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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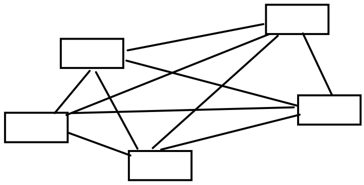

Fig. 1.1 Architecture of fully connected networks

(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.

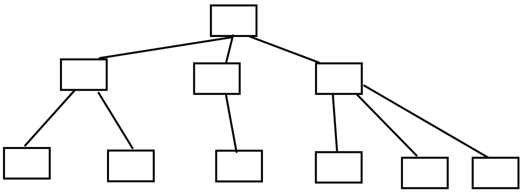

Fig. 1.2 Architecture of fully layered networks

(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.

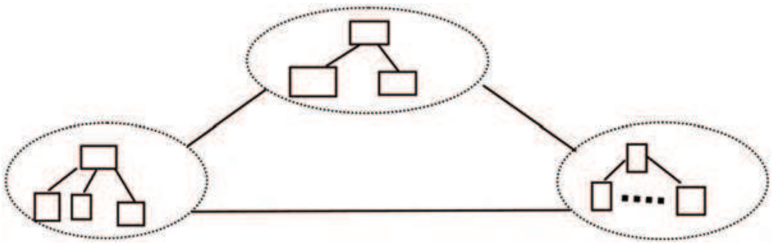

Fig. 1.3 Architecture of allied networks

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.

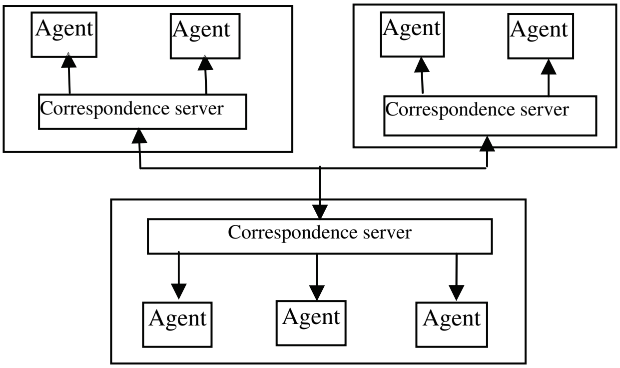

Fig. 1.4 allied system [4]

(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.

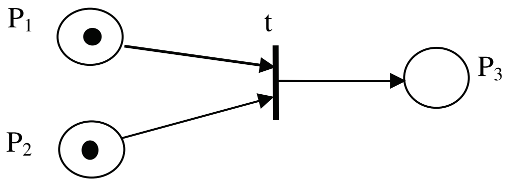

Fig. 1.5 Petri Net

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.

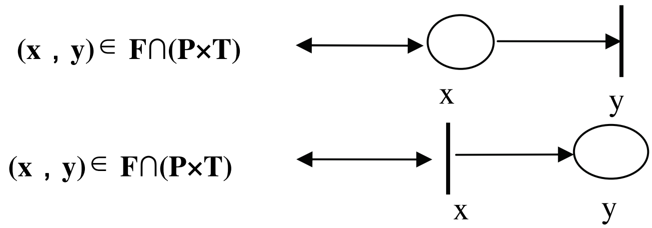

Fig. 1.6 Flow relationship

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° 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° 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.

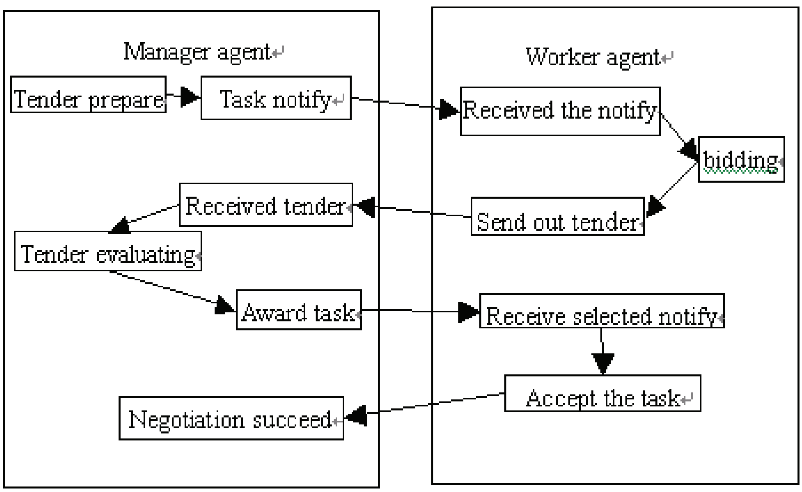

Fig. 2.1 The negotiation process based contract net

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 λ_i be the integrative reliability of agent i; let δ_i be the average energy consumption of agent i and let $f(\delta_i)$ be the factor of energy consumption; let ζ_i be the influence level to the environment of agent i. The computational methods are as follows:

2.3.1 The integrative reliability computation

λ is a set of integrative reliability of agents and the dimension is equal to the number of agents. The value of λ_i fall into [0,1]. It means completely credible of the system when λ_i=1 and unbelievable when λ_i = 0.
Let λ_{ifr} be the reliability related to faults; let λ_{iwt} be the reliability related to the working time and let λ_{iwe} be the reliability related to working environment. All the values of that variable are fall into [0,1].
The computation of integrative reliability λ_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 λ_{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 λ_{igz} = 1 and is the lowest when λ_{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.

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

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

Here,

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

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

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

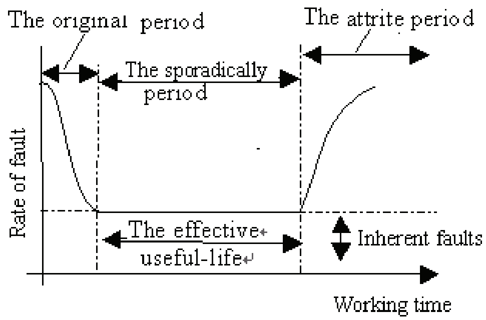

Fig. 2.2 Graph of equipment fault ratio

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.

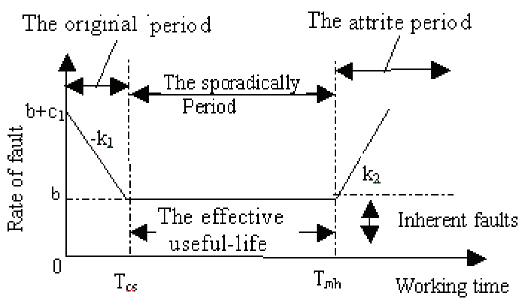

Fig. 2.3 Simplified graph of equipment fault ratio

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

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 λ_{iwt} is given as (6).

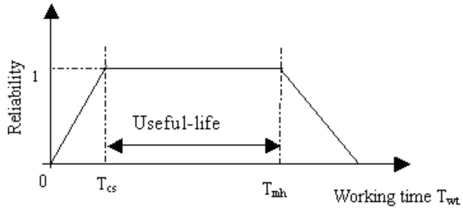

Fig. 2.4 The relationship between reliability and working hours

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 λ_{iwt} is given as (6).

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

The reliability related to the working time of agents is the highest when λ_{iwt}=1 and is the lowest when λ_{iwt}=0.

λ_{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 λ_{iwe} =1 and of not benefit when λ_{iwe} =0.

2.3.2 The computation of influencing factors of energy consumption

δ 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 δ_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).

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

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

ζ 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 ζ_i=1 and is the biggest when ζ_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 ρ_{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 ρ can be describes as the Fig. 2.5.

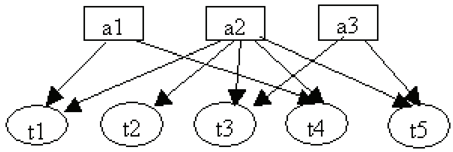

Fig. 2.5 An exmple of the relation between agents and tasks

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;

μ_i represents the average working efficiency of agent i;

λ_i represents the integrative reliability of the agent i;

δ_i represents the average energy consumption of agent i;

ζ_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 λ_i, $f(\delta_i)$ and ζ_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 λ_i , $f(\delta_i)$ and ζ_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.

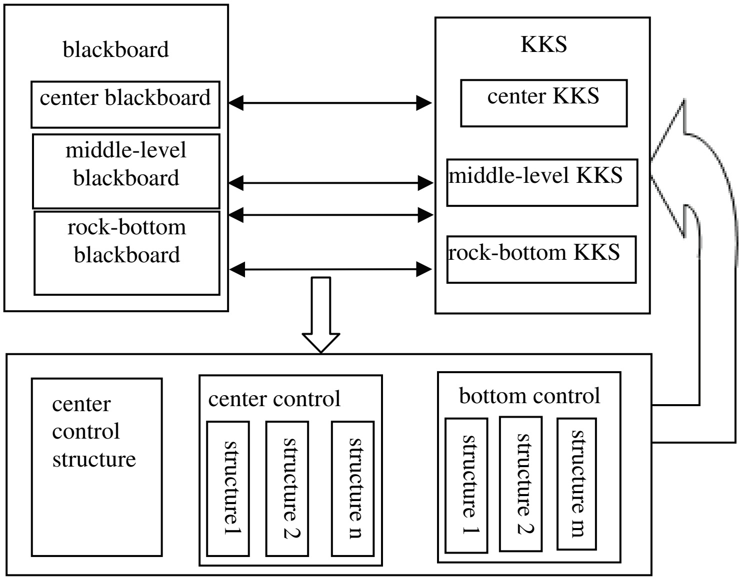

Fig. 3.1 Multilevel blackboard model of packing line system

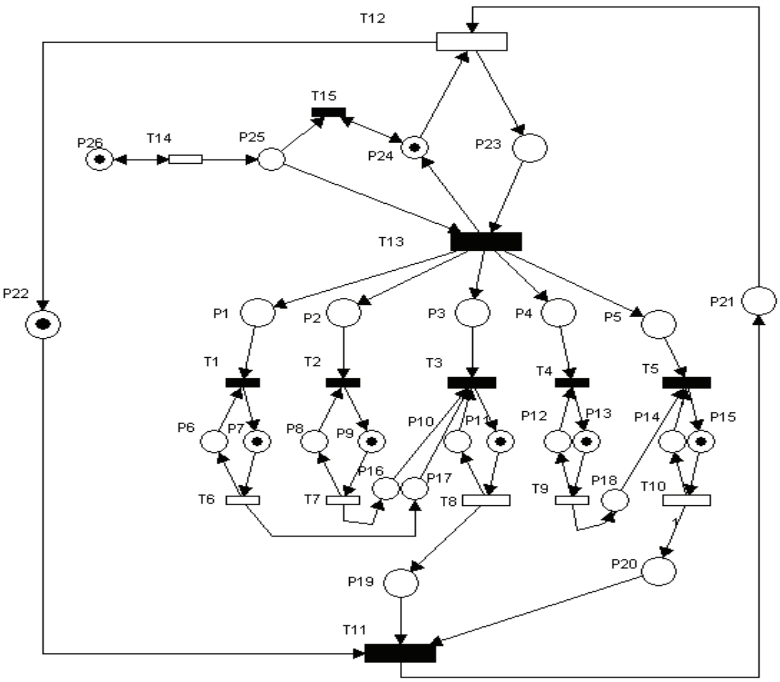

Fig. 3.2 Petri Net coordination model of multi-agent system