equipment and the wash, hydraulic maintenance, safe ground and the snow removal of the flight deck.

Suppose all the processes can be conducted at the same time except filling oxygen, and every support site is equipped with the same set of jet fuel system, the deck support model can be established as shown in Fig. 123.9.

123.5 Simulation and Analysis

Petri network has powerful analytical techniques and means. Analysis of workflow's behavior, status, and performance can be solved through the nature of Petri network (such as accessibility, safety, livability, etc.); moreover, the analysis techniques of Petri network can be used to calculate various performance indicators of the model, such as response time, latency time and share.

CPN-Tools is a Petri network modeling and simulation platform developed by the Petri network Research Center for the University of Aarhus, Denmark. It is featured with fast simulation speed and powerful network grammar checker. It supports for Linux and Windows operating system, supports hierarchical modeling and analysis of Timed Colored Petri network and supports secondary development. After modeling by Petri network, the features of the system can be analyzed to check the characteristics of the actual system. CPN-Tools support the state equation analysis and time simulation. By assigning the corresponding model's transition, arc, and the place, it can be clearly learnt the overall situation of the

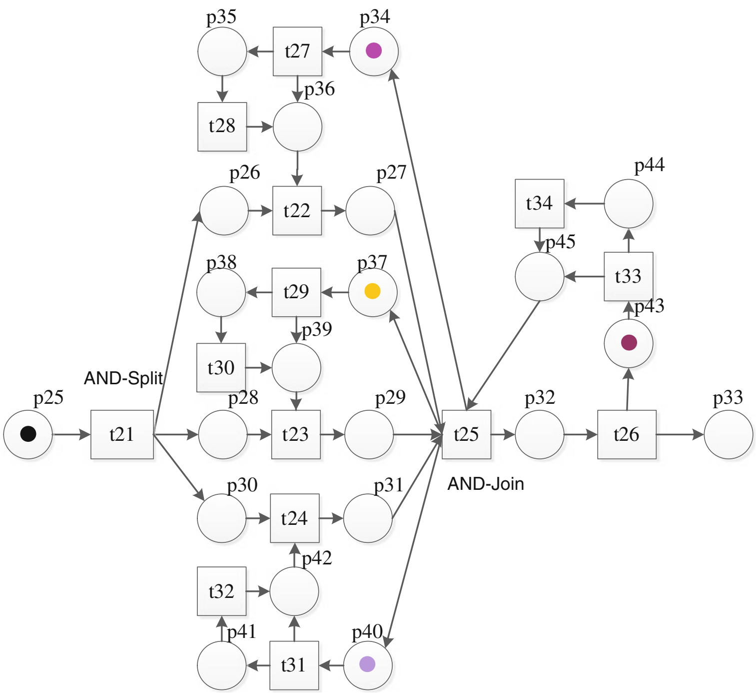


Fig. 123.9 The model of deck support process. *t21*: repair the deck support. *t22*: refuel. *t23*: charge. *t24*: load ammunition. *t25*: oxygenate. *t26*: complete deck support. *t27*: check the refuel equipment. *t28*: repair the refueling equipment. *t29*: check the charging equipment. *t30*: repair the charging equipment. *t31*: check the loading equipment. *t32*:repair the loading equipment. *t33*: check the oxygenating equipment. *t34*:repair the oxygenating equipment

operational support, parameters like the average support delay time and the support resources' utilization can be obtained, and the operational support time of the shipboard aircraft can be analyzed according to the simulation results so as to achieve the optimization of support resources (Song et al. 2007).

123.6 Conclusion

Based on the operational support feature of shipboard aircraft, this paper utilizes the hierarchical Timed Colored Petri Network (HTCPN) to establish the process model of shipboard aircraft to achieve a simple hierarchical modeling, which makes up for the shortage of time performance analysis of Petri network, achieves the distinction for support resources, provides a reference for the research of the support process of aviation support system, and plays a significant role in the tasks persistence of aviation support system.

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