# Coordination Control and Fault Diagnosis of Production System Using Multi-agent Technology

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## 1. Introduction of multi-agent and Petri net

### 1.1 Introduction of multi-agent

#### 1.1.1 The conception of multi-agent

The so-called multi-agent system is the collection of many calculable agents, and every agent is a physical or abstract entity, which can effect both itself and the circumstance and correspond with other agents.

The main idea of multi-agent is that a complicated problem should be divided and the portions should be contributed to every independent agent, then they compose of the answer to the question. Agent can resolve some local problems independently, and finish the whole answer by collaboration.

The incompact network is composed of many agents, these agents interact with each other to resolve the problems that single agent cannot solve because of its insufficient in ability or knowledge. Its main feature is every agent hasn't sufficient ability or knowledge to resolve the problems, when these agents operate at the same time, not only the data is incompact, but also there's no whole control system.

#### 1.1.2 Control structure of multi-agent system

Multi-agent is composed of many agents which have the function of circumstance observation, task layout and operation. In order to make these agents into a big complicated system to fulfill some stated tasks efficiently, a proper control system is needed. Therefore, the main research problem of control structure is to design a correct proper local control plan to guarantee that multi-agent system can resolve the given problems efficiently, including relevant task distribution, correspondence and conflict solution. According to agents' relative relations in the system, generally, there are some kinds of structures[1,2]:

**(1) Architecture of fully connected networks**

In this system structure, as shown in Fig.1.1, every agent is in an equal relation, every two agents can correspond directly. Equal correspondence and locality of information are the main feature of this kind of structure. This structure demands that every agent should have the function module of correspondence and control, and save all the agents' information and knowledge in the system.

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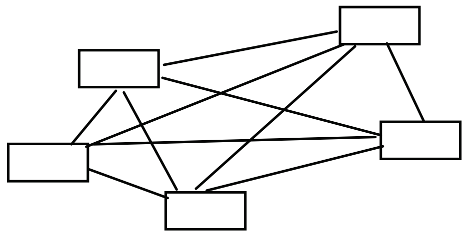

Fig. 1.1 Architecture of fully connected networks

**(2) Architecture of fully layered networks**

In this system, as shown in Fig.1.2, agents are divided into different layers, the agents at the same layers cannot correspond directly, but have to be finished by the upper layers. The agents of upper layer take charge of decisions and controls of agents at the under layers. Each agent in this structure needn't save all the agents' information in the system, just save the under layers' agents' related information and knowledge, but it is inferior to the structure of fully connected networks in correspondence.

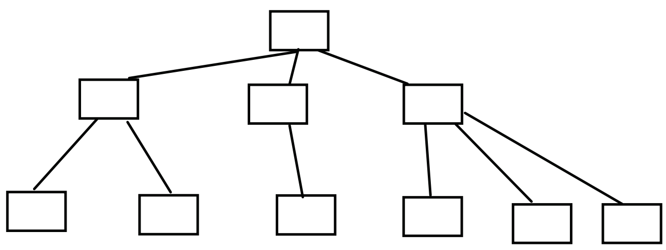

Fig. 1.2 Architecture of fully layered networks

**(3) Architecture of allied networks**

Agents in the system are divided into different agents allies according to some way (generally according to distance , functions and so on). There's a assistant agent in the inner of every ally, it is in charge of different allies' correspondence. Different allies are in the opposite relation, similar to the relations of every agent in fully connected networks.

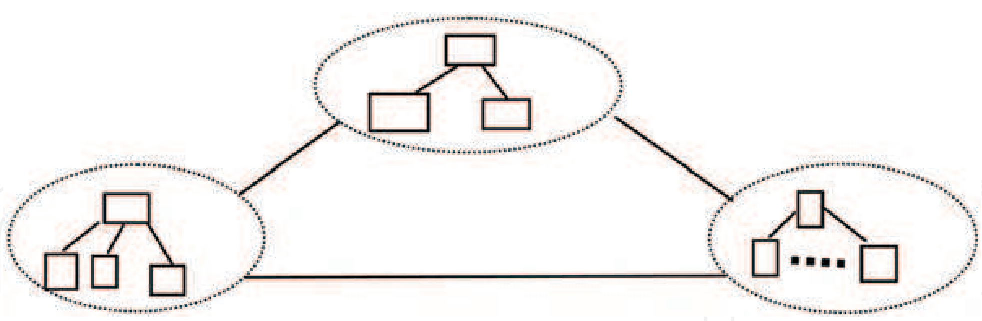

Fig. 1.3 Architecture of allied networks

### 1.1.3 Correspondence in the multi-agent system

In the system of multi-agent, correspondence means the information exchange between different agents and agents and the circumstance, then they can negotiate and collaborate to fulfill the goal. There are four kinds of ways of agents' information exchange. [3,4]

**(1) Direct correspondence**

Agents have its own physical connection and send information to the target agent directly by certain protocol, such as TCP/TIP . In this way, agent sends information to the target agent with its own address.

**(2) Combine into allies freely, then correspond by Correspondence server**
When there are too many agents, the cost is expensive by wholly direct correspondence. One solution is to combine multi-agent into allies, every ally has a correspondence server to fulfill correspondence function, that is there's no direct correspondence among agents, but correspondence server as the media. Structure of allied system is as Fig.1.4.

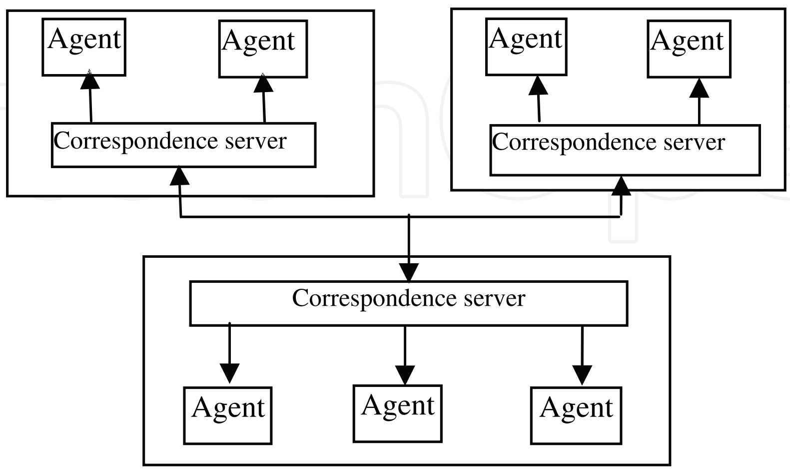


Fig. 1.4 allied system [4]

**(3) Broadcast correspondence**
If an agent need send information to all the agents in the circumstance, or it doesn't know which agent it should sent to, it has two choices: sends the message by broadcast; or sends it directly to every agent by correspondence. When the message is longer, it will burden the internet largely by direct correspondence. As broadcast correspondence needn't copy many shares of the message and send them separately, therefore, it can avoid the big burden of the networks.
**(4) Blackboard Correspondence**
This way is the traditional correspondence in the field of artificial agents. All the agents give away and read information in the share area (or blackboard) In order to realize the secrecy of part of information, the problems are generally divided into different abstract layers, agents in different layers have different visited rights.

### 1.1.4 Multi-agent cooperation and harmony
Harmony and Cooperation among multi-agents are the basic conception of multi-agent system. Harmony means that every agent continuously ratiocinates its behavior purpose and makes decisions to realize a harmonious work process. Generally the cooperation among agents is for fulfilling the common task[5]. Correspondence is very important to the operation and harmony of multi-agent system, agents must share their plans, goals and data to fulfill their cooperation and solution[5]. The ways of cooperation among multi-agent are mainly contract net, blackboard model and the consequence share model.

## 1.2 Basic knowledge about Petri net
### 1.2.1 The introduction of Petri net model[6]
System model is an abstract show of the factual system. Petri Net aims at researching the organized structure and dynamic behaviors of the system, with an eye to the possible changes and their relations in the system, it describes the various dependent relations in the accidents,

such as orders, subsequence and so on. It is fit for describing the system which has rules and is featured by flowing behaviors, such as substance flows, information flows and so on.

The structure factors of a Petri Net mainly include place, transition and arc. Place mainly describes the possible local status of the system, for example, fault symptom and phenomenon in the fault diagnose or buffer in the computer and so on. Transition is used to describe the incident of modifying the system status, such as the information process and transmission in computers or correspondence system. Arc is factor to connect place and transition, describing the direction of the system status change .

In Petri Net model, signs are included in the place, their dynamic changes in the place represent the different status of the system. If one place describes one resource, it may include some signs or zero, the amount of the signs represents the amount of the resources. If one place describes one proposition, it can include one sign or no sign, when it has one sign, that shows the proposition represented by the place is true, or that is false. Just as Fig. 1.5, the circles represent the place, the thin sticks represent the transition, and the directed lines represent the arc, and the black dots in the place represent the signs.

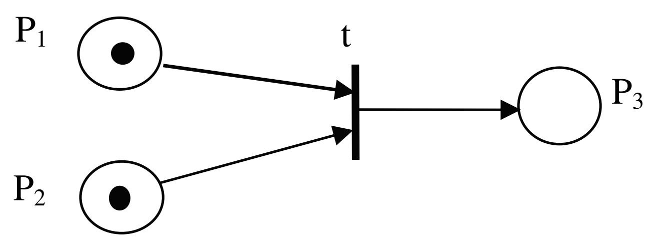


Fig. 1.5 Petri Net

### 1.2.2 The definition of Petri Net

**Definition 1-1** A three tuple $N = (P, T; F)$ is called directed net, shortened form Petri, its sufficient and necessary conditions are:

1. $P \cap T = \Phi$;
2. $P \cup T \neq \Phi$;
3. $F \subseteq (P \times T) \cup (T \times P)$;
4. $dom(F) \cup cod(F) = P \cup T$.

there, $dom(F) = \{x \mid \exists y : (x, y) \in F\}$, $cod(F) = \{x \mid \exists y : (y, x) \in F\}$ are defining region and value region of F.

In the net, $P$ and $T$ are two no-intersectant set, called basic factors set of net $N$, $P$ is places set of net $N$, $T$ is transitions set of net $N$, $F$ is the flows relations of net $N$. One net can be represented by a directed dimidiate figure: generally little dots represent place $P$, a length of black line represents transition $T$, the arrows from $x$ to $y$ represent the $(x,y)$ in the flow relationship, its description is shown in Fig.1.6.

**Definition 1-2** Prepositive set and postpositive set. Set $N = (P, T; F)$ is a Petri Net, $X = P \cup T$ are elements set, then

$^{\circ}x = \{y \mid (y, x) \in F\}$ is called Prepositive set of $x$;

$x^{\circ} = \{y \mid (x, y) \in F\}$ is called postpositive set of $x$.

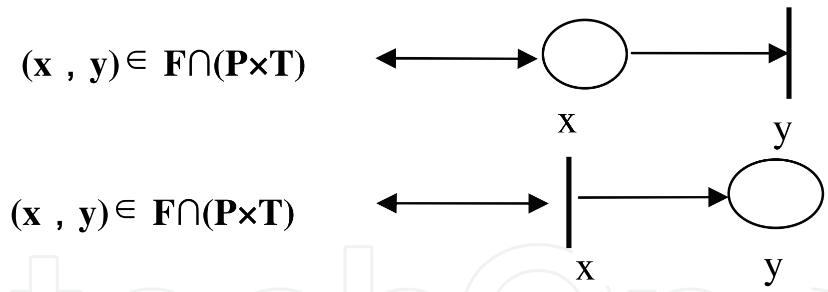


Fig. 1.6 Flow relationship

If place $p \in P$ and transition $t \in T$ , makes $p \in t^{\circ} \cap {}^{\circ}T$, then when t happens, $p$ will lose and get token. This feature in the structure shows that the resources in $p$ affect t similar to the activator in chemical reaction. The net which hasn't this structure is called pure net.

On the other hand, if $x,y \in X$, $x \neq y$, but ${}^{\circ}x = {}^{\circ}y \wedge x^{\circ} = y^{\circ}$ , then no matter in structure or in behavior, $x$ cannot distinguishes from $y$, the net which hasn't this structure is called simple net, the feature of simple net is there's no two transitions which have the same input and output place set.

**Definition 1-3** If $\forall x \in X : x^{\circ} \cap {}^{\circ}x = \Phi$, then N is called pure net.

If $\forall x, y \in X : {}^{\circ}x = {}^{\circ}y \wedge x^{\circ} = y^{\circ} \Rightarrow x = y$, then N is called simple net.

### 1.2.3 Petri Net system

Net is different from system. Net just includes place, transition and arc, while system means nets and the original sign related to net. In the circumstance without special introduction, the Petri Net is Petri Net system. In the process from net to net system, the original distribution of resources has to be demonstrated, the activity rule on the frame has to be regulated.

**Definition 1-4** the conditions which a six tuple $\sum=(P , T , F , K , W , M_o)$ is a Petri Net system are:

1. $N = (P, T, F)$ is a Petri Net, is called basis net of $\sum$.
2. $K : P \rightarrow N^{+} \cup \{\infty\}$ is capacity function of place.
3. $W : F \rightarrow N^{+}$ is right function.
4. $M_0 : P \rightarrow N_o$ is original mark, it satisfied : $\forall p \in P : M_0(p) \leq K(p)$.

$N^{+} = \{1,2,3 , \ldots\}$, $N_o=\{0,1,2,3,\ldots \}$. In the figure show of the net system, to arc $f \in F$, when $W(f)>1$, labels $W(f)$ on the arc. When the capacity of place is limited, generally writes $K(p)$ on the side of the circle of place p, and when $K(p) =1$, the sign is generally omitted. The black dots of place represent the original sign which represents a kind of resource distribution in place.

**Definition 1-5** The condition of transition.

1. $t^{\circ} = {}^{\circ}t \cup t^{\circ}$ is called the expansion of $t$.
2. The condition that t has friable in $m$:

$$\forall s \in {}^{\circ}t : M(s) \geq W(s,t) \wedge \forall s \in t^{\circ} : M(s)+W(t,s) \leq K(s)$$

Labels that $t$ has friable in m $M[t>$, and M enables $t$ happen or $t$ enabled happens by $M$. Here ${}^{\circ}t$ represents all the input place's set of $t$. $|{}^{\circ}t|$ represents the amount of input place of $t$; $t^{\circ}$ represents all the output place's set of $t$. $|t^{\circ}|$ represents the amount of output place of $t$.

**Definition 1-6** The consequence of transition
If $M[t>$, then t can happen in $M$, changes labeled $M$ to $M$'s successor $M'$, the definition of $M'$ is any $s \in S$:

$$M'(p) = \begin{cases} M(p) - W(p,t) & if\ p \in {}^{\cdot}t - t^{\bullet} \\ M(p) + W(t,p) & if\ p \in t^{\cdot} - {}^{\cdot}t \\ M(p) - W(p,t) + W(t,p) & if\ p \in {}^{\cdot}t \cap t^{\cdot} \\ M(p) & if\ p \notin {}^{\cdot}t^{\cdot} \end{cases}$$

$M^{\circ}$ is $M$'s successor, the truth can be labeled $M[t>M^{\circ}$.

### 1.2.4 The basic relationship of incidents

Petri Net has description abilities of various structures, these structures are the basis to construct other net system of all levels, and also instruments in the basic phenomenon and related theories research. Here are the most basic structures:

1. Order: Transition $t_2$ must happen after $t_1$;
2. Conflict: One of transition happens in the transitions of $t_1$, $t_2$, $t_3$, other two can't happen, the substance of conflict is the competition of resources, $t_1$, $t_2$, $t_3$ compete for the share resources;
3. Subsequence: Transition $t_1$, $t_2$, $t_3$ can happen at the same time;
4. Synchronization: Transition can happen just in the circumstance of having all the resources;
5. Union: The happens of transition $t_1$, $t_2$, $t_3$ affect the same resource, if one of transition $t_1$, $t_2$, $t_3$ happens, $t_4$ will happen;
6. Mixed: The concomitant status of subsequence and conflict.

## 2. The task allocation of multi-produce line

The problem of the task allocation is a kind of typical problem in combined optimization, it is applied in production, plan and flexible manufacture system, such as mode classification, work allocation, equipment collocation, production arrangement and printed circuit board design and so on.

In the system of multi-agent, the task allocation's mechanism is one of the research hotspots. The reason is that in one aspect whether or not it can make the ability of each agent maximal and avoids taking more resources, and in another aspect task allocation relates to how to complete the tasks together through the effective dialogue and the negotiation if one of the agents did not has the ability to complete its task. Task allocation mechanism establishment is the foundation of studying the multi-agent cooperation [7]. There are four steps in the multi-agent task allocation: task decomposition, task allocation, task solution and result synthesis [8].

### 2.1 The ways and mechanism of task allocation

#### 2.1.1 The ways of task allocation

Task allocation mainly has two ways: concentration and distribution. In the way of concentration, there are two means: one is man-made allocation in advance, which the task is arranged by personnel in advance to agent in the system. The other is one agent is in charge of task decomposition (which is called Trader), this agent saves the ability table of every agent in the present MAS system. When there is a task to be finished, Trader inquires the able agent whether accepts this task, if it receives the agreeable information, Trader will tell the promulgator of the task, or tell that no agent can fulfill the task at present. In the way of distribution, there are also two means: acquaintance and contract net.

### 2.1.2 The mechanism of task allocation

The mechanism of task allocation mainly has:

1. General market balance[8]: general market balance furnishes a structure of distributing task and resources to agents efficiently by market mechanism. In this structure, resources are dominated by market with some commodities, and these commodities are the resources that can deal with the task. Every commodity is thought limitless and successive. There are two kinds of agents in market: manufacturers and consumers; the agents which have resources are considered as manufacturers, while the agents which have tasks to resolve are considered as consumers. Manufacturers and consumers balance the market by bargain.
2. Auction: The way of auction is widely used in the task allocation of multi-agent. Auction is a market mechanism, it decides resources allocation and price by a series of clear rules. Price decision is based on the huckster of market anticipants[8].
3. Contract net: Contract net is an important mechanism of task allocation; it is widely used in the arithmetic of task allocation. The basic ideas are: when the manager has some tasks to be solved by other agents, it broadcasts the messages which relate to the tasks to other agents, agents who have received the messages will examine the ability to solve the problem; and then send out its value of bidding and become the bidder; finally, the manager evaluate those values and elect the most appropriate bidder to award the task, that is to say, it fulfill the negotiation process according to the mechanism of tender-bidding–selected as it does in the market[9]. The task allocation negotiation process is given as the Fig. 2.1.

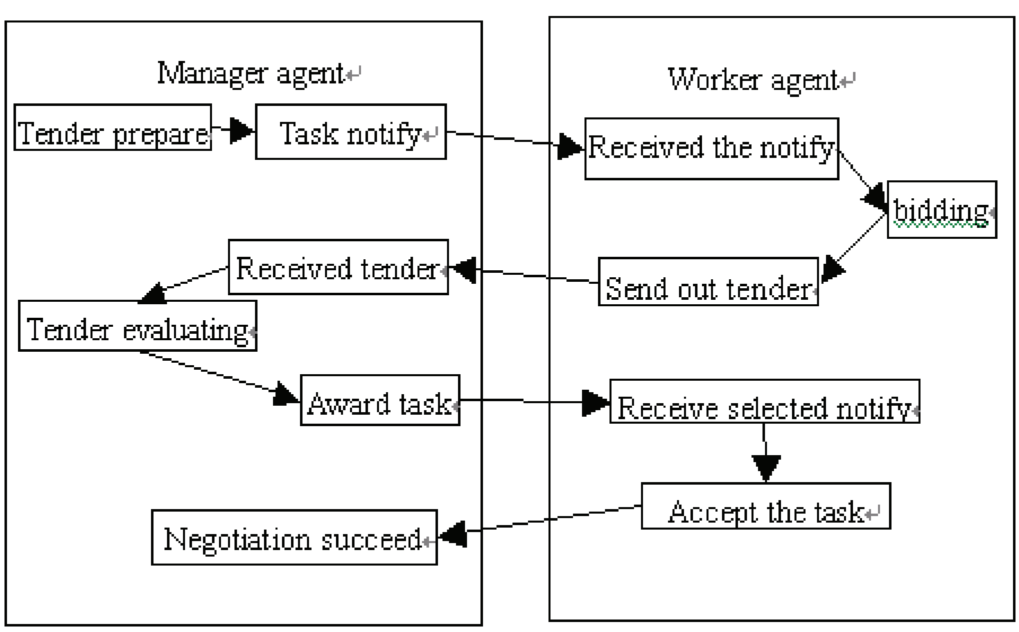


Fig. 2.1 The negotiation process based contract net

### 2.2 The goal and principles of task allocation and some simplification to the system

#### 2.2.1 The goal of task allocation

The goal of task allocation is to find a feasible way of allocating tasks to the agents, and make the system achieving the set goal and minimize the sum-dissipation after allocating the tasks. The dissipation needs to synthesize factors of the time consumption to complete the task, the reliability of the system, the energy consumption of the system and the effect to the environment of the system.

#### 2.2.2 Principles of task allocation

1. Minimize the consumption time

To minimal the overall time of completing the task, that is, request for $T^*=min(\Sigma Tij)$, and $Tij$ represents the time agent $i$ finish the task $j$. It contains two parts of the time to fulfill the task: the cost of executing and the cost of communication.

2. Equilibrated the load of each agent

Suppose the load of agent $i$ is $Li$, that is, it need to satisfy $L1=L2=\ldots\ldots=Ln$, this means each agent work with same load, avoiding the phenomena that some of the agents overload longtime but some of agents work with relatively little load. The load of each agent needs to be equilibrated as possible as we can in the process of task allocation

3. Maximize the reliability

The reliability needs to be maximized in the task allocation. The reliability needs synthesize those influence factors: rate of average failure of system, the working time of system and the working environment of system. The system which a person has joined must consider men's factor. Here, we did not consider the incredible because of cheating of agents; the reliability here is focus on the reliability caused by the failure, the working time and the environment of the system. Task allocation should assign the task for the equipment which has the highest reliability.

4. Minimize the energy consumption

Different quantity of energy may be consumed when accomplish a particular task by different agents, task should be allocated to the agent who with minimal energy consumption when accomplish the task.

5. Minimize the influence to the environment

Different systems will cause the different influence to the environment, we should allocate more tasks to the system which with the minimal influence to the environment.

#### 2.2.3 Assumptions and simplification to the practical system

The agents in the system are heterogeneous, that is, a particular task may take a different mounts of running time, rate of fault and influence to the environment if executed on different agents. But we consider it is same for an agent to deal with different type of tasks with same quantity except for the difference at ability, that is, if an agent can solve different types of tasks, the efficiency is same while executing those tasks.

Deeming the communicate costs are zero. Speaking strictly, two parts of the time are cost to finish the task: the time is used for executing and the time is used for communication[10]. The time used in the communication occupied only a very small part then the execution, so we ignore the costs of communication in the article and deem the overall costs of time only used for execution; it is accord with the practical system and can make the discussion simplified.

The tasks needed to be allocated are independent, that is, there are not dependent relationships between tasks, i.e. the tasks $T=\{t1,t2........tm\}$, it did not need to finish $t_j$ firstly if we want to finish $t_i (i \neq j)$.
The agents are absolutely honest. That is, deeming the values of state which are returned by agents are absolutely believable in the article. There is no cheating when send the values of state for all the agents (include person).
The tasks which need to be allocated have been decomposed. Task decompose is a very important step in the task allocation, but we will not take the task decompose into account in the article and think the task have been decomposed, it can be done by the former agent or the person.

### 2.3 Factors influence on task allocation and its computinon[11]

There are three factors influence on the task allocation: the integrative reliability of agent; the average energy consumption of agent; the factor influence on the environment; let $\lambda_i$ be the integrative reliability of agent $i$; let $\delta_i$ be the average energy consumption of agent $i$ and let $f(\delta_i)$ be the factor of energy consumption; let $\zeta_i$ be the influence level to the environment of agent $i$. The computational methods are as follows:

#### 2.3.1 The integrative reliability computation

$\lambda$ is a set of integrative reliability of agents and the dimension is equal to the number of agents. The value of $\lambda_i$ fall into [0,1]. It means completely credible of the system when $\lambda_i$=1 and unbelievable when $\lambda_i = 0$.
Let $\lambda_{ifr}$ be the reliability related to faults; let $\lambda_{iwt}$ be the reliability related to the working time and let $\lambda_{iwe}$ be the reliability related to working environment. All the values of that variable are fall into [0,1].
The computation of integrative reliability $\lambda_i$ is given by (1).

$$\lambda_i = \frac{1}{3} \times \lambda_{ifr} + \frac{1}{3} \times \lambda_{iwt} + \frac{1}{3} \times \lambda_{iwe} \tag{1}$$

Assuming agent $i$ has gone wrong $N$ times and its maximal allowed number is $M$, then $\lambda_{ifr}$ can be computed as

$$\lambda_{igz} = \begin{cases} \frac{M-N}{M}, ......N \le M \\ 0, ..........N > M \end{cases} \tag{2}$$

The reliability is the highest when $\lambda_{igz} = 1$ and is the lowest when $\lambda_{igz} = 0$. The computation of $M$ is given by (3) and (4) based on the relationship between rate of equipment faults and the working time, as in Fig. 2.2.

$$GZL = \begin{cases} c \;\; -k_1 T_{wt} + b, .........\,..T_{wt} < T_{cs} \\ b.........\;..........\;....T_{cs} \le T_{wt} < T_{mh} \\ k_2 (T_{wt} - T_{mh}) + b, .......T_{mh} \le T_{wt} \le T_{sm} \end{cases} \tag{3}$$

$$GZS=\begin{cases} L_1 \ldots\ldots\ldots\ldots\ldots\ldots\ldots T_{sm} < T_{cs} \\ L_2 \ldots\ldots\ldots\ldots T_{cs} \le T_{sm} < T_{mh} \\ L_3 \ldots\ldots\ldots\ldots T_{mh} \le T_{wt} \le T_{sm} \end{cases} \tag{4}$$

Here,

$$L_1 = (c+b)T_{sw} - \frac{1}{2}k_1 T_{wt}^2$$

$$L_2 = (c+b)T_{cs} - \frac{1}{2}k_1 T_{cs}^2 + b(T_{wt} - T_{cs})$$

$$L_3 = (c+b)T_{cs} - \frac{1}{2}k_1 T_{cs}^2 + b(T_{mh} - T_{cs}) + \frac{1}{2}k_2 (T_{wt} - T_{mh})^2 + b(T_{wt} - T_{mh})$$

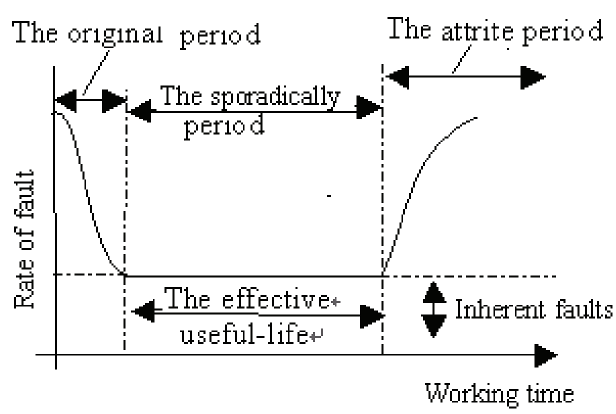


Fig. 2.2 Graph of equipment fault ratio

We simplified it to a linear relationship, as in Fig.2.3. There is not much influence on the practical model after simplified, but it is better for the follow analysis.

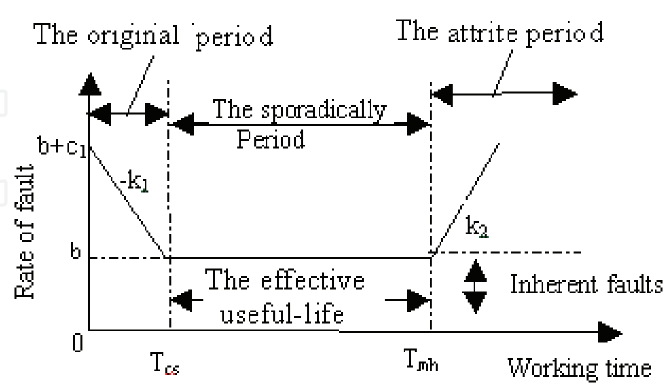


Fig. 2.3 Simplified graph of equipment fault ratio

$$M = Int\,(GZS + 0.5) \tag{5}$$

In (5), Int() denotes to acquire integer for the content in the parenthesis and the GRL in formula (3) denotes the rate of faults. The relationship between the rate of faults and the

working time is expressed by the formula (3), the relationship between the numbers of faults, the working time is represented by the formula (4) and the GZS represent the number of faults. Coefficients $k_1$, $k_2$ and $c$ can be given by practical system and experience.
Considering the relationship between the working time and the dependability of normal machine is not linear, we simplified it to linear as the Fig.2.4. The calculation of $\lambda_{iwt}$ is given as (6).

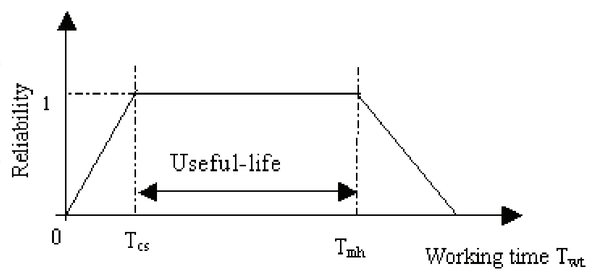


Fig. 2.4 The relationship between reliability and working hours

Let $T_{sm}$ be the life-span of agents; let $T_{mh}$ be the attrite life-span of agent; let $T_{cs}$ be the original life-span of agents; let $T_{wt}$ be the whole working time of agents. The computation of $\lambda_{iwt}$ is given as (6).

$$\lambda_{iwt} = \begin{cases} \frac{1}{T_{cs}} \times T_{wt}, \ldots\ldots T_{wt} < T_{cs} \\ 1 \ldots\ldots T_{cs} \le T_{wt} \le T_{mh} \\ 1 - \frac{1}{T_{sm} - T_{mh}} (T_{wt} - T_{mh}), \ldots T_{mh} < T_{wt} \le T_{sm} \end{cases} \tag{6}$$

The reliability related to the working time of agents is the highest when $\lambda_{iwt}$=1 and is the lowest when $\lambda_{iwt}$=0.
$\lambda_{iwe}$ represents the influence to the dependability related to environment and its value, whose range is [0 , 1], depends on the practical environment. It means the working environment of system is of great benefit to the agent when $\lambda_{iwe}$ =1 and of not benefit when $\lambda_{iwe}$ =0.

### 2.3.2 The computation of influencing factors of energy consumption

$\delta$ is the set of energy consumption of multi-agent system with n elements and $f(\delta_i)$is also a vector of n dimensions which corresponds with a value of $\delta_i$. The value range of $f(\delta_i)$ is [0,1], here we defined δmax is the maximal energy consumption and δmin is the minimal energy consumption. The consumption of $f(\delta_i)$ is given as (7).

$$f(\delta_i) = \begin{cases} 1, \ldots\ldots \delta_i < \delta_{\min} \\ \frac{\delta_{\max} - \delta_i}{\delta_{\max} - \delta_{\min}}, \ldots\ldots \delta_{\min} \le \delta_i \le \delta_{\max} \\ 0, \ldots\ldots \delta_i > \delta_{\max} \end{cases} \tag{7}$$

It is absolutely fulfilled the demands for the energy consumption when $f(\delta)$=1 and it means energy consumption is too much when $f(\delta_i)$=0.

#### 2.3.3 The factor of influence to the environment

$\zeta$ represents the set of influence factors to the environment, and the value range is [0,1]. It is means the smallest influent upon t the environment when $\zeta_i$=1 and is the biggest when $\zeta_i$=0 .the value can be decided by person or the agent based on the practical situation.

### 2.4 Definitions of some interrelated matrix and its calculation methods

#### 2.4.1 Ability matrix

We consider a system consisting of a set of agent A. The agent can perform different tasks. The set of types of tasks that the agents can perform is denoted by $T$. Every agent $a_i \in A$ may be able to perform only tasks that are a subset of the overall set of types of tasks in the system. We assume that there is a binary relation $\rho \subset A \times T$ such that for any $a_i \in A$, $t_j \in T$, $\rho_{ij}=1$ if agent $ai$ can carry out a task of $t_j$ and $\rho_{ij}=0$ if agent $a_i$ can not carry out a task of $t_j$, it can be described as a matrix[12].

For example, suppose there are three agents in the system, $A = (a_1, a_2, a_3)$ and five type of tasks $T = (t_1, t_2, t_3, t_4, t_5)$. The first agent can carry out the tasks of type $t_1$ and $t_4$, the second one can carry out the tasks of both types $t_1$, $t_2$, $t_3$, $t_4$ and $t_5$, the third agent can carry out tasks $t_3$ and $t_5$. The relation $\rho$ can be describes as the Fig. 2.5.

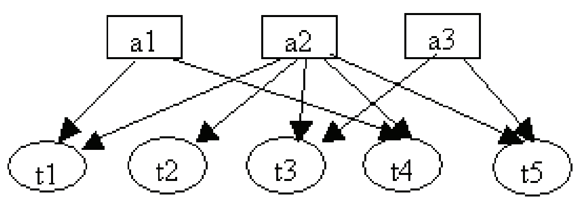


Fig. 2.5 An exmple of the relation between agents and tasks

The relation ρ also can be defined a matrix as

$$\rho = \begin{bmatrix} 1 & 0 & 0 & 1 & 0 \\ 1 & 1 & 1 & 1 & 1 \\ 0 & 0 & 1 & 0 & 1 \end{bmatrix}$$

#### 2.4.2 State matrix

Let the state matrix be $S= \{s_1, s_2, s_3 \ldots s_n\}$, and $S_i= (i, l, \mu_i, \lambda_i, \delta_i, \zeta_i)^T$. The state matrix shows the states of each agent in the system and the meanings of the symbols in the formula are that:

$i$ represents the tab of the agent in the system;

$l$ represents the residual tasks for the agent $i$;

$\mu_i$ represents the average working efficiency of agent $i$;

$\lambda_i$ represents the integrative reliability of the agent $i$;

$\delta_i$ represents the average energy consumption of agent $i$;

$\zeta_i$ represents the influence level to the environment of agent $i$ .

#### 2.4.3 The dissipated matrix $C_{n\times n}$

Let the dissipated matrix be $C_{n\times n}== \{c_{ij} \mid 1\le i\le n \;\&\; 1\le j\le n\}$, $c_{ij}$ represents the integrative consumption that the agent $a_i$ need to accomplish $t_j$. We define the consumption of time that a agent to accomplish a task to be the basic dissipated matrix, and define the generalized consumption which consider the reliability of agents ,the energy consumption and the factors affect to the environment to be the generalized dissipated matrix. The basic dissipated matrix can be calculated as (8).

$$Cj_{ij} = \frac{l + t_j}{\mu_i + \rho_{ij}} \tag{8}$$

The generalized dissipated matrix can be calculated as (9).

$$C_{ij} = \frac{cj_{ij}}{\lambda_i \times f(\delta_i) \times \zeta_i} \tag{9}$$

When the influencing factors of $\lambda_i$, $f(\delta_i)$ and $\zeta_i$ equal to 1, the elements in the generalized dissipated matrix do not change, if one of the factors equal to 0 when agent ai to carry out the task $t_j$, then one of rows correspond with $a_i$ will become infinite and we filled it use INF, in this situation we will consider ai has not the ability to fulfill the task and supposed it did not exist. In the normal situation, the range of $\lambda_i$ , $f(\delta_i)$ and $\zeta_i$ are [0,1], and $C_{ij}$ will be bigger when thinking the influence of those factors.

#### 2.4.4 Task allocation matrix $X_{m \times n}$

The value of $x_{ij}$ is 0 or 1, when $x_{ij}$ = 1, it means to allocate $t_j$ to agent ai; when $x_{ij}$ = 0, it means does not to allocate $t_j$ to agent $a_i$; A task allocation matrix shows a way which the task can be allocated.

### 2.5 The limiting conditions and allocation arithmetic of the task allocation

#### 2.5.1 The limiting conditions of the task allocation

Certain conditions should be satisfied when in the task allocation, here we call those conditions as the limiting conditions, when the tasks have been allocated ,each of the agent has to check whether the tasks allocated to them satisfy the limiting condition or not, if the task satisfy the limiting condition, the agent performed it next, if not, the tasks need to be decomposed again.(the work can be done by the agent or the people, and we do not discuss it here),then the agent allocate the tasks again. In the paper, the limiting condition is given as follows (here suppose the task $t_j$ have been allocated to the agent $a_i$):

$$\begin{aligned} l + t_j &\le E_{i\max} \\ t_j &= E_{i\min} \end{aligned} \tag{10}$$

Let $E_{imax}$ be the maximal task the agent ai can receive and let $E_{imin}$ be the minimum task the agent $a_i$ can receive; $l$ is the tasks the agent ai is dealing with.

#### 2.5.2 Arithmetic of task allocation

In conclusion, when the task allocation agent receives each agent's status, it can figure out the generalized dissipated matrix based on the above method. And then it deem the generalized dissipated matrix as coefficient matrix in Hungary arithmetic to allocate tasks, the task allocation process is as follows:
Allocating the tasks to the task allocation agent by person;

When the task allocation agent receives tasks, it sends the status request to each agent;
Agent who receives the request sends its status to the task allocation agent;
The task allocation agent figure out the generalized dissipated matrix as the coefficient matrix in Hungary arithmetic based on Equ.(8) and Equ.(9);

1. Judging the relationship between rows ($m$) and columns ($n$) in the matrix, if $m=n$, using the standard Hungary arithmetic to allocate tasks (take the generalized dissipated matrix as the coefficient matrix); if $m \neq n$, then we can translate the coefficient matrix (the generalized dissipated matrix) into a square matrix through adding, then we can allocate tasks through standard Hungary arithmetic takes the square matrix as the coefficient matrix.
2. The task allocation agent send the task allocation information to agents, then agents who received the message check whether the task satisfy the limiting condition or not, if the task satisfy the limiting condition, the agent start to work; if not, it need person to decompose the tasks and assign to the task allocation agent, then go to the step 2.

## 3. Coordination control of multi-production lines system

### 3.1 Definition of multi-agent cooperation

Multi-agent cooperation refers to a behavior of multi-agent's assorting of themselves to accomplish a common goal. Most document regard cooperation as a kind of common sense behavior. Some definitions are [13,14,15]:

**Definition 3-1**: an agent use the goal of another agent. On the assumption that both the agents have been designed , there is no conflict of targets, an agent just accomplishes the other's goal passively.

**Definition 3-2**: an autonomous agent uses another agent's goal, on the assumption that the cooperation happenes between the agents with capacity of accepting or refusing cooperation.

**Definition 3-3**: between two autonomous agents, if either meets one of the acquirement, we say that the two agents cooperate.

1. an agent uses another agent's target.
2. Between agents there is conflict, but it can still reach a balance.
3. two or more agents finish their own targets due to their exchange.

We can see that cooperation's goal is to make two autonomous agents get a common target to finish a common task.

**Definition 3-4**: the so called cooperation is a interaction to make two or more agents exchange information and finish a task together.

**Definition 3-5**[16]: Multi-agent collaboration means many agents cooperate to finish a common task.

### 3.2 Definition of multi-agent coordination

**Definition 3-6**: coordination means each agent infers and disposes its behavior in order to guarantee harmony and consistency in behavior.

**Definition 3-7**: coordination is the interaction among group of agents taking the same action, is the adaption of the environment. The agent changes its willing to get coordination.

**Definition 3-8** [17]: coordination is a procedure that each agent continuously reasons their action desires and makes decision to let all the member get into harmony and consistency.

Typical assorting includes timely delivering messages between agents, guarantying the relating agents synchronism and avoiding redundant solution.

Mintzberg considers the three basic coordination procedures[18]:

1. Mutual adjustment is the most easy form of coordination. It happens when two or more agents agree to share the sources to get a certain common target. Agents always need to exchange information, and continuously modify their behavior according to other agent's behavior.
2. Direct Supervision happens between two or more agents when one of them has the capacity of controlling others, this kind of priority relation usually erects by mutual modify.
3. Standardization is an usual way to assort. In a certain circumstance, the manager assort in a standard way, namely to erect a standard procedure for its subordinate to follow in some circumstance.

### 3.3 Mechanism of blackboard

The basic idea of blackboard is: when many agent experts solve a question, blackboard is a share work space , all these experts can see the blackboard. The seeking answer begins when question and original data are recorded on the blackboard. All experts see the blackboard and find opportunity to solve question by others' experience knowledge. A solution is recorded on the blackboard when an expert finds enough information to make a answer. Then the new information maybe let other experts continue. Repeat this procedure until the answer is obtained.

There is three basic component in blackboard model. They are:

1. Knowledge Source(KS): the knowledge source means all the knowledge needed to solve problems, each knowledge source accomplishes a complete and independent work , it always use some information on the blackboard to modify the information of another blackboard layer. There are two parts in KS: precondition and action. Precondition is used condition of KS, it is judgement about information change on blackboard. Action describes operation which KS effects blackboard, it is a process. When the information change accords with the precondition of KS, the KS is activated and carries out corresponding action, it adds, deletes or updates solution elements. Each KS is independent and cannot direct call mutually, then only communicate with blackboard. Control mechanism is in charge of monitoring information change on blackboard and checks KS precondition continuously. Once some KS precondition is tenable, the KS is activated and its action is carried out. The information on blackboard is modified which may be activate other KS by control mechanism. Blackboard information changes like this, till find the final solution.
2. Blackboard: solving room for shared problems. It is organized in hiberarchy, it stores information and state data, such as initial data, part solution, substitution solution and final solution, sometimes control data is stored. In the process of seeking solution, KS modifies blackboard continuously. Correspondence among KS only uses blackboard., and the information in blackboard only be added ,deleted and modified through KS.
3. Mechanism of supervise and control：according to the problems on the blackboard and solution skills of KS, adaptive KS is activated which made KS fit for the blackboard change. The design of control mechanism is the most complex task. Its object is to exert pretty KS in context.

### 3.4 Coordination control of multi-production lines system based on multi-blackboard mechanism

#### 3.4.1 Multi-blackboard mechanism model of multi-production lines system

The traditional blackboard cooperation mechanism applies a public blackboard, which each agent sends messages to and acquire messages from. Here a new model is put forward, in this model, blackboard is classified into there different levels: central blackboard, middle-level blackboard and rock-bottom blackboard. Different hierarchic agent of the system is corresponded to the three different hierarchic blackboards. Every agent has its own knowledge source and control system, and each agent is given a blackboard.

The division among the three-level blackboard and corresponding knowledge source and control mechanism is different. The main responsibility of central blackboard is to manage high-level system administration and coordination, for example, the beginning and ending of system, the overall allocation of resources, and the fault diagnosis. The responsibility of middle-level blackboard lies in the resources allocation and administration of subsystem, the cooperation and fault diagnosis of subsystem, reporting the movement of subsystem to high-level blackboard and resources request. The responsibility of rock-bottom blackboard is to coordinate operation of related agent combination in subsystem, report staggered situation and the corresponded fault code to middle-level blackboard etc.

In this blackboard model, agent of different levels is all considered as an agent. Every agent has its own blackboard. The data produced from each agent is classified into two groups: "result date" and "middle data". Besides added into its own blackboard, result data need to be added into the blackboard of upper agent at the same time in order to make decisions for the upper agent. Middle data need not be added into upper agent blackboard and only need be added into its own blackboard. Thus the quantity of data stored and processed by middle-level blackboard and high-level blackboard will reduce significantly, and in particular when the amount of data in system is large the efficiency of the whole of system will be improved. The multi-blackboard cooperation model is established in Fig.3.1.

#### 3.4.2 Multi-agent coordination Petri Net model based on multi-blackboard mechanism

Each agent owns blackboard in the system and different levels' agent is corresponded to different levels' blackboards. Each agent in the system can reason independently, so there must be have a coordination mechanism to complete the coordination among different levels' agent and different agent at the same level, in order to assure the coordination of the overall system. The qualitative analysis and quantitative analysis of the system and dynamic analysis to agent system can be accomplished by applying Petri Net to describe the complex multi-agent system, which time factor is added into Petri Net and Petri Net coordination simulated model is established.

1. Coordination model of multi-agent system in synchronous forms

For different levels' blackboard, there are agents in three different levels, which are center management decision agent, production lines agent and stand-alone agent. They work at the same clock signal which called in synchronous forms. In conveniency, there are three stand-alone agents and two production lines agents. The Petri Net coordination model of multi-agent system is shown as Fig.3.2.

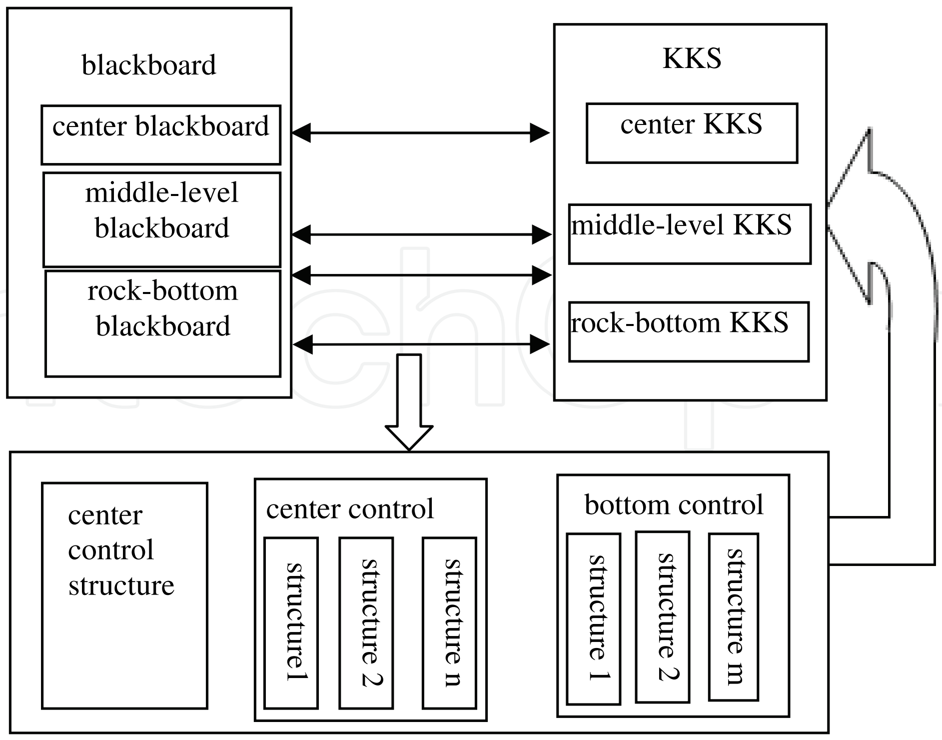


Fig. 3.1 Multilevel blackboard model of packing line system

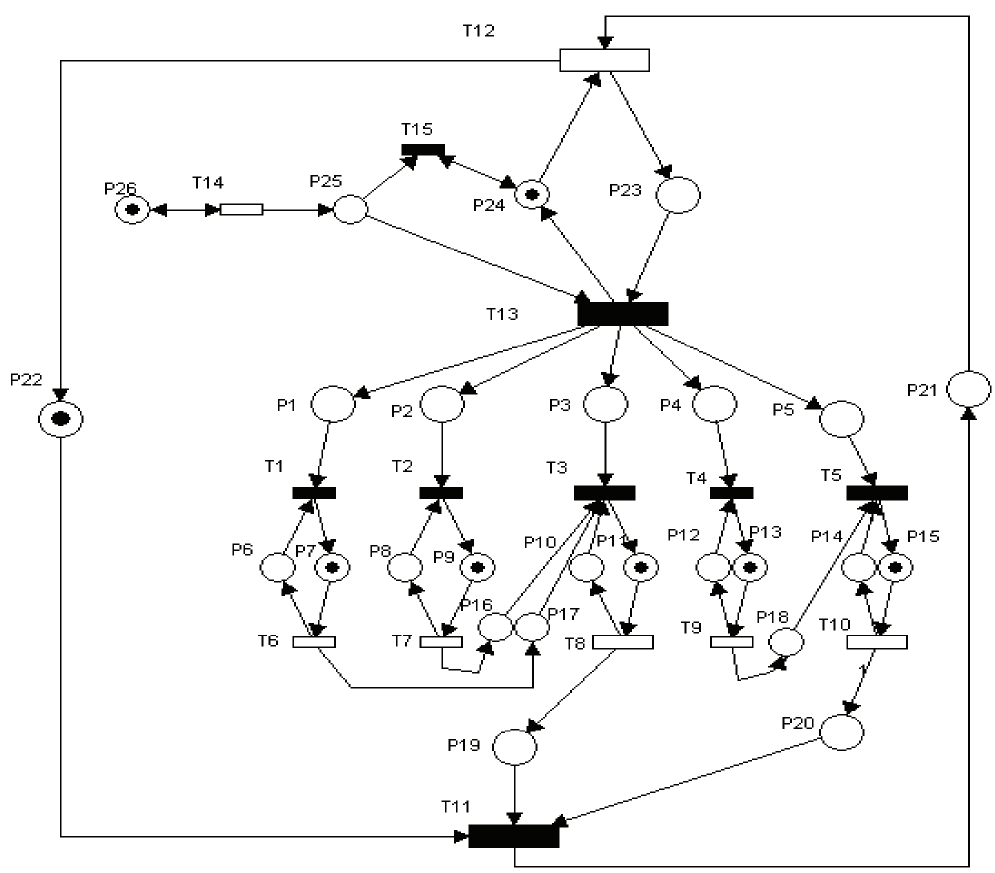


Fig. 3.2 Petri Net coordination model of multi-agent system

The meanings of transition in Fig. 3.2 are:
T1: stand-alone agent 1 begins to work;
T2: stand-alone agent 2 begins to work;
T3: blackboard scheduler of production lines management agent 1 begins to work;
T4: stand-alone agent 3 begins to work;
T5: blackboard scheduler of production lines management agent 2 begins to work;
T6: stand-alone agent 1 fulfills work;
T7: stand-alone agent 2 fulfills work;
T8: blackboard scheduler of production lines management agent 1 fulfills work;
T9: stand-alone agent 3 fulfills work;
T10: blackboard scheduler of production lines management agent 2 fulfills work;
T11: blackboard scheduler of center decision-making management agent begins to infer ;
T12: blackboard scheduler of center decision-making management agent fulfills inference;
T13: blackboard scheduler of center decision-making management agent sends starting sign;
T14: clock sign reached;
T15: waiting for the starting sign;
The harmony process is: P22 expresses that the blackboard scheduler of center decision-making management agent is in free state, P21 expresses that the blackboard scheduler of center decision-making management agent is in transacting state, P19 and P20 means incident signs from production lines management agent to center decision-making management agent. When P22, P19 and P20 all have token, transition T11 happens, and token center decision-making management agent is in place P21 with working state. Center blackboard scheduler begins inference. T12 is a time-lapse transition. Time-lapse means times of blackboard scheduler transacting task. When center blackboard scheduler finishes inference, token transfers to P23, and the system state information is stored in buffer.T13 is starting command and clock sign of synchronization blackboard scheduler. P26 is clock which is timing. P25 is arrived clock sign. When P25 and P23 both have token T13 happens. Each agent receives starting sign sent from blackboard scheduler, token transfers to P1, P2, P3, P4, P5.
Take the production lines agent as an example, the work process of each agent is described as follows. P11 and P12 expresses production lines agent 1 is in free or working state respectively, P3 is the starting sign from center blackboard scheduler.P16 and P17 are information from stand-alone agent 1 and agent 2. When P3,P10,P16,P17 all have token, T3 happens, and blackboard scheduler of production lines agent 1 begins work, token transfers to P11, after a period of time, T8 happens, token transfers to P19,P11, then blackboard scheduler of production lines agent 1 finishes its inference.
2. The working process of multi-production lines system
The actual working process corresponded to the model is shown as follows:
- After the system starting, rock-bottom starts initialization. Then the middle-level agent starts the process of initialization and decision making according to the information preserved last close-down.
- After the middle-level agent finishing initialization and decision making, firstly the basic decision-making information is delivered to rock-bottom agent for the necessary of the next initialization and operation of rock-bottom agent, simultaneity essential information is delivered to central management decision agent, then central management decision agent starts initialization and calculation of task allocation based on entered task data.

- After bottom stand-alone agent finishing initialization, the information is delivered to middle-level administration agent.
- When central management decision agent finishes initialization and calculation and the clock signal arrives, the central management decision information is delivered to corresponding middle-level agent and rock-bottom agent by central management decision agent and starting signal is sent.
- After the rock-bottom agent receives starting signal and the basic information of middle-level agent, it begins running, and middle-level agent starts administration and inference according to decision information from central agent and rock-bottom information from middle-level agent.
- After the middle-level agent finishes the process, it sends decision information to rock-bottom agent and sends essential information to central agent. The central agent begins making decision and turns into step 4.

## 4. Study on distributed intelligence diagnosis illation mechanism based on Petri Net

The multi-agent system is a complex system, where there are inter current, synchronism, asynchronism, resources competition and coordination etc. System fault is inevitable, when it happens the reasons must be found as soon as possible. The former fault diagnosis only enumerates fault reasons but does not have the function of fault inference, which results in the situation that the fault reasons is undefined, the faults seeking time is overlong, so the fault of early warning can not be realized after the system fault happens. It is imperative to find a powerful tool of fault inference to solve these problems.

Petri Net theory is a kind of newly developed modeling and simulation tool combined "figure" and "shape". It is a theory related to distributed system theory which has the ability of processing supervention phenomena and nondeterminacy, and deducing the matter. If token and a actual value between 0-1 of traditional Petri Net denotes the credibility of event , transition and the probability between 0-1 denotes the possibility of events, thus fuzz Petri Net is formed, which can describe the dynamic process and dissemination process of fault phenomena , and it is an excellent tool used for fault diagnosis.

### 4.1 The structure of distributed intelligent fault diagnosis

There are two main task of fault diagnosis for the equipment: state monitoring and fault diagnosis. There is a close relationship between the two tasks that state monitoring is the foundation and prerequisite of diagnosis, but their discrepancy is obvious in task, objection, function and implement method etc. Monitoring agent and diagnosis agent is two different agents. Considered both the construction complexity of the diagnosis object and the variety of fault diagnosis methods, we can integrate these different systems and methods in the thought of distributed artificial agent.

The distributed agent diagnosis system is composed of some agents and two system interfaces. The agents are knowledge process entities and each agent has autonomy, so it can make inference, plans and communication according to its knowledge and surrounding events. Agents are independent from each other, they coordinate and solve problems through sharing knowledge, task and middle results. Agents are classified into three types: monitoring agent, diagnosis agent and coordination management agent, and there are two interfaces: equipment system interface and man-machine conversation interface. The structure is shown in Figure 4.1.

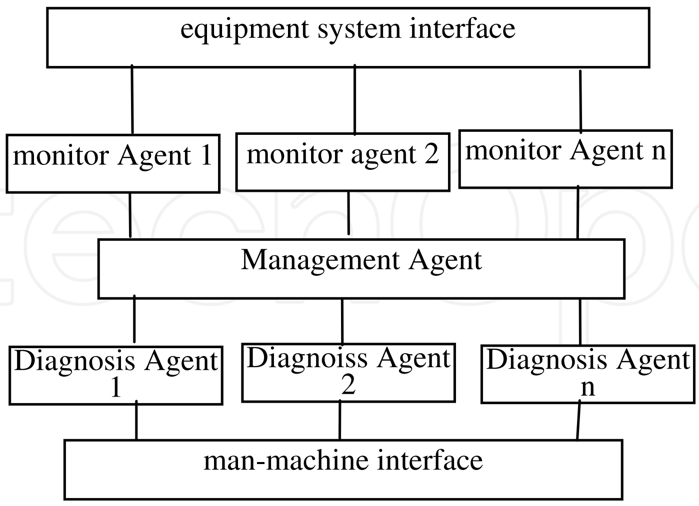


Fig. 4.1 Distributed intelligence diagnosis system structure based on multi- Agent

Monitoring agent is organized based on the equipment structure and function. The distributed state monitor and alarm processing system are used to concurrently acquire parameters reflected the system operation state on line. It can take different approach on different monitoring targets when some parameters go out of normal.

Diagnosis agent can use different methods on different diagnosis targets. Each agent has different knowledge sources and knowledge processing methods, so it can exert respective advantages of different diagnosis methods, and improve the ability of processing problems of the whole system.

Management agent mainly completes the task administration, coordination control and correspond among the distributed agents, which include task allocation, exchange of data and knowledge, conflict process, result colligation and so on.

### 4.2 Organization and coordination of distributed fault diagnosis system

#### 4.2.1 Multilevel blackboard structure of distributed fault diagnosis system

In the distributed intelligence diagnosis system the agents are organized and administrated by level structure. In this section, the coordination control policy of multi-level blackboard structure is constituted, shown as Figure 4.2, and the policy of multi-level blackboard mechanism are corresponded with the multi-agent coordination mechanism mentioned earlier.

Multi-level blackboard structure is suitable for multi-level mixed decomposition policy and parallel process of equipment fault diagnosis, it can meet the solving needs of real-time and complex , avoid some correspondence bottleneck problems caused by single blackboard, reduce the complexity of diagnosis problems, it is propitious to process of complex information. Different information is distributed into different blackboards so that the quantity of information contained in each blackboard is very small, which can improve system efficiency, make it easy to extend and reduce the complexity of blackboard management. This agent diagnosis structure not only makes the exchange between distributed diagnosis and distributed information possible but also has a good openness.

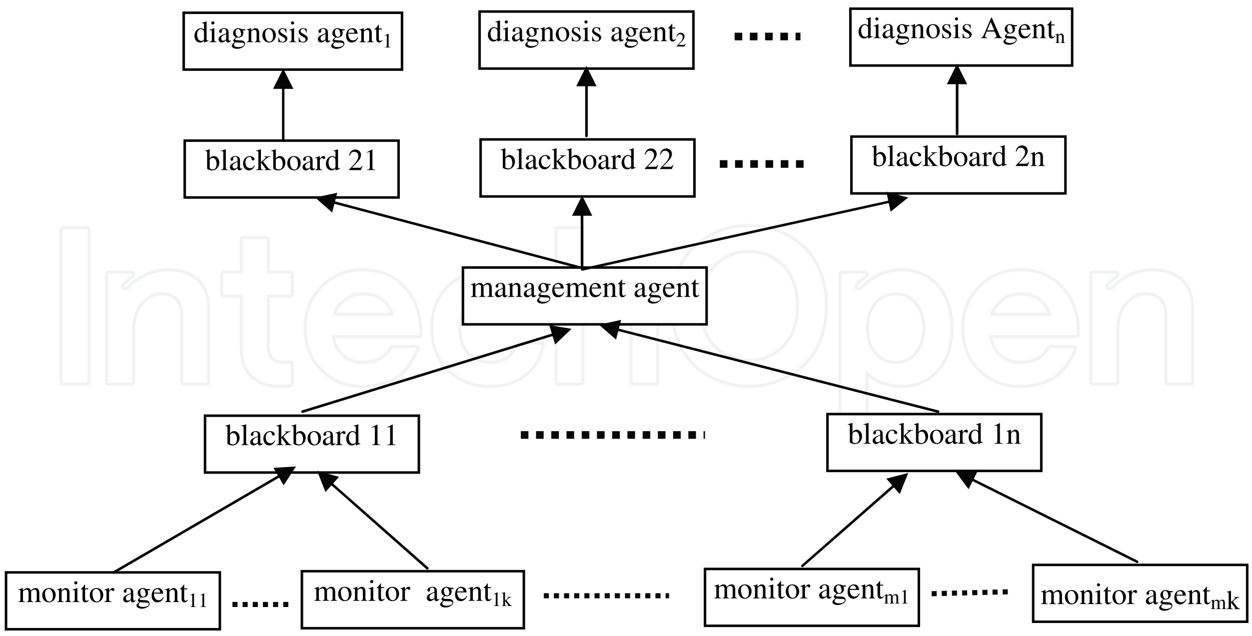


Fig. 4.2 Multilevel blackboard structure of distributed intelligence diagnosis system

#### 4.2.2 A diagnosis process of distributed fault diagnosis

Taking the multi-packing production lines as the example, its stand-alone agent has the function of fault diagnosis and monitoring. In order to form more reliable fault diagnosis system, part of necessary sensors are added on stand-alone agent to form monitoring agent with more powerful functions. Middle-level management agent and the corresponding fault diagnosis functions are composed of fault diagnosis agents. The fault diagnosis process corresponding with the multi-blackboard of distributed intelligence fault diagnosis system above is shown as follows:

- some component has a fault;
- corresponding monitoring agent generates fault code, and sends it to the blackboard opened by corresponding middle-level administration agent;
- middle-level administration agents reports to high-level administration agents after it receiving fault code;
- high-level administrator chooses a suitable middle-level diagnosis agent to start fault diagnosis;
- the result produced by fault diagnosis agent is sent to high-level administration and decision agent for decision-making and display.

### 4.3 Study on fuzzy Petri Net

Fuzzy Petri Net (FPN) is expanded from Petri Net. Like Petri Net, FPN is a bidirectional directed graph composed of two kinds of nodes that is place and transition. But what is different is that in FPN token included in place is connected with a true value from 0 to 1 while transition is connected with a CF from 0 to 1. Enable and stimulate rules of transition are modified too.

**Definition 4-1:** Fuzzy Petri Net structure

The structure of Fuzzy Petri Net is defined into a eight-element:

$$FPN = (P, T, D, I, O, f, \alpha, \beta)$$

Where:
$P=\{p_1, p_2, \dots, p_n\}$ is a place finite set;
$T=\{t_1, t_2, \dots t_n\}$is a transition finite set;
$P \cap T = \Phi$;
$D=\{d_1, d_2, \dots d_n\}$ is a proposition finite set;
$|P|=|D|$.
$I: P \times T \rightarrow \{0,1\}$ is the input function, if $I(p,t)=1$, it suggests that $p$ and t are related, $p$ is the input place of $t$, and all place sets of $t$ is expressed as $\circ t$ or $I(t)$; if $I(p,t)=0$, $t$ and $p$ are not related;
$F: T \rightarrow [0,1]$ is a correlation function of $T$, it denotes the real number mapping from $T$ to a "0-1";
$\alpha: P \rightarrow [0,1]$ is a correlation function of $P$, it denotes the real number mapping from $P$ to "0-1";
$\beta: P \rightarrow D$ is the correlation function of $P$, it denotes the bidirectional mapping from $P$ to proposition set.
Making A a directed arc set, if $p_j \in I(t_i)$, then a directed arc $a_{ji}$ from $p_j$ to $t_i$ exists, $a_{ji} \in A$; if $pk \in O(t_i)$, then a directed arc $a_{ik}$ from $t_i$ to $p_k$ exists, $a_{ik} \in A$. If $f(t_i)=\mu_i$, $\mu_i \in [0,1]$, then it is said that $t_i$ is related with real number $\mu_i$; if $\beta(p_i)=d_i$, $d_i \in D$, it is said that $p_i$ is related with proposition $d_i$.
**Definition 4-2**: the marked Fuzzy Petri Net
If in the FPN structure some place include token, it is called the marked Fuzzy Petri Net.
The token of place $p_i$ is expressed as $a(p_i)$, $a(p_i) \in [0,1]$. If $a(p_i)=\gamma_i$, $\gamma_i \in [0,1]$ and $\beta(p_i)=d_i$, then it denotes that the confidence of the proposition $d_i$ is $\gamma_i$.
**For example:** fuzzy rule: $R_i$ : IF $d_j$ THEN $d_j$ $(CF=\mu_i)$ is represented by figures as Fig4.3:

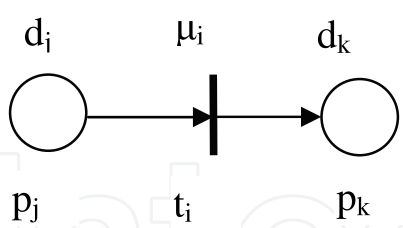


Fig. 4.3 A example of FPN

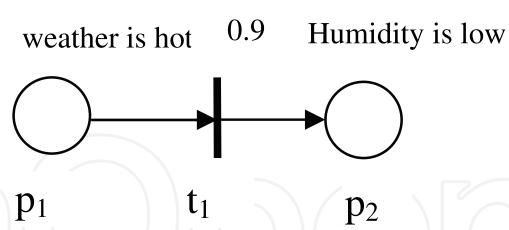


Fig. 4.4 Knowledge expression based on marked FPN

If the fuzzy rule example $R_i$ above is transferred into: IF weather is hot THEN humidity is low ( $CF = 0.9$) and the confidence of hot weather is 0.9, it is presented with Petri Net in Fig.4.4, each parameter is defined as follows:
$FPN=(P, T, D, I, O, f, a, \beta)$
$P=\{p_1, p_2\}$;
$T=\{t_1\}$;
$D$={*weather is hot, humidity is low*};
$I(t_i)=\{p_1\}$, $O\{t_i\}=\{p_2\}$, $f(t_i)=0.90$;
$\alpha=\{0.90,0\}$, namely $\alpha(p_1)=0.90$, $\alpha(p_2)=0.0$;
$\beta$={*weather is hot, humidity is low* }, *namely* $\beta(p_1)$ = *weather is hot* , $\beta(p_2)$ = *humidity is low*;
**Definition 4-3**: enable and stimulate rules of fuzzy Petri Net

Under the system identification $m_1$, for transition $t_i$, if $\forall p_j \in I(t_i) : m_1(p_j)=1 \wedge a(p_j)= \gamma_i \geq \lambda$ where $\lambda \in [0,1]$ is the threshold of $t_i$, $m_1(p_j)$ is the token amount of $p_j$ under the system identification $m_1$, which is called $t_j$ enable. If the enable $t_j$ simulates, new system identification $m_2$ will happen:

1. $\forall p_j \in I(t_i) : m_2(p_j) = m_1(p_j)-1$;
2. $\forall p_k \in O(t_i) : m_2(p_k) = m_1(p_k)+1 \wedge a(p_k)= \gamma_k=\gamma_i \times \mu_i$ , *where* $\mu_i = f(t_i)$ is the correlation function of $t_i$.

Definition 4-3 can be presented by Figure 4.5. what must be noticed is that , different from PN, it is not allowed to exist any more than 2 token in FPN. So it is required $m_1(p_j) = 1$ but not $m_1(p_j) \geq 1$ in the transition enable rule.

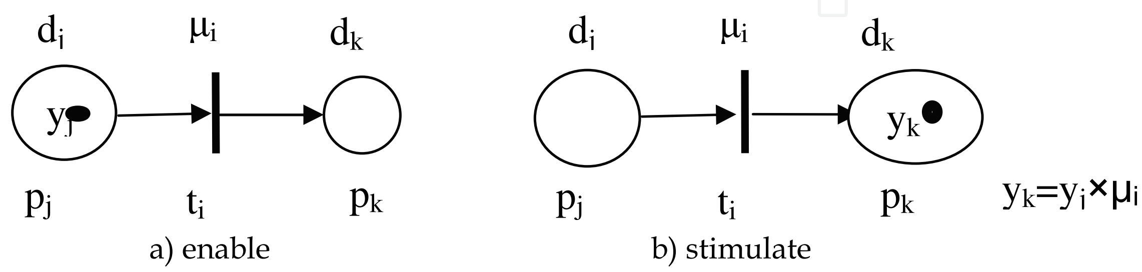


Fig. 4.5 The process of FPN enable and stimulate

### 4.4 Establishment of production lines fault diagnosis

#### 4.4.1 Conception of Petri Net fault diagnosis model

**Definition 4-4**: the unit of the system with input and output behaviors is called components. According to the definition above, these, as big as system and subsystem and as small as module and organ, are all belonged to components.

**Definition 4-5**: the measurement for identifying the system behaviors at the input ends and out ends of the system is called observation.

**Definition 4-6:** if the fault output of $C_A$ can result in the fault output of $C_B$, it is said that there is fault transmission relationship between $C_A$ and $C_B$, represented with $R_J$.

Therewithal suppose that the fault transmission relationship has the characteristic of transmission.

**Definition 4-7**: denoted the structure or behavior state of components with place, denoted changes in state or behaviors of the component with transfer, denoted changes in trends or the operation process of a behavior through connecting place node and transfer node with the directed arc, the fundamental Petri Net model of the system is established as $N=(P,T,F)$.

#### 4.4.2 The steps of Petri Net model establishment

**Step 1:** Analyze minutely Petri Net model system to be established, find all components of the system from the high-level;

**Step 2:** Analyze the fault transmission relationship between components from high-level components to the low-level, and find the next lower-level component that causes the high-level possibly until to the lowest-level;

**Step 3:** Denote the structure or behavior state of components with place, denote changes in state or behaviors of the component with transfer, denote changes in trends or the operation process of a behavior through connecting place node and transfer node with the directed arc to establish the fundamental fault Petri Net model.

**Step 4:** Confirm the transition reliability of fundamental fault Petri Net model and determine blur measurement table of system events ( it is unnecessary if the event reliability is given by the system when asked, but it is necessary to establish system reliability professional system).

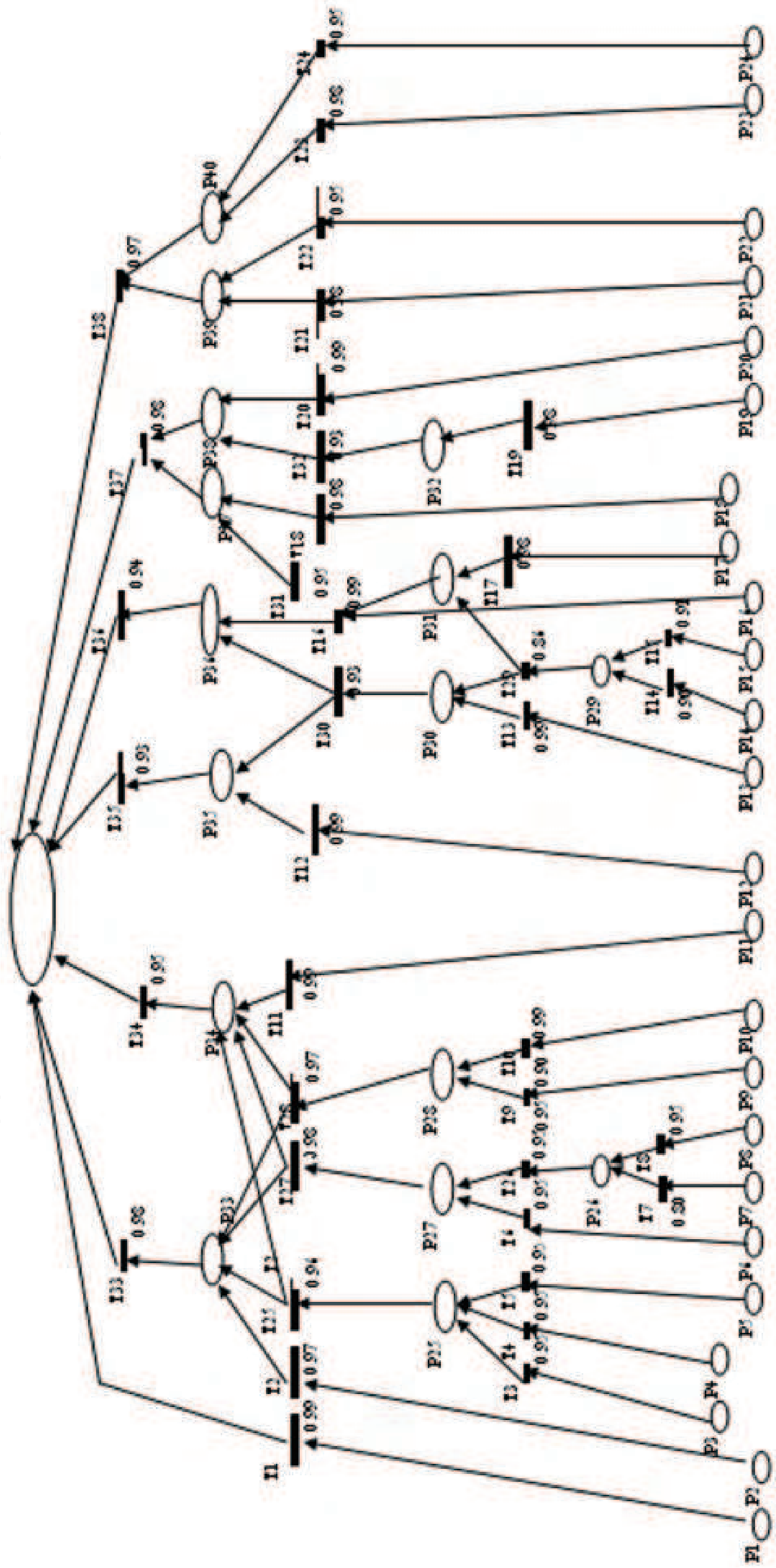

Fig. 4.6 Fault diagnose Petri Net model of sucking and pressing cover machine

#### 4.4.3 Production lines fault diagnosis model

Taking sucking and pressing cover machine as an example to establish its fault diagnosis model, because the concrete structure and establishment methods are the same as the establishment methods of the model in the example, it will not narrate. The Petri model of the system is the basis to make fault diagnosis inference. The model adopts HPSim plotting analysis tool to plot. Fault diagnose Petri Net model of sucking and pressing cover machine is shown in Figure 4.6.

#### 4.4.4 Fault diagnosis inference algorithm based on Fuzzy Petri Net

Petri Net is used to describe two important elements of the dynamic system, which are condition and transition. Condition is the logic description to the system and transition denotes the production process of event or behavior of the system, activation of transition is decided by the condition. Once a transition is evoked, its precondition cannot stand any longer and some examination conditions will be formed and established. The original identification of the net marks the original state of the system, the activity process of transition is the process of moving identifications in the net, which simulates the state exchange process of the system. The transition's activity characteristics of Petri Net makes it describe conditional events and transition activity rules very well. In the process of transition activity, one or more conditions of transition set can be satisfied at the same time, namely that one or more state represented by transition can happen simultaneously. This is one of the important characteristics of Petri Net to describe multi faults happen simultaneously, namely "concurrent".

Fault diagnosis and fault transmission are a reverse process. The process of fault diagnosis refers to, according to a fault phenomena observed, seek for the fault reasons. In the FPN, if there is only input function but no output function in a position, that means the diagnostic fault phenomena is object position. If there is only output function but no input in a position, that means the diagnostic fault reason is original position. The fault diagnosis is the process of seeking for the original position by target position. This process generally adopts reverse inference policies. First of all defined the fault phenomena, namely that selecting a target, then seek for the rule sets that can infer the fault from the fault repository, then selected these rules one by one according to the rule reliability. If the prerequisite of a rule is consistent with the fact in diagnosis database, the rule is active and produce new facts; or takes the prerequisite of the rule as the sub target, enforces the process recursively until to find the fault reasons or not to find a rule producing the fault phenomena.

1 Fuzzy Petri Net fault diagnosis inference algorithm

Fuzzy Petri Net fault diagnosis inference algorithm is shown as follows:

**Step 1**: establish the reachability set $RS(p_i)$, immediate reach set $IRS(p_i)$, and adjacent place set $AP_{ik;}$

**Step 2:** according to the fault phenomena, choose the corresponding fault repository and find the corresponding omen place $p_{o}$ ;

**Step 3**: for any place, if $p_o \in IRS(p_k)$, compare the reliability of all $p_k$ , choose the most reliable place which is supposed to be $p_{j,}$ if some place, whose reliability is the same and is the most, exist at the same time, choose one of the most reliable place arbitrarily. The mark $\upsilon=1$ on $p_j$ suggests that the system has visited the place in searching for the fault reasons, which can avoid repeated searching in depth priority;

**Step 4:** search for all place in IRS including $p_j$ and compare the corresponding reliability, choose the most reliable one and turn to Step 3 until find the fault place, which is supposed $p_{f;}$

**Step 5**: the system inquires the severity of $p_f$ by its corresponding proposition, $a$ is calculated according to blur measurement table enacted by the system in advance or input by experts directly. If $a$ is more than pre-set threshold, the corresponding proposition to $p_f$ is regarded as an active event, and according to the path finding $p_f$, calculates its reliability and the reliability of all place from $p_f$ to $p_o$ at the same time, so that finds the reliability of the fault omen corresponding to $p_o$ which is gotten from the fault origin corresponding to $p_f$. Reliability = the reliability of input place * the confidence of corresponding rules, turn to Step 7;
**Step 6**: in Step 5 if α is less than pre-set threshold, the corresponding proposition to $p_f$ is not active, then continued to search for other place according to depth priority principle till to find fault reasons and calculate the reliability of the omen place;
**Step 7:** inference ends. In the process of inference, seek for all the possible paths triggering the omen in repository, select these paths one by one according to the reliability of transition and the depth priority principle. If the input place of a transition matches the fault fact, startup the transition; or repeat the process above until to find fault place or not to find the fault place that can trigger the omen.

#### 4.4.5 An example of production lines fault diagnosis system inference

Now taken the fault of sucking and pressing cover machine at loading position as an example to illuminate the application of fuzzy Petri Net fault diagnosis inference algorithm. The establishment rules are shown as follows:
R1 : IF A THEN B (CF = 0.90)
R2 : IF C THEN D (CF = 0.95)
R3 : IF E THEN D (CF = 0.93)
R4 : IF F THEN D (CF = 0.80)
R5 : IF D THEN B (CF = 0.98)
R6 : IF G THEN H (CF = 0.98)
R7 : IF I THEN J (CF = 0.92)
R8 : IF K THEN J (CF = 0.90)
R9 : IF L THEN B (CF = 0.98)
R10 : IF M THEN N (CF = 0.95)
R11 : IF O THEN N (CF = 1)
R12 : IF P THEN B (CF = 0.98)
R13 : IF Q THEN B (CF = 0.95)
Here,
A: Q230 occurs fault
B: action abnormity on encasement position
C: coupling becomes flexible
D: lead screw doesn't run
E: lead screw is distortion
F: there is eyewinker on lead orbit
G: driver faults
H: servo motor faults
I: motor is over pressure
J: motor is over hot
K: motor is over loading
L: servo motor faults
M: l control card is loose

N: fault on pulse card
O: pulse card is demolished
P: pulse card faults
Q: program faults
Shown with FPN as follows:

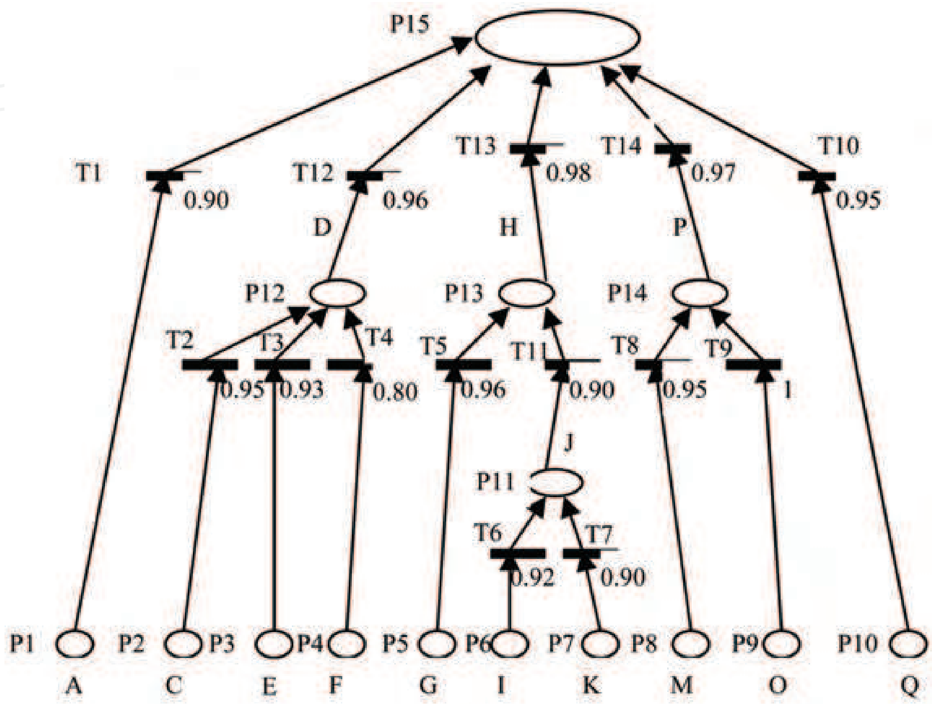


Fig. 4.7 FPN model of sucking and pressing cover machine at loading position

Known from Fig. 4.7, the origination place set is $P_s = \{P_1, P_2, P_3, P_4, P_5, P_6, P_7, P_8, P_9, P_{10}\}$, the target place is $P_g=\{P_{15}\}$. The process of inference diagnosis is to infer in reverse direction from the target place to find the original place that can lead fault in target place. The detail process is shown as follows:

| place $p_i$ | IRS($p_i$) | RS($p_i$) |
|---|---|---|
| $p_1$ | { $p_{15}$} | { $p_{15}$} |
| $P_2$ | { $p_{12}$} | { $p_{12}$, $p_{15}$} |
| $p_3$ | { $p_{12}$} | { $p_{12}$, $p_{15}$} |
| $p_4$ | { $p_{12}$} | { $p_{12}$, $p_{15}$} |
| $p_5$ | { $p_{13}$} | { $p_{13}$, $p_{15}$} |
| $p_6$ | { $p_{11}$} | { $p_{11}$, $p_{13}$, $p_{15}$} |
| $p_7$ | { $p_{11}$} | { $p_{11}$, $p_{13}$, $p_{15}$} |
| $p_8$ | { $p_{14}$} | { $p_{14}$, $p_{15}$} |
| $p_9$ | { $p_{14}$} | { $p_{14}$, $p_{15}$} |
| $p_{10}$ | { $p_{15}$} | { $p_{15}$} |
| $p_{11}$ | { $p_{13}$} | { $p_{13}$,$p_{15}$} |
| $p_{12}$ | { $p_{15}$} | { $p_{15}$} |
| $p_{13}$ | { $p_{15}$} | { $p_{15}$} |
| $p_{14}$ | { $p_{15}$} | { $p_{15}$} |
| $p_{15}$ | {Φ} | {Φ} |

Table 4.1 The immediate reachability and reachability set of place

| place $p_i$ | place $p_k$ | $AP_{ik}$ |
|---|---|---|
| $p_1$ | $p_{15}$ | Φ |
| $P_2$ | $p_{12}$ | Φ |
| $p_3$ | $p_{12}$ | Φ |
| $p_4$ | $p_{12}$ | Φ |
| $p_5$ | $p_{13}$ | Φ |
| $p_6$ | $p_{11}$ | Φ |
| $p_7$ | $p_{11}$ | Φ |
| $p_8$ | $p_{14}$ | Φ |
| $p_9$ | $p_{14}$ | Φ |
| $p_{10}$ | $p_{15}$ | Φ |
| $p_{11}$ | $p_{13}$ | Φ |
| $p_{12}$ | $p_{15}$ | Φ |
| $p_{13}$ | $p_{15}$ | Φ |
| $p_{14}$ | $p_{15}$ | Φ |
| $p_{15}$ | Φ | Φ |

Table 4.2 The adjacent place of places

1. Established the reachability set $RS(p_i)$, immediate reach set $IRS(p_i)$, and adjacent place set $AP_{ik,}$ shown in table 4.1, table 4.2.
2. Suppose the known fault "action abnormity when marching encasement position", namely $p_{15}$ in the figure. Check table 4.1, table 4.2 to find there are five paths triggering $p_{15}$; $p_1 \rightarrow p_{15}$, $p_{12} \rightarrow p_{15}$, $p_{13} \rightarrow p_{15}$, $p_{14} \rightarrow p_{15}$, $p_{10} \rightarrow p_{15}$; then inquire the reliability of $p_1$, $p_{12}$, $p_{13}$, $p_{14}$, $p_{10}$, of which $p_{13} \rightarrow p_{15}$ is the most reliable. Choosing this path and marking $p_{13}$ suggests that this place has been visited. Then seek in reverse direction, there are two paths triggering $p_{13}$: $p_5 \rightarrow p_{13}$, $p_{11} \rightarrow p_{13}$; according to the principle of the greatest reliability, the system prefers $t_5$ and find the input place $p_5$;
3. Because place $p_5$ is the original place, the diagnosis system inquires when it enters man machine interface: "servo drivers a fault?". if the answer is "yes" the system will calculates the fuzziness of $p_5$, where suppose the result of calculation is $a(p_5)$=0.93, because $a(p_5)$ is more than the pre-set threshold 0.7, the corresponding rule to $p_5$ is considered to be active, calculate the reliability of $p_{13}$, $a(p_{13}) = a(p_5) \times 0.98 = 0.9114 > 0.7$, because the proposition corresponding to $p_{13}$ is to be active, calculate the reliability of $p_{15}$ is $a(p_{15}) = a(p_{13}) \times 0.98 = 0.8932 > 0.7$ and endow the mark of $p_{15}$ with 1, which suggests that the fault reason is found that is the proposition "servo drivers fault" corresponding to $p_5$ and the reliability of the fault is $a(p_{15})$ = 0.8932.
4. If the answer to the inquiry "servo drivers a fault?" is "no", the system sets the proposition $a(p_5)$=0.2, which is less than threshold 0.70, then the corresponding proposition will not be active. But there is another path triggering $p_{13}$: $p_{11} \rightarrow p_{13}$; and there are two paths triggering $p_{11}$: $p_6 \rightarrow p_{11}$, $p_7 \rightarrow p_{11}$. According to the size of reliability of transition, the system carries over the inference process above. Only if the fact inquired is defined, namely that the reliability of the proposition is more than threshold 0.70, the reliability of $p_{11}$ is $a(p_{11})$ and set the mark of $p_{15}$ 1 and find the fault reason paths.

5. If the traversal path: $p_6 \rightarrow p_{11} \rightarrow p_{13} \rightarrow p_{15}$, $p_6 \rightarrow p_{11} \rightarrow p_{13} \rightarrow p_{15}$ still failed, the diagnosis system seeks for other path $p_{14} \rightarrow p_{15}$, and carries over the process above until to find the fault reason and calculate the reliability of the target place.

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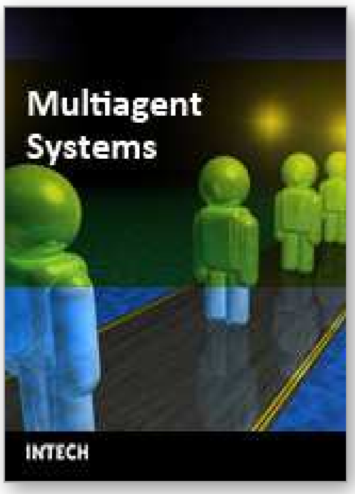


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Multi agent systems involve a team of agents working together socially to accomplish a task. An agent can be social in many ways. One is when an agent helps others in solving complex problems. The field of multi agent systems investigates the process underlying distributed problem solving and designs some protocols and mechanisms involved in this process. This book presents an overview of some of the research issues in the field of multi agents. It is a presentation of a combination of different research issues which are pursued by researchers in the domain of multi agent systems as they are one of the best ways to understand and model human societies and behaviours. In fact, such systems are the systems of the future.