Uncertain Temporal Reasoning for the Distributed Transportaion Scheduling Problem *

Maroua Bouzid and Abdel-Illah Mouaddib
CRIL, IUT de Lens Rue de l'Université d'Artois
SP 16 62307 Lens-Cedex, France
(bouzid,mouaddib)@cril.univ-artois.fr

Abstract

Distributed Artificial Intelligence (DAI) is suitable to applications where there is no central control. One of these applications with which we are concerned is Transportation Scheduling. We noticed that all the approaches dedicated to this application use a weak representation of time and a simple reasoning. Furthermore, these approaches ignore the uncertainty behavior of agents. What we propose is an approach based on Fuzzy Temporal Characteristic Functions (FTCF) which allow a powerful representation of agent companies behaviors making us informed at each time on the degree that the agent is available. Thinks to this representation, we develop a temporal reasoning allowing a cooperation inter and intra companies to allocate trucks and delegate orders.

1 Introduction

The growing interest in the development of Distributed Artificial Intelligence (DAI) methods for large and complex applications requires new extensions to existing methods in order to increase their efficiency and expressiveness. Indeed, DAI techniques such as Contract-Net Protocol (CNP) [4] have so far failed to provide adequate solution to cope with applications characterized by a high level of uncertainty and rapid change. These characteristics are common to several domains such as transportation scheduling. Algorithms used to efficiently solve static scheduling problems such as classical techniques, Operational research, and centralized approaches have failed to deal with open dynamic scheduling problems in the presence of uncertainty. Some investigators have proposed approaches devoted to dynamic scheduling problems in presence of uncertainty [8, 9].

Transportation scheduling application consists of distributed transportation companies that have to carry out transportation orders which arrive dynamically. Each company have a set of trucks at their disposal. Each company should maximize the satisfaction of orders according to the availability of its trucks. Several approaches have been proposed to this application such as MARS [5], TRACONET [10] based on the task delegation method by using the CNP techniques. The distributed AI approach is suitable to this application because of: first the complexity of a centralized scheduling algorithm and second the distributed nature of the application (companies and trucks are geographically distributed). Indeed, most existing approaches assume that each company uses the local plans of its trucks to decide whether all orders will be satisfied or not. When unsatisfied orders exist a negotiation protocol is fired to delegate these orders to other companies.

Existing approaches assume that each local plan (for each truck) is known in a precise way ignoring the presence of uncertainty. However, the task of transportation is characterized by a high level of uncertainty regarding different factors such as the traffic density, the power of the truck used and so on that cannot be ignored. Consequently, the time at which a truck arrives to destination is not usually known in a precise way, but we know with uncertainty the interval during which the truck is possible to arrive. During this interval the availability of the

*This work has been supported by the GanymèdeII project of the contract Plan Etat Nord-Pas-De-Calais and by the MENESR

truck is weighted by uncertainty. Consequently, during task transportation, there exist, intervals during which the truck availability is not known in a precise way but it is assumed that it can be represented by a degree of uncertainty. Furthermore, the formal framework used for representing the availability of trucks, in the existing approach, is so weak that no powerful reasoning can be performed.

In our approach, we propose a suitable temporal representation of trucks based on *Temporal Characteristic functions* (TCF) [3]. A characteristic function is a (possibly partial) function describing for what instants of time a logical property holds (or does not hold) – thus it refers to the idea of characteristic function of a set. Roughly speaking, it can be also considered as a kind of two-valued 'trajectory' (or 'history' [11]) characterizing logical behavior given by certain atemporal formulae. Moreover, the possibility of representing uncertainty on the validity of property over time seems to follow naturally from our functional approach and leads to the *Fuzzy Temporal Characteristic Function* (FTCF). FTCFs allow the representation of the uncertainty on the behavior of trucks due to traffic density and unpredictable events that prevent them from respecting their schedules. Thus, the FTCFs allows the representation of the uncertainty that characterizes the availability of trucks during task transportation. This approach is combined by an extended contract-net protocol to deal with negotiation-based delegation of orders when companies are not able to satisfy all orders and negotiate to delegate the remaining orders.

In this paper we outline in Section 2 a description of temporal and fuzzy temporal characteristic functions used by agents in their reasoning. In Section 3 we present the approach and proposed solution. Section 4 concludes our paper and describes further work in this field.

2 Temporal approach

2.1 Temporal characteristic functions

In this Section, we present the idea of a temporal approach to knowledge representation based on characteristic functions [3]. Basically, a characteristic function is a function describing for what instants of time a logical property holds (or does not hold) – thus it refers to the idea of characteristic functions of a set. A characteristic function for some set Φ is any function ψ_Φ of the form: $\psi_\Phi : T \longrightarrow L$, where T is the global domain of interest and L denotes some set of values describing to "what degree" an element of T belongs to Φ. In this paper, only the sets Φ which have the form of $\{x : \phi(x)\}$ are considered; where ϕ is some property. Thus, a characteristic function is defined to be a function of the form $\psi_\phi : T \longrightarrow L$ describing to "what degree" an element of T satisfies the property (formula) ϕ, or, for convenience, to what degree the property expressed by ϕ is satisfied by any of the elements of T. For further discussion let us first establish the domain (maximal time interval) of interest. We shall consider events happening after some distinguished time 0 and before $+\infty$. This defines the domain for all characteristic functions. The formal definition of a characteristic function is as follows:

Definition 1 *Let $T = [0, +\infty[$ be the time domain of interest and let $L = \{0, 1\}$ be the set of distinguished values. Any mapping $\psi : T \Longrightarrow L$ will be called a Temporal Characteristic Function (TCF). Any mapping $\psi : T^{'} \Longrightarrow L$ will be called a* **weak (partial) characteristic function**, *where $T^{'} \subseteq T$*

If T is reduced to an interval $[a, b]$ and L is reduced to $\{1\}$ or to $\{0\}$, we are back to the classical knowledge representation based on convex time intervals[1]. If L is reduced to $\{1\}$ or to $\{0\}$, and T remains arbitrary, we are back to the knowledge representation based on non-convex time intervals[6, 2]. It is normally assumed that a TCF changes its value over T only a finite number of times. Thus any TCF is an interval-stable function taking values 0 or 1 over time. Any point of the domain where the function changes its value will be referred to as a change point, specific point or landmark. When considering weak TCFs one may be especially interested in *positive* weak functions and *negative* weak ones.

Definition 2 *A positive weak TCF is a weak TCF which takes as its value only 1 ($inf\{x | x = \psi(t) \;\; for \;\; t \in T\} = 1$). A negative weak TCF is a weak TCF which takes as its value only 0 ($sup\{x | x = \psi(t) \;\; for \;\; t \in T\} = 0$).*

Definition 3 *Let ψ be a TCF (either a weak or a strong one). A function $\overline{\psi}$ taking 1 where ψ takes 0 and taking 0 where ψ takes 1 will be called a* complement function *to ψ ; $\overline{\psi}$ is undefined for all $t \in T$ for which ψ is undefined.*

Note that any TCF can be represented in fact as a finite union of convex intervals [6] denoting the biggest intervals within which the function does not change its value. Thus ψ can be given by $\{(\alpha_1, \beta_1), \ldots, (\alpha_k, \beta_k)\}$ provided that α-values denote the beginnings of intervals for which the function has value 1 or the end of intervals for which the function has as value 0 and β-values denote the ends of respective intervals for which the function has the value 1 or the beginnings of intervals for which the function is equal to 0. A similar representation can be applied to weak TCFs; however, the domain of the function must be given explicitly. The problem of what value (0 or 1) is taken at the α and β-values can be solved in an arbitrary way depending on current needs.

Weak TCFs can be *weaker* (*stronger*) than some other weak functions, i.e. there is some established partial order relation among them; by intuition, a stronger TCF provides more information than a weaker one.

Definition 4 *A weak TCF ψ_1 (defined for $T_1 \subseteq T$) is* stronger than *some weak characteristic function ψ_2 (defined for $T_2 \subseteq T$) if and only $T_2 \subseteq T_1$ and $\psi_1(t) = \psi_2(t)$ for any $t \in T_2$; we shall write $\psi_1 \succeq \psi_2$.*

We define a union operation for characteristic functions. The operation, to be denoted ω is aimed at replacing several weak functions defined on different domains by a single (weak) TCF.

Definition 5 *Let $\psi_1, \psi_2, \ldots, \psi_k$ be weak TCFs, such that for any $t \in T$ all the values of the functions which are defined for t are identical; such a set of functions is called* consistent *(otherwise; inconsistent).*

Definition 6 *Let $\psi_1, \psi_2, \ldots, \psi_k$ be a consistent set of weak TCFs. We define the union operation ω as follows:*

$$\omega(\psi_1, \psi_2, \ldots, \psi_k) = \begin{cases} \psi_i, & \textit{if there exists } i \textit{ for} \\ & \textit{which } \psi_i \textit{ is defined} \\ \textit{undefined}, & \textit{otherwise} \end{cases}$$

Proposition 1 *Let $\psi_1, \psi_2, \ldots, \psi_k$ be weak TCFs satisfying the above assumptions (consistency). Then, for any $i \in \{1, 2, \ldots, k\}$ we have $\omega(\psi_1, \psi_2, \ldots, \psi_k) \succeq \psi_i$.*

The idea of the knowledge representation language to be used consists in associating a propositional symbol p and a TCF ψ for expressing explicitly when p is true, false or unknown over the time domain T. Thus, the elementary objects of the language are pairs of the form $\langle p, \psi \rangle$. The basic intuition concerning the semantics of $\langle p, \psi \rangle$ is that some property p holds over time if the associated characteristic function ψ takes 1 as its value, and does not hold if it takes 0 (for weak episodes, p is undetermined for undefined ψ). TCFs constitute formal means for representing some properties over time; they seem to be more general and more powerful than intervals. Basically, a single function can represent 'behavior' of some property over the whole time domain T; thus, in fact, it represents the "history" of certain phenomenon. Moreover, contrary to intervals, they can be easily extended to deal with multiple-valued or fuzzy logics.

2.2 Fuzzy Temporal Characteristic Functions (FTCF)

The idea of fuzzy characteristic functions consists in allowing the truth values to cover the entire range of truth-values between *true* and *false*, i.e. in terms of characteristic functions between 1 and 0.

Definition 7 *Let $T = [0, +\infty[$ be the time domain of interest and let $L = [0, 1]$ be the set (closed interval) of distinguished values. Any mapping $\psi : T \longrightarrow L$ will be called a* Fuzzy Temporal Characteristic Function. *Any mapping $\psi : T^{'} \longrightarrow L$ is called a* weak *(or* partial*) FTCF, where $T^{'} \subseteq T$.*

Thus any FTCF takes as its values some real numbers from the closed interval $[0, 1]$; for simplicity we assume that the function is "sufficiently regular". Note that any characteristic function satisfies the definition of FTCF (the converse is not necessarily true). Similarly we can apply Def. 4 directly to FTCF. Further, one can redefine the concept of complement function.

Definition 8 *Let ψ be a fuzzy temporal characteristic function (either a weak or strong one). A function $\overline{\psi}$ such that $\overline{\psi}(t) = 1 - \psi(t)$ will be called the complement function to ψ ; $\overline{\psi}$ is undefined for all $t \in T$ for which ψ is undefined.*

Note that an arbitrary FTCF cannot be represented using just a set of intervals (the α and β values): the discussed extension yields a concept significantly more general than a simple interval. However, as mentioned above, some further definitions e.g. the ones of strength among characteristic functions and the complement (positive and negative strong one) can be applied directly.

Further, we define the *filtering operation* for FTCF. The operation aimed at determining from a FTCF ψ defined on T and a condition C, a weak FTCF ψ^C defined on $T^{'} \subseteq T$ and such that $\psi^C(t)$ satisfies C. More formally:

Definition 9 *Let ψ be a FTCF defined on T and C a condition.* filtering(ψ, T, C) *is the weak fuzzy characteristic function ψ^C defined on $T^{'} \subseteq T$ and such that:*

$$\forall t \in T, \psi^C(t) = \begin{cases} \psi(t), & \textit{if } \psi(t) \textit{ satisfies } C \\ \textit{undefined}, & \textit{otherwise} \end{cases}$$

Example 1 *Let ψ be a FTCF defined on T and $s \in [0, 1]$:*

$$\text{filtering}(\psi, T, \psi(t) \leq s) = \begin{cases} \psi(t), & \textit{if } \psi(t) \leq s \\ \textit{undefined}, & \textit{otherwise} \end{cases}$$

With respect to union, two cases can be distinguished. When the set of functions are consistent (Definition 5), the union operation is reduced to the ω operation (Definition 6). However, when the set of functions are not consistent – i.e. they take different truth values at some moment t – one can consider three solutions. The first one consists in strict following of the binary case. Thus, we simply do not apply union since the information is inconsistent (this solution is simple but not very interesting). The second solution consists of the *optimistic* union, i.e. for each instant where a set of functions is defined, we take the maximum of the functions - this reflects the optimistic point of view. In other words, when information comes from many sources, we assume that the *truest is true*. The converse of this solution constitutes the *pessimistic* union, we take the minimal of the functions defined for the same instant. Further, one can take some *weighted mean* as some intermediate solution.

3 Our approach

3.1 Architecture

The architecture with which we work consists of a modified real-time specialist society [7] system which is a group of *associations* communicating through message-passing mechanism. Each association is a group of agents communicating through a blackboard. Each association has a controller that decides which agent to activate given a specific goal and communicates with the other controllers of other associations. The transportation scheduling problem can be easily implemented with this architecture by modeling each company as an association and its trucks as agents. With this architecture we distinguish between two levels of cooperation: inter-company and intra-company cooperation. Our paper is based on establishing a formal framework using FTCFs of these two levels of cooperation. Indeed, each truck agent is associated with a particular shipping company from which it receives orders of the form "*Load amount s of good g at location l_1 and transport it to location l_2 during a duration equal at most to d^w before a deadline D*. Each truck is assigned a specific time qualification. The time qualification is a FTCF ψ taking the value 1 when the truck is allocated and the value 0 when the truck is free. The FTCF allows the representation of the uncertainty of the availability of the truck during the intervals where the availability is not known in a precise way.

The shipping company association allocates orders to its truck agents of the form mentioned above. Among its truck agents, the controller selects those which can load s of good g at location l_1 and transport it to location l_2. Among this last, we select all trucks of which FTCFs take 0 for $t < D$ (the deadline of the order). After that, we determine for this truck the maximal duration needed to this task. The duration is calcutaled according to the type of the truck, the type of good and the distance $l_2 - l_1$. More formally, we have: $d = f(TA, g, l_2 - l_1)$, where TA is the type of the truck agent and g is the type of good. This duration d includes the time required to travel from one location to another one, to load and to unload goods and to come back to the company. Finally, the selected truck is the one with the highest *utility*. This concludes the first level of cooperation. Afterwards, the company association through its controller performs a contract-net protocol by announcing the unsatisfied orders and receiving bids conveying the contracts proposed by the other companies to satisfy these orders. The intuition behind the conceptual framework consists in satisfying the most important orders and delegating the least important to the other companies . Furthermore, a company tries to optimize its satisfaction to maximize its utility. To this, it allows to allocate the smallest truck-availability interval that is begger than the required task duration. We describe in the following these two levels of cooperation.

3.2 Formal Framework

The global scenario with which we work consists of a high level of a contract-net protocol: announcing unsatisfied orders, receiving bids conveying the proposed contracts and awarding the best selected bid. Each step of this protocol is itself a cooperation process. Indeed, the inter-company cooperation to select the trucks best suited to satisfy the orders allows the construction of the announcement while the intra-company cooperation allows the negotiation of the best contract with the other companies to satisfy locally unsatisfied orders. The cooperation consists of utility-based approaches where each company tries to maximize its own utility.

3.2.1 First cooperation: inter-company temporal reasoning

Let us consider $\mathcal{O}$ the set of orders received by a given company where each order o_i is characterized by its deadlines D_i before which the order should be satisfied, a duration d_i^e representing an estimate of the time required to satisfy the order, and the worst-case duration d_i^w. These durations are determined from statistical data gathered from previous execution of the truck. We use for the duration d_i^e the average duration over the gathered data and the duration d_i^w the average duration increased with the standard deviation computed from the same gathered data. Furthermore, we consider that each truck r has its FTCF ψ_r that indicates at any time t to what degree the truck is allocated $\psi_r(t)$ = p.

Given a set of trucks R and a set of orders $\mathcal{O}$, we need to generate a service schedule of the set $\mathcal{O}$. For this, the company, that we name in the following C_1, uses an algorithm based on the following steps:

- Compute expected utilities for all orders o_i, $Utility_{C_1}(o_i)$ = Reward(o_i)- Cost(d_i^w);
  where $cost$ is a function depending on the duration and charges to satisfy an order while $Reward$ is a function representing the rewarded value gained when the order is satisfied, it can for example represent the amount of money that the company is wanting to earn.

- Sort the set $\mathcal{O}$ according to the utility of orders;

- Satisfy the orders one by one as follows:
  - Search among the set of FTCFs of trucks those which are defined in the interval [Now, D_i] and of which values are less than a threshold s. This step is performed through a *filtering operation* to find these trucks. Let S_{truck} be the set of selected trucks.
  - For each truck $j \in S_{truck}$, let $I^{o_i}_{j,d_i^e}$ be the intervals such that duration($I^{o_i}_{j,d_i^e}) > d_i^w$ (if $I = [x, y]$, duration$(I) = y - x$)
  - Let $I^{o_i}_{k,min}$ be the interval with the least duration for all trucks $j \in S_{truck}$: $\forall j \in S_{truck}$ $I^{o_i}_{k,min} = arg(MIN(duration(I^{o_i}_{j,d_i^e})))$. The intuition behind the selection of the smallest truck-availability interval is first to maximize the utility of the truck and second to reducing the allocation of the truck to be useful for (most) tasks.
  - Send to the selected truck, the order o_i, its estimated and worst-case durations d_i^e and d_i^w and the interval $I^{o_i}_{k,min}$.

- Let $\mathcal{S}$ be the set of satisfied orders and $\mathcal{N}$ its complementary.

3.2.2 Second cooperation: intra-company temporal reasoning

When the company C_1 finishes its processing to allocate trucks for orders, it starts a negotiation process to delegate the set $\mathcal{N}$ containing unsatisfied orders to other companies. This process is based on an extended contract-net protocol that integrates FTCF in its processing. This processing is based on three steps:

1. *Announcing*: this step consists in broadcasting the set $\mathcal{N}$ to the other companies that we name in the following C_i.

2. *Bidding*: this step allows the iterative analysis of each order in the set $\mathcal{N}$ such that:

   - For each $o_i \in \mathcal{N}$ the algorithm of satisfying the orders is used, and let I be the interval computed. The algorithm of satisfying the orders is based on the cooperation inter-company as described bellow.

- Send bids $Bid_i^{C_i}$ containing $(I, \psi(t) : t \in I, \text{utility}_{C_i}(o_i))$

3. *Awarding*: This step allows the selection of the best bid from the bids proposed for each order. This step is as follows:

   - For each order o_i, construct a set of proposed bids $\mathcal{B}_{o_i} = \{b_{o_i}^{C_i} | C_i \ is \ a \ company\}$

   - Select the companies C_i such that $utility_{C_i}(o_i) < utility_{C_1}(o_i)$.
     If no company is selected, the order is not satisfied because it is expensive.

   - Compute the utility of each selected company's bid such that: $U_{C_i} = |tangent_{\psi}| \quad utility_{C_i}(o_i)$, ($tangent_{\psi} = \frac{\psi(\alpha)-\psi(\beta)}{\alpha-\beta}$)

   - For each order o_i, select the best bid with the lowest utility. In other words, the order is delegated to the company proposing the cheepest contract: $C_k = arg_{b_{o_i}^{C_i} \in \mathcal{B}_{o_i}}(MIN(U_{C_i}))$

   - For each order o_i send awards to the selected company C_k as the best contractee.

   - Each company C_k should update the FTCF of its truck. This step uses a specific temporal reasoning using FTCF that we describe in the following section.

3.2.3 Allocating interval: temporal reasoning in truck agent to update FTCF

From the inter- and intra-company cooperation result in the selection of the truck that will be in charge of satisfying an order. This truck of the company C_k has, then, to take into account the received award carrying the order. To this end, the truck should allocate the interval during which it satisfies the order. This operation consists in updating its FTCF by changing its value for every $t \in I$, where I is the interval during which it satisfies the order. The truck r receives the order o_i, its interval I_i=[a,b] during which it satisfies the order, the duration d^e required to satisfy the order and the duration d^w as the worst-case duration for satisfying the order. To update the FTCF, the agent have to assess several situations. To maximize its own utility, the truck tries to allocate the interval where the possibility to be free is the highest. Consequently, the truck agent performs a filtering operation over its FTCF in I_i such that: *filtering*($\psi_r, I_i, \psi_r(t) = 0$). This operation allows to select a set S^c of intervals $\{I_r^c\}$. There are two possible outcomes for the set S^c:

- $S^c = \emptyset$: this situation means that there is no interval during which the truck is sure that it is free. Then, we select intervals during which the possibility that the truck is free is the highest. Because a FTCF during these intervals is approximated with a linear feature, the most important intervals are the ones with the smallest $|tangent|$. Since the *tangent* allows us to measure the overall uncertainty over an interval (other measures can be used such as the integral over the interval, but the tangent is sufficient to give us the required information). Let $[\alpha, \beta]$ be this interval and ψ_r be the FTCF of the truck. We consider two possible subcases:

  – $Tangent$ is positive: this means that during this interval ψ_r increases. Then, the allocation of the interval is performed as follows: we allocate the interval $[x, x + d^e]$ such as the middle of this interval is the same as the interval $[\alpha, \alpha + d^w]$ (x is easily computed as x = $\frac{d^w - d^e}{2}$ + α). Consequently, if $\psi(\alpha) = k$ and $\psi(\alpha + d^w) = j$, we find (Figure 1, dashed-lined is the FTCF before the update):

$$\forall t \in [x, x + d^e], \psi(t) = 1$$

$$\forall t \in [\alpha, x],$$

$$\psi(t) = \frac{2-k}{d^w - d^e} t + \frac{k(2\alpha + d^w - d^e) - 2\alpha}{d^w - d^e}$$

$$\forall t \in [x + d, \alpha + d^w],$$

$$\psi(t) = \frac{2(\alpha - 1)}{d^w - d^e} t + \frac{2(\alpha + d^w) - j(2\alpha + d^w + d^e)}{d^w - d^e}$$

  – $Tangent$ is negative: this means that during this interval ψ_r decreases. Then, the allocation of interval is performed as follows: we allocate the interval $[x, x + d^e]$ such as the middle of this

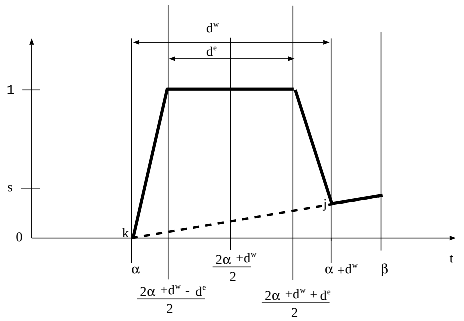

Figure 1: case of a positive tangent

interval is the same as the interval $[\beta - d^w, \beta]$ (x is easily computed as $x = \beta - \frac{d^w + d^e}{2}$). Consequently, if we consider that $\psi(\beta) = j$ and $\psi(\beta - d^w = k)$, we find (Figure 2, dashed-line is the FTCF before the update):

$$\forall t \in [x, x + d^e], \psi(t) = 1$$

$$\forall t \in [\beta - d^w, x],$$

$$\psi(t) = \frac{2(k-1)}{d^e - d^w} t + \frac{2(\beta - d^w) - k(2\beta - d^w - d^e)}{d^e - d^w}$$

$$\forall t \in [x + d^e, \beta],$$

$$\psi(t) = \frac{2(j-1)}{d^w - d^e} t + \frac{2\beta - j(2\beta - d^w + d^e)}{d^w - d^e}$$

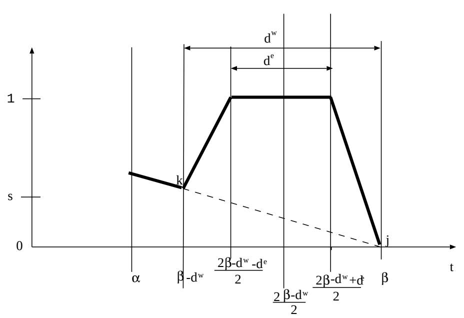

Figure 2: case of a negative tangent

- $S^c \neq \emptyset$: this situation conveys the fact that there are intervals $[x, y]$ in the interval $[a, b]$ during which ψ_r takes the value 0. We select the interval $[x, y]$ with the highest duration, $y - x = MAX_{[x_i, y_i] \in S^c}$ $(y_i - x_i)$. Two possible subcases are considered:

  – $y - x \geq d^e$: we allocate the interval $[x, x + d^e]$ such as ψ_r takes the value 0. To take the worst-case duration d^w, we allocate the interval $[\alpha, \alpha + d^w]$ in ordr to be sure that we don't meet β. Consequently, if we suppose that $\psi(\alpha) = k$ and $\psi(\alpha + d^w) = j$, we have (Figure 3, dashed-line is the FTCF before the update):

$$\forall t \in [x, x + d^e], \psi(t) = 1$$

$$\forall t \in [\alpha, x],$$

$$\psi(t) = \frac{x - kx}{x(x - \alpha)} t + \frac{kx - \alpha}{x - \alpha}$$

$$\forall t \in [x + d^e, \alpha + d^w],$$

$$\psi(t) = \frac{1}{x + d^e - d^w - \alpha} t - \frac{j(x + d^e) - (\alpha + d^w)}{x + d^e - \alpha - d^w}$$

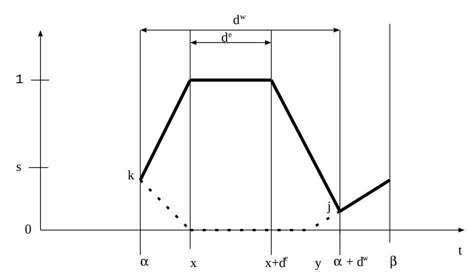

Figure 3: case of $y - x \geq d^e$

  – $y - x < d^e$: we allocate an interval $[z, z + d^e]$ such as its middle is the same of the middle of $[x, y]$ (z easily computed as $z = \frac{x + y - d^e}{2}$). In the same way, in order to take the worst-case duration into account and to avoid meeting β, we consider the interval $[\alpha, \alpha + d^w]$. Consequently, suppose that $\psi(\alpha + d^w) = j$ and $\psi(\alpha) = k$, so we have (Figure 4, the dashed-lined is the FTCF before the update).

$$\forall t \in [z, z + d], \psi(t) = 1$$

$$\forall t \in [\alpha, z],$$

$$\psi(t) = \frac{2(k-1)}{\alpha(2 - x - y - d^e)} t + \frac{2 - k(x + y + d^e)}{2 - x - y - d^e}$$

$$\forall t \in [z + d^e, \alpha + d^w],$$
$$\psi(t) = \frac{(j-1) + 2jd^e}{2(\alpha + d^w) - (x + y - d^e)} t + \frac{2(\alpha + d^w) - j(x + y + d^e)}{2(\alpha + d^w) - (x + y - d^e)}$$

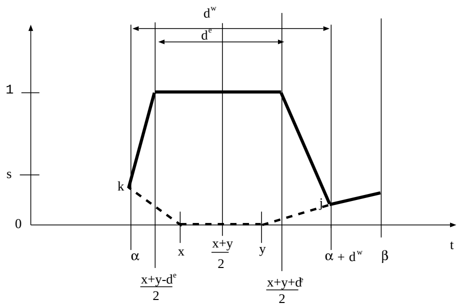

Figure 4: case of $y - x < d^e$

For all cases, to compute the value of FTCF ψ, we consider the linear feature of ψ between two points (with known values of ψ) and then we generate the linear equation representing the feature of ψ between these points. In some cases, the allocation of the interval is based on constructing interval having the same middle as the one computed for the truck. This strategy is motivated by the fact that we guarantee the allocation of the interval where the degree of the availability is highest regardless of the fact that the allocation is not necessarily the optimal one.

4 Conclusion

The approach we have presented consists in using fuzzy characteristic functions to express the uncertain behavior of agents. A simple and powerful temporal reasoning based on fuzzy temporal characteristic functions is developed resulting in a good performing approach to allocate trucks. The representation and reasoning with fuzzy temporal characteristics contributes to the definition of a formal framework for inter- and intra-companies cooperation. The representation and the reasoning result in a sophisticated contract-net protocol that is much more expressive and suitable to applications with high level of uncertainty. The contract-net protocol based on the utility allows each company to maximize its own utility. The implementation and assessment of this approach in real-time society of specialist is under development. Further work in this approach will concern the monitoring of the agent execution by taking the information gathered during execution into account and performing a re-cooperation and the update of the FTCF afterwards. The optimality of this approach will also be studied.

References

[1] J. Allen. Maintaining Knowledge About Temporal Intervals. *Communications of the ACM*, 26(11):832–843, November 1983.

[2] M. Bouzid and P. Ladkin. Rules for Simple Temporal Reasoning. In *Proceedings of TIME-95, International Workshop on Temporal Representaion and Reasoning*, pages 73–88, 1995.

[3] M. Bouzid and A. Ligeza. Temporal logic based on characteristic functions. In C. R. I. Wachsmuth and W. Brauer, editors, *Advances in Atrificial Intelligence, 19th Annual German Conference on Artificial Intelligence, volume 981 of Lecture Notes in Artificial Intelligence*, pages 221–232. Speinger Verlag, 1995.

[4] R. Davis and R. Smith. Negotiation as a Metaphor for Distributed Problem Solving. *Artificial Intelligence*, 20(1):63–101, 1983.

[5] K. Fischer, J. Muller, and M. Pischal. Cooperative Transportation Scheduling: an Application Domain for DAI. *Technical Report RR-95-01*, 1995.

[6] P. Ladkin. Time Representation: A Taxonomy of Interval Relations. In *Proceedings of the 5th National Conference on AI, AAAI'86*, pages 360–366. Morgan Kaufmann, 1986.

[7] A.-I. Mouaddib. Progressive goal-directed reasoning for real-time systems. *Ingineering Intelligent Systems*, 3(2):67–77, 1995.

[8] A.-I. Mouaddib and S. Zilberstein. Handling Duration Uncertainty in Meta-Level Control for Progressive Reasoning. In *IJCAI-97*, pages 1201–1206, 1997.

[9] D. T. R. Morris and K. Ford. Time and Uncertainaty in Reasoning about Order. In *Proceedings of TIME-95, International Workshop on Temporal Representaion and Reasoning*, pages 129–136, 1995.

[10] T. Sandholm. An Implementation of the Contract Net Protocol Based on Marginal Cost Calculations. In *AAAI*, pages 256–262, 1993.

[11] B. Williams. Doing time: putting qualitative reasoning on firmer ground. In *Proceedings of the 5th National Conference on AI, AAAI'86*, pages 105–112, 1986.