Analysis of real-time system conflict based on fuzzy time Petri nets

Zhao Tian\textsuperscript{a,∗}, Zun-Dong Zhang\textsuperscript{b,∗}, Yang-Dong Ye\textsuperscript{c} and Li-Min Jia\textsuperscript{a}
\textsuperscript{a}State Key Laboratory of Rail Traffic Control and Safety, Beijing Jiaotong University, Beijing, China
\textsuperscript{b}School of Transportation Science and Engineering, Beijing University of Aeronautics and Astronautics, Beijing, China
\textsuperscript{c}School of Information Engineering, Zhengzhou University, Zhengzhou, China

Abstract. The time uncertainty and the resource conflict are two very important aspects in modeling and analyzing real-time system. The paper defines a kind of Fuzzy Time Petri Nets (FVPN) to simulate the behavior of real-time system limited by time. It studies the conflict with time attribute and space-time collision in real-time system and utilizes time constraints property and the collision possibility to resolve the conflict through knowledge reasoning of fuzzy time interval. Compared with existing methods of conflict analysis and resolution, it takes into account the uncertainty of the time with the system of conflict and contact behavior, which could be better to simulate and analyze real-time system in reality.

Keywords: Conflict detection, conflict resolution, real-time system, fuzzy time Petri nets

1. Introduction

Time is a very important factor in modeling and analyzing the real-time system [1]. But time is always uncertain in the real world, so the fuzzy time intervals is used to describe the uncertain of the time [2]. The time intervals with fuzzy boundaries, fuzzy durations, and uncertain precedence relations between events can be dealt with in modeling temporal knowledge [3]. Now a lot of researchers studied and analysed the system behavior based on the fuzzy temporal knowledge and the fuzzy time interval. For example, Pranab et al. [4] have proposed a scheduling algorithms to deal with the real-time task scheduling with fuzzy uncertainty in processing times and deadlines.

Petri nets is one of several mathematical modeling languages for the description of real-time systems [5]. The Petri net model having fuzzy timing and fuzzy real-time temporal logic was proposed by Zhou Yi [6]. Based on the above Petri net the temporal knowledge reasoning and time consistency check in expert system of traffic control is significant [7].

The limitation of resources always results in competition conflicts in real-time systems. At parents, there are some valuable researches on the system conflict [8–10]. Zhou hang et al. [11] proposed a method to detect conflict based on the time Petri nets, the method can calculate the occurrence time span of conflict and the possibility of transition firing, but not consider the time uncertainty. Ye Yang dong et al. [12] described and analyzed the uncertainty of the conflict event based on the extended fuzzy time Petri nets, but not gave the conflict resolution methods.

The time and the space are not overlapped, it always lead to time and space competition collision. Time-space can be seen as a special resource, so collision also can be seen as a special conflict. The effective solution to the conflict problem is an important goal in analyzing
dynamic behavior of real-time system [13]. This paper defined the Fuzzy Time Petri nets (FTPN) on the basis of Murata’s research [14] and Yi Zhou’s research [15], the modeling and analysis the real-time system based on FTPN can analyze, detect and resolve conflict through the fuzzy time knowledge reasoning. The FTPN can make the analysis clearer and easier. The approach not only considers the uncertainty time of the event and the fuzzy delay time of the behavior in the system but also presents the quantitative analysis method for conflict resolution by determining the choice probability which can be computed from the possibility of the fuzzy time.

2. FTPN

Definition 1. The fuzzy time interval is defined as a 4-tuple with possibility, described as $FTI = (a, b, c, d)$, where:

1) $h$ means the possibility, and $0 < h \leq 1$;
2) $[a, b, c, d]$ means a fuzzy time interval, and $0 \leq a < b \leq c < d$.

The possibility is equal to $h$ in the interval $[b, c]$, and it is less than $h$ in the interval $[a, b)$ and $(c, d]$. The paper describes the fuzzy time interval by trapezoidal or triangular possibility distributions, as shown in Fig. 1. The $h$ can be abridged if $h = 1$.

Definition 2. The structure of the Fuzzy Time Petri nets is a 7-tuple, which is described as $FTPN = (P, T, A, S, TST, PST, M_0)$. Where:

1) $P$ is a finite set of places, $P = \{p_1, p_2, \ldots, p_n\}$, $n$ is the number of the places;
2) $T$ is a finite set of transitions, $T = \{t_1, t_2, \ldots, t_m\}$, $m$ is the number of the transitions, $P \cap T = \emptyset$ and $P \cup T \neq \emptyset$;
3) $A$ is a finite set of arcs, $A = I \cup O$, $I$ is a finite set of input arcs and $O$ is a finite set of output arcs, $I \subseteq (P \times T), O \subseteq (T \times P)$;
4) $S$ is a finite set of tokens, $S = \{s_1, s_2, \ldots, s_k\}$, $k$ is the number of the tokens;
5) $TST : \subset T, S \rightarrow h[a, b, c, d]$ is the mapping function from transitions and tokens to fuzzy time intervals and means the fuzzy time which the token consumes from the precursor places to the descendant places through the associated transitions;
6) $PST : \subset P, S \rightarrow h[a, b, c, d]$ is the mapping function from places and tokens to fuzzy time intervals and means the fuzzy time in which the token arrivals the place;
7) $M_0$ is the initial marking.

Definition 3. The marking of the Fuzzy Time Petri nets is $M_0 = ((p_i, s_j) | s_j \in S) | p_i \in P)$. The marking of the FTPN can describe the status of the system. $M(t_1 > M_j)$ means that the marking $M_t$ is changed to the marking $M_j$ through the transition $t_1$ firing.

3. Fuzzy time function

The fuzzy time function is a mapping function from the time scale to the real interval $[0, 1]$. It indicates the value of the possibility of the event occurring at time $t$.

Definition 4. The fuzzy timestamp function $\pi(\tau)$ gives the possibility that the token arrives at time $\tau$ in the place.

The fuzzy timestamp $\pi_{p_i, t_j}(\tau) = h[a, b, c, d]$ means that the possibility which the token $s_i$ arrives at the places $p_i$ in the time interval $[b, c]$ is equal to $h$ and it is less than $h$ in the time interval $[a, b)$ and $(c, d]$. $\pi(\tau)$ corresponds to $PST$ in the FTPN.

Definition 5. The fuzzy enabling time function $e(\tau)$ gives the possibility that the transition can be enabled at time $\tau$.

The fuzzy enabling time $e_{t_j}(\tau) = \text{latest} \{\pi_{p_i, t_j}(\tau) | p_i \in M_j, s_i \in p_i\}$ means that the possibility which the token $s_i$ makes the transition $t_j$
enabled at time \( t \), where: \( latest \) is the latest possibility time and \( \pi_i \) is a set of the precursor places of the transition \( t_j \). The following formula can be used as an approximate computation of latest operations:

\[
latest[\pi_i(t), i = 1, 2, \ldots, n] = \text{min} \{h_1[\pi_1, \pi_2, \pi_3, \pi_4], i = 1, 2, \ldots, n\}
\]

Using the above formula, the fuzzy enabling time \( e_{i,t}(t) \) can be computed which is showed in Fig. 2, it means the possibility which the token \( t_i \) makes the transition \( t_j \) enabled at time \( t \).

\[
e_{i,t}(t) = \text{latest}[\pi_i, p_j(t), \pi_{p_1}, p_j(t)] = \text{min}\{1, 1\}[\max\{\pi_{p_1}, \max\{\pi_{p_2}, \max\{\pi_{p_3}\}\}\}, \max\{\pi_{p_1}, \max\{\pi_{p_2}, \max\{\pi_{p_3}\}\}\}\} = [6, 7, 8]
\]

Definition 6. The fuzzy firing time function \( f(t) \) gives the possibility that the transition can be fired at time \( t \).

The fuzzy firing time \( f_{i,t}(t) = \text{MIN}\{e_{i,t}(t), \text{earliest}[\pi_i(t), t_j]\} \) means that the possibility which the token \( t_i \) makes the transition \( t_j \) fire at time \( t \), where: \( \text{earliest} \) is the earliest possibility time and \( \text{MIN} \) is the intersection of distributions. The transitions \( t_i \) and \( t_j \) have conflict on the structure. The following formula can be used as an approximate computation of \( \text{earliest} \) operations:

\[
\text{earliest}[e_i(t), i = 1, 2, \ldots, n] = \text{MIN}\{h_1[e_{12}, e_{23}, e_{34}], i = 1, 2, \ldots, n\}
\]

Also the fuzzy enabling time \( f_{i,t}(t) \) which is showed in Fig. 2 can be computed by using the above formula, it means the possibility which the token \( t_i \) makes the transition \( t_j \) fire at time \( t \).

\[
f_{i,t}(t) = \text{MIN}\{e_{i,t}(t), \text{earliest}[e_{i,n}, e_{i,t}(t)]\} = \text{MIN}\{[6, 7, 7], 6, 7, 7, 8\}, [5, 6, 6, 7]\}
\]

Definition 7. The fuzzy delay function \( d(t) \) gives the possibility time which the firing of the transition will be delayed.

The fuzzy delay \( d_{i,t}(t) = h[a, b, c, d] \) means the delay time which the token \( t_i \) takes from the input place to the output place of the transition \( t_i, d(t) \) corresponds to \( \text{TST} \) in the FTPN.

Definition 8. The fuzzy time knowledge reasoning can calculate the possibility time which every token arrives at every place through the four fuzzy time functions above.

\[
\pi(t) = f(t) \oplus d(t) = h_1[a_1, b_1, c_1, d_1] \oplus h_2[a_2, b_2, c_2, d_2] = \text{min}(h_1, h_2)[a_1 + a_2, b_1 + b_2, c_1 + c_2, d_1 + d_2]
\]

4. Conflict detection and resolution

Conflict means that two or more transitions are ready to fire but the firing of any leads to the disabling of the other transitions under a certain system state. If \( M(t_1) = \text{True} \), \( M(t_2) = \text{True} \), \( M(t_1, t_2) > t_1, t_2 \) are in conflict.

Conflict is one of important properties of Petri Nets, it reflects the contention for limited resources, the uncertainty of path routing, and so on, in reality. This paper aims to resolve the uncertainty of path routing with fuzzy time Petri Nets. In this paper, the state machines are used to define the Petri nets; the purpose is to accel-
erate the computation with clear problem statement [5]. In state machines in which a transition has only one input place and one output place, the fuzzy timestamp function, the fuzzy enabling time function and the fuzzy firing time function are completely equal.

4.1. Conflict detection

In the basic Petri nets, the conflicts are determined if the tokens in $\bullet_1 \cap \bullet_2$ both satisfy the firing condition of $t_1$ and $t_2$.

**Theorem 1.** If $\forall p \in \bullet_1$, then $M(p) > I(p, t_1)$; if $\forall p \in \bullet_2$, then $M(p) > I(p, t_2)$, if $\exists p \in \bullet_1 \cap \bullet_2$ makes $M(p) < I(p, t_1) + I(p, t_2)$, so $t_1$ and $t_2$ are in conflict under the marking $M$.

**Proof.** As stated in Theorem 1, that is, $t_1$ and $t_2$ can be both firing under the marking $M$, if $e_1(t) \cap e_2(t) = \phi$, there is not a time interval in that $t_1$ and $t_2$ can be firing simultaneously. The conflict condition $M(t_1 \wedge e_2(t)) \neq \phi$, so $t_1$ and $t_2$ are in conflict under $M$. On the contrary, if $e_1(t) \cap e_2(t) \neq \phi$, there must be a time interval in that $t_1$ and $t_2$ can be firing simultaneously. It means $t_1$ and $t_2$ are in conflict under $M$.

In Fig. 3, it can be easily computed that $e_{12}(t) = [2, 3, 4, 5]$ and $e_{22}(t) = [6, 7, 8, 9]$ through the definition 5, then $e_{12}(t) \cap e_{22}(t) = \phi$, so $t_1$ and $t_2$ are not in conflict. In Fig. 4, $e_{12}(t) = [2, 3, 4, 5]$ and $e_{22}(t) = [3, 4, 5, 6]$ can be got through the Definition 5, then $e_{12}(t) \cap e_{22}(t) = [3, 4, 5, 6] \neq \phi$, so $t_1$ and $t_2$ are in conflict. Then it can be got $f_{12}(t) = [2, 3, 4, 5]$ and $f_{22}(t) = [3, 4, 5]$ which are shown in Fig. 5.
The possibility of \( f_{s,t_1}(t) \leq f_{s,t_2}(t) \) which means \( t_1 \) fires before \( t_2 \) can be computed by the following formula.

\[
\Psi(f_{s,t_1}(t) \leq f_{s,t_2}(t)) = \frac{\text{Area}(f_{s,t_1}(t),+\infty)\cap(f_{s,t_2}(t),+\infty)}{\text{Area}(f_{s,t_1}(t))}
\]

In the same way, the possibility of \( f_{s,t_1}(t) \geq f_{s,t_2}(t) \) which means \( t_1 \) fires after \( t_2 \) can be computed by the following formula.

\[
\Psi(f_{s,t_1}(t) \geq f_{s,t_2}(t)) = \frac{\text{Area}(f_{s,t_1}(t),-\infty)\cap(f_{s,t_2}(t),+\infty)}{\text{Area}(f_{s,t_1}(t))}
\]

In FTPN models, if conflicts are detected, the conflict resolution will be discussed at the two aspects which include time constraints and collision avoidance.

4.2. Conflict resolution

In FTPN models, if conflicts are detected, reasonable decision approaches are adopted to change to a better system state. In this paper, the conflict resolution will be discussed at the two aspects which include time constraints and collision avoidance.

4.2.1. Time constraints

In real-time systems, time constraints exist commonly. When a system is required to be a certain state in a given time, the analysis of potential conflicts that determines the possibility of achieving the certain system state in a required time is needed. It is useful to make economical and efficient decisions as conflicts emerging that to complete overall assessment of the possibility.

In the FTPN model as shown in Fig. 6, the token \( s \) in \( p_1 \) can reach \( p_4 \) by two routes. From the figure, it can be got \( \pi_{s,p_1}(t) = [1, 2, 3, 4], \pi_{s,p_4}(t) = [1, 2, 2, 3], d_{s,t_1}(t) = [2, 3, 4, 5], d_{s,t_2}(t) = [1, 3, 3, 5], d_{s,t_3}(t) = [1, 2, 3, 4] \). \( t_1 \) and \( t_2 \) are in conflict, and the conflict fuzzy time interval is \( \epsilon_{s,t_1}(t) \cap \epsilon_{s,t_2}(t) = [1, 2, 3, 4] \).

By the time knowledge reasoning, the fuzzy time, the token \( s \) arrives in \( p_4 \) through the route \( 1 (p_1,p_2,p_3,p_4) \), is \( \pi_{s,p_1}(t) = [3, 7, 8, 12] \), and the fuzzy time interval, \( s \) arrives in \( p_4 \) through the route \( 2 (p_1,p_2,p_3,p_4) \), is \( \pi_{s,p_4}(t) = [4, 7, 10, 13] \). The fuzzy time that the token \( s \) arrives in \( p_4 \) is shown in Fig. 7.

Suppose the token \( s \) reaches \( p_4 \) before the time 8, the possibility \( s \) reaches \( p_4 \) through route 1 is \( p_{01} = \text{area}(\text{AFCG})/\text{area}(\text{AFCGD}) = 3/5 \), and the
possibility $s$ reaches $p_4$ through route 2 is $p_{r2} = \text{area}(BFGC)/\text{area}(BFHE) = 5/12$. So the probability that $s$ reaches $p_4$ through route 1 is $p_{r1} = (3/5)/(3/5 + 5/12) = 0.59$, so the probability that $s$ reaches $p_4$ through route 2 is $p_{r2} = 1.00 - 0.59 = 0.41$.

4.2.2. Collision avoidance

The collision in Petri nets means under a certain system state with two or more transitions enabling, the firing of one enabling transition may cause other enabling transitions lost the enabling conditions. If $M(y > 1)$ and $M(y > 1) = \pi(y > 1) + \pi(y > 1)$, the firing of $t_2$ and $t_3$ is in collision at the place $p$ under $M$.

The collision refers to the competition of space resources, whose metaphor is the competition of limited space. For avoiding collision, it is resource dispatch reasonable to avoid excessive demands for space resources at the same time.

In Fig. 8, the tokens $t_1$, $t_2$, and $t_3$ reach $p_0$ from $p_1$, $p_2$, and $p_3$ through different places respectively. When $s_2$ reaches $p_0$ through route 1 ($p_{r21}, p_{r22}, p_{r23}$), the collision may happen between $s_2$ and $s_1$ at place $p_4$. Similarly, the collision may exist between $s_3$ and $s_2$ at place $p_5$, when $s_2$ reaches $p_0$ through route 2 ($p_{r23}, p_{r24}, p_{r25}$).

By using the fuzzy time knowledge reasoning function, the fuzzy timestamps can be computed which is $\pi_{t_2, p_1}(t) = [2, 4, 5, 7]$, $\pi_{t_2, p_2}(t) = [3, 5, 6, 8]$, $\pi_{t_2, p_3}(t) = [3, 5, 7, 9]$ and $\pi_{t_3, p_4}(t) = [4, 6, 8, 10]$. As shown in Fig. 9, the fuzzy time of the collision happening between $s_1$ and $s_2$ at place $p_4$ is $\pi_{s_1, p_4}(t) = [2, 4, 5, 7] \cap \pi_{s_2, p_4}(t) = [2, 4, 5, 7] \cap [3, 5, 6, 8] = [3, 5, 5, 7]$.

The possibility of $s_1$ reaching $p_4$ in the fuzzy time $[3, 5, 5, 7]$ is $p_{s_1, p_4} = \text{area}(BFIC)/\text{area}(AEFC) = 2/3$. And the possibility of $s_2$ reaching $p_4$ in the fuzzy time $[3, 5, 5, 7]$ is $p_{s_2, p_4} = \text{area}(BFIC)/\text{area}(BFGD) = 2/3$.

Then, the possibility of $s_1$ colliding with $s_2$ at $p_4$ is $p_{s_1, p_4} = (2/3) \times (2/3) = 4/9$. In the same way, the possibility of $s_2$ colliding with $s_1$ at $p_3$ can be got which is $p_{s_2, p_3} = (3/4) \times (3/4) = 9/16$.

Because the different routes of $s_2$ reaching $p_4$ cause different collision possibility, so the probability of the different routes of $s_2$ chosen can be determined by the corresponding collisions possibility. The probability of $s_2$ reaching $p_4$ through route 1 is $p_{r1} = (1 - 4/9)/(1 - 4/9 + 1 - 9/16) = 0.56$. The probability of $s_2$ reaching $p_4$ through route 2 is $p_{r2} = 1 - 0.56 = 0.44$.

5. Case study

5.1. Case 1

In a local railway system, the route choice of the trains is always very important. When the travel time of the trains is uncertainly, the system should improve efficiency on the basis of making sure the higher security. A simple railway system is shown in Fig. 10. St5 and St6 are the tunnels, St4 and St7 are the bridges, and others are the stations. The trains 1–3 in station St1–St3 are ready to depart. The destinations of the trains are St10, St11 and St12 respectively. The fuzzy time Petri net model of the system with trains 1–3 is shown in Fig. 11.

It can be seen that the train 2 have two paths to choose from the departure station 2 to the destination station 11 in Fig. 10. The train 2 can choose the path 1 in which the St5 (tunnel 1) is the key section, or choose the path 2 in which the St5 (tunnel 2) is the key section. The
Fig. 10. A simple railway system.

train 2 may be in the collision with the train 1 in the St5 when it choose the path 1, in the same way when the train 2 choose the path 2 it may be in the collision with the train 3 in the St6.

The initial state of the system model is $M_0 = \{(p_1, s_1), (p_2, s_2), (p_3, s_3)\}$. It means that the train 1, the train 2 and the train 3 are ready to depart from the station St1, the station 2 and the station St3 respectively.

The corresponding fuzzy departing time is $[0, 1, 2]$, $[1, 2, 3, 4]$ and $[5, 6, 7, 8]$. The every transition in the model has a fuzzy time attribute, which means the fuzzy time that the train will take to across the section. For example, the fuzzy time attribute of transition $t_1$ is $[20, 121, 122, 123]$ which means the train 1 will take the fuzzy time $[20, 121, 122, 123]$ through the Section 1 from the departing station St1 to the tunnel 1.

By the fuzzy time knowledge reasoning, the fuzzy time $\pi_{s_i,p_2}(\tau) = [120, 122, 123, 125]$ can be calculated. It means that the train 1 can arrive the tunnel 1 in the fuzzy time $[120, 122, 123, 125]$. In the same way, $\pi_{s_1,p_3}(\tau) = [122, 124, 126, 128]$, $\pi_{s_2,p_3}(\tau) = [108, 110, 112, 114]$ and $\pi_{s_3,p_3}(\tau) = [109, 111, 113, 115]$ can be computed. The train 2 and the train 1 may be in the collision because of $[120, 122, 123, 125] \cap [122, 124, 126, 128] \neq \phi$. So when the train 2 choose path 1, it may crash with the train 1 in the fuzzy time 0.75$[122, 123.5, 123.5, 125]$, and the possibility of the collision is $81/768$. Similarly, the collision possibility of the train 2 and the train 3 is $9/16$ in the tunnel 2 when the path 2 is chosen. So the probability that the train 2 chooses the path 1 is $p_{r_1} = (1 - 81/768) / [(1 - 81/768) + (1 - 9/16)] = 0.67$ and the probability that the train 2 chooses the path 2 is $p = 1.00 - 0.67 = 0.33$ based the maximum safe.

When the train 2 is the only train in the system, it can’t be in the collision. The fuzzy time Petri net model of the system only with trains 2 is shown in Fig. 12.

The efficiency will be the maximal factor. The train 2 should arrive at the destination station St11 within the prescribed period of time. When the train 2 arrives at the destination station St11 through the path 1, the fuzzy time which the train 3 will take is $[308, 313, 318, 323]$ by the fuzzy time knowledge reasoning. In the same
way, the fuzzy time which the train 2 will take when it across the path 2 to arrive at the destination station St11 is [304, 309, 314, 319]. If the train 2 should arrive at the destination station St11 before 310, the probability that the train 2 chooses the path 1 is \( pr_1 = 0.04/(0.04 + 0.35) = 0.10 \) and the probability that it chooses the path 2 is \( pr_2 = 1.00 - 0.10 = 0.90 \), because the possibility that the train 2 can arrive at the destination station St11 before 310 through the path 1 is 0.04 and the possibility through the path 2 is 0.35.

5.2. Case 2

The manufacturing system is very common in the most factories and it always is a real-time system. A simple manufacturing system is shown in Fig. 13. The materials 1–6 can be processed into products 1–2. In the product process, two kinds of semi-finished products 1–2 are produced and stored in the storage jar 1–2. The corresponding fuzzy time Petri net model is shown in Fig. 14. The fuzzy timestamp with the places \( p_1 \sim p_6 \) mean the fuzzy time which the material 1–6 can be used by the equipment. The firing of the transitions means the production process of the equipment, and the corresponding fuzzy delay time is the process time of the equipment. For example, the material 1 and the material 2 can be produced to the semi-finished product 1 by the equipment 1. The material 1 and the material 2 can be used at time [2, 3, 4, 5] and [1, 2, 3, 4] respectively, and the process time of the equipment 1 is [1, 2, 3, 4].

It can be seen that the material 2 can be used by equipment 1 or equipment 2. Because the material 2 is cheap but limited and other material is not limited, the use of the material 2 by equipment 1 or equipment 2 is a question. The fuzzy enabling time \( e_{c_{2,1}}(t) = [2, 3, 4, 5] \) and \( e_{c_{2,2}}(t) = [3, 4, 5, 6] \) can be computed.

Because \( e_{c_{2,1}}(t) \cap e_{c_{2,2}}(t) \neq \emptyset \), \( t_1 \) and \( t_2 \) are in conflict. The fuzzy firing time \( f_{c_{2,1}}(t) = [2, 3, 4, 5] \) and \( f_{c_{2,2}}(t) = [3, 4, 5, 6] \) can be computed. At last, the firing probability of \( t_1 \) and \( t_2 \) can be computed by the formulas in Section 4. The result is that \( p(t_1) = 2/3 \) and \( p(t_2) = 1/3 \). It means that the material 2 can be chosen by the equipment 1 with the probability 0.67 and by the equipment 2 with the probability 0.33.

When the capacity of the storage jar 1 is certain, the semi-finished product 1 in the jar 1 may overflow because of the excess production of the equipment 1 and 3. Similarly, the semi-finished product 2 in the jar 2 may overflow because of the excess production of the equipment 2 and 4. It can be got the overflow possibility of the semi-finished product 1 is 9/16 and the overflow possibility of the semi-finished product 2 is 1/48. At last, the material 2 can be chosen by the equipment 1 with the probability 0.31 and by the equipment 2 with the probability 0.69.
6. Conclusion and future work

In real-time systems, the resource limitation and the temporal-spatial constraints are critical factors for conflicts. The paper was focus on the resource conflicts caused by time uncertainty; introduce the fuzzy time knowledge reasoning approach integrating with the fuzzy time Petri net models for detecting and resolving system conflicts. Furthermore, the case study about conflicts in the railway systems and the manufacturing system validates the effectiveness of the method. The future work includes the comprehensive description of complex hybrid systems and the construction of evaluating models for system efficiency under the constraint of system safety.

References


