Non-normative behaviour in multi-agent system: some experiments in traffic simulation

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***Abstract*— Most of the works related to norms and multi-agent systems focus on the design of normative agents systems making the assumption that agents always respect norms. Our aims in this article are (i) to discuss the relevance of this assumption in some specific contexts and to highlight some benefits of designing non-normative behaviour agents, (ii) to expound the methodology followed in a concrete application which consists in traffic simulation at junction. In particular, based on statistical traffic results, we show how non-normative behaviours contribute to improving the realism of simulation.**

I. Introduction

One of the crucial issues in multi-agent system addresses the coordination of agents' actions. Coordination concerns all local processes that allow to achieve a global state of the system. Many definitions exist in litterature, each of them highlights a particular point of view.

Coordination can be assimilated to search process performed in the distributed problems solving ([1], [2]). In this specific context, coordination refers to internal reasoning of agents, mechanisms of partial solutions exchanges, etc.

For Jennings, coordination is the process which allows an agent to reason about its own actions and the actions of other agents in order to ensure that the global system behaves correctly [3]. In this manner, coordination can be used to satisfy and guarantee some criterions of consistency without any global processes.

Malone defines coordination as the set of all extra activities that are necessary to fulfill in a multi-agent system in order to have interactions between agents [4].

Coordination also provides a way to solve different types of conflicts between agents, for example: resource conflict (two agents try to accede to a same thing at a same time) or interest conflict (agents have opposite goals and consequently their actions are antagonistic).

Originally, first works on multi-agent coordination have investigated the coordination from a cooperative viewpoint. They made the assumption that all agents were motivated on by the fulfillment of a common goal. We can quote for instance Lesser and Corkill's works whose model was based on exchanged messages describing aims, priorities and preference of the agents [5].

The coordination has also been expressed as a planning problem [6]. Each agent can formalize in a plan its actions and interactions in the future. In this context, the coordination consists in constructing with all individual plans a multi-agent plan describing the global behaviour of the system. The coordination mechanism has therefore to identify and find: the possible link between actions, the sequential and parallel executions of actions, the potential conflicts which can occur.

More recently, this background of cooperative agents has been discussed and coordination has been considered from a competitive way. The idea is that each agent has individual motivation, acts to achieve its own goal and interacts with other agents to ensure some global properties of the system.

In [7], for example, Shoham *et al.* obtain coordination between agents having antagonist aims by introducing social laws. Their application deals with robots which have to move in an unknown environment. Since their motivations are individual and their behaviour not necessarily cooperative, conflicts can appear. To avoid such a situation, the authors introduce rules which allow to restrict possible actions for agents in conflict. These rules are comparable to the Highway Code defining how agents have to act. Such social laws create a norm in the multi-agent system.

In a first part, we present the concept of norm for the multi-agent systems. Then we focus on the violation of norms in a traffic simulation context. To finish, we give some experimental results which justify our choices and show that non-normative behaviour is an interesting concept for multi-agent coordination.

II. Norms in multi-agent systems

A. Introduction

In the common meaning, norms are a set of rules and principles applied to an object and defining how it has to be or what it has to do. Consequently, norms are used to describe and obtain an ideal state of a system.

As norms are used in various domains, it is difficult to give a precise definition of what norm means. In sociology for example, the studies of societies or simply groups of persons based on authority show that relations between the individuals are controled by norms [8]. Human societies usually establish laws and more particularly use a juridical system in order to preserve the rights of citizens. In industrial fields, norms bring together data (measures, charateristics, quality criterions,

...) and manufacturing processes which help to improve the production.

This brief overview of different uses of norms allows us to exhibit some properties. A norm has no meaning without any authority. This one has two main roles. Firstly, it has to formulate the set of rules defining the norm. Usually these rules are designed to satisfy the aims of the authority. The second function of the authority concerns the application of the norm, this includes control and penality management in the case of norm violation.

A norm is usually used to guarantee some properties at a collective level. It allows for example to satisfy goals of a society or a group. Consequently, a norm can be at variance with individual aims and desires. This is generally one of the justifications of norms violation.

B. Norms and agents

In a multi-agent system, norms are used to specify what an agent has to do. In other words, norms give a way to perform a coordination by regulation. Shoham *and al*'s works that we have previously quoted give an example of such an approach for coordination.

In [9], the authors introduce a multi-agent coordination using policies. Under the term policy, the authors identify three elements: *the actions guided by the policy, the participating group and the guiding principles*. Based on this triple, they formally define the coordination of policy. Laws relating to a policy are expressed as a set of situation-action rules and allow to treat exchanged messages between agents by regulating two kinds of event: sending and receiving messages.

Some works tend to extend well-known existing coordination frameworks with the notion of norms. For example, in [10], the authors extend the BDI model in such a way that agents are able to consider norms as motivation. The proposed model introduces a new type of events which are the result of norms applying.

Some researches are focused on the way to consider and create norms. Boella's works for example focus of formalization of normative system viewed as a multi-agent system. In [11], the authors stress that *the first advantage of a normative system as agents perspective is that the interaction between an agent and the normative systems [...] can be modelled as a game between two agents [12]*.

All these works and even other more ([13],[14]) use norms to express a standard behaviour of agents against a specific situation. The terms *normative agent* correspond to agents which act according to the specified norms of the system. By misuse of language, we can say that a normative agent is an agent whose behaviour is coded with the norms of the system.

C. Norm versus autonomy

The autonomy is one of the most important aspect of an agent. This concept is usually a central point in the defintion of an agent. The autonomy expresses the ability to act without extern control, consequently it seems that norm and autonomy are two opposite notions.

The non-respect of norms is usually mentioned. In [11], the authors give some reasons to justify why agents may violate obligations. Nevertheless this concept is barely investigated in the litterature.

To our mind, the violation of norms has several advantages. First of all, it seems to be more realistic than a strict respect of rules. For example, when agents have to reproduce human behaviours, we think that the approaches described above ([7], [9], [10]) are not suitable. A human behaviour is essentially individualistic and consequently is hardly reproducible with norms and obligations.

Another criticism adresses to the contradiction which can exist between norms and autonomy in a multi-agent system. Indeed one of the most interesting aspects of the agent concept is the autonomy. In [15], the authors note that an aspect of autonomy consists in the degree of influence of norms over the agent's decisions. Mixing norm and autonomy is difficult unless the agents are able to violate obligations.

We have presented briefly two notions: norm and autonomy. A compromise between both concepts leads to consider the violation of norms. In the next section, we illustrate these ideas by presenting a traffic simulation issue in which agents are submitted to norms and laws. We show that the violation of norms is necessary and allows to render realistic behaviours. We give some details of the multi-agent approach and we expound in particular the different problems generated by the use of non-normative behaviours.

III. Non-normative behaviour in traffic simulation

Agents are currently used in the field of transportation. Many works have been led around road traffic issues. For instance, agents can be used for traffic management. In [16], the authors propose an application based on coordination of agents to diagnostic and inform drivers about traffic problems in a located area. This traffic management issue is also dealt in [17]. The author introduces a decentralized traffic control based on evolutionary games.

In this article, we are interested in the simulation of road traffic which consists in reproducing in a realistic way the move of vehicles on a road network. Depending on the degree of desired realism, traffic simulation at junction is quite complex. It consists in a coordination between conflictual traffic flows (intersection and merging streams) in a highly dynamic environment.

A. Description of the context

The common approach simplifies the process by using a centralized scheduler to coordinate the traffic flow on each branch of the crossroad. This method is a really dractic simplification of the initial problem since the scheduling process usually lets enter into the intersection only the vehicles whose trajectories are not in conflict.

With a good parametering of this centralized process, it is usually possible to obtain a good accuracy with traffic date like flow, average speed, etc. In other words, such approaches can be sufficient for statistical traffic studies. When the aim of the simulation is to mimic actual behaviours of real drivers, these methods are too simple and not sufficient enough. For instance, when the traffic simulation has to generate a realistic traffic for a driving simulator, it is necessary to consider the issue from another point of view.

The ARCHISIM model[1] is an original concept since it associates a behavioural traffic simulation model with a driving simulator. It allows to reproduce a large variety of traffic situations in which a human (a real driver) can be situated. The main difference between the traffic model of ARCHISIM and the commercial traffic simulation tool is the way to consider traffic phenomenon. In many tools like PARAMICS[2] or AIMSUN[3], traffic is considered from a centralized and mathematical way. In the ARCHISIM model, the traffic is considered in a distributed way: it is an emergent phenomenon which results from the actions and interactions of the different actors of the road system: car drivers, pedestrians, road operator, ...

The computing model of ARCHISIM follows the multi-agent principles. Each simulated driver is considered as an autonomous software agent with its own skills, knowledges, goals and strategies. It evolves into a virtual environment made up of roads and intersections whose structure is close to a graph. As in real life, many agents may want to reach a same part of the road at the same time. Such a situation generates a conflict between the agents. Such situations are very common at intersections. Consequently, to avoid collisions or deadlocks inside the crossroad, agents have to coordinate with each other as real drivers do. So, the traffic simulation at a junction can be expressed as a multi-agent coordination issue.

B. Description of non-normative behaviours

The moving of human drivers on the roads are governed by several rules and priorities relations what are commonly known as the Highway Code. The traffic system can consequently be considered as a normative system. In agreement with Boella's ideas[12], we can model as games the interactions between two agents subjecting to the obligation of the Highway Code.

For example, let us consider two agents x and y coming closer to an intersection. Four elementary situations are possible and presented in the figure 1:

- x and y are on the same road and no one turns: no conflict exists between x and y
- x arrives at the right of y and in absence of any signalisation (yeld / stop road signs or traffic lights), x has priority
- y arrives at the right of x and consequently has priority
- x and y are on the same road and both turn on the left, according to the Highway Code they have both the priority

[1] has been developed for many years at the French Institute of Transport (INRETS)

[2] www.paramics-online.com

[3] www.aimsun.com

Based on this modelling, it is possible to define a coordination mechanism [18]. Each agent can choose between two possible actions: Go and $Stop$ which allow to calculate the longitudinal acceleration of the simulated vehicle. For each situation a matrix decision containing the payoffs associated to the selected action can be calculated by applying these rules:

- if the agent chooses to Go without solving its conflict, the payoff in the corresponding cell of the matrix is negative
- if the agent solves the conflict with the action Go, the payoff is positive
- when the agent brakes to stop, the conflict is solved but the payoff is nil

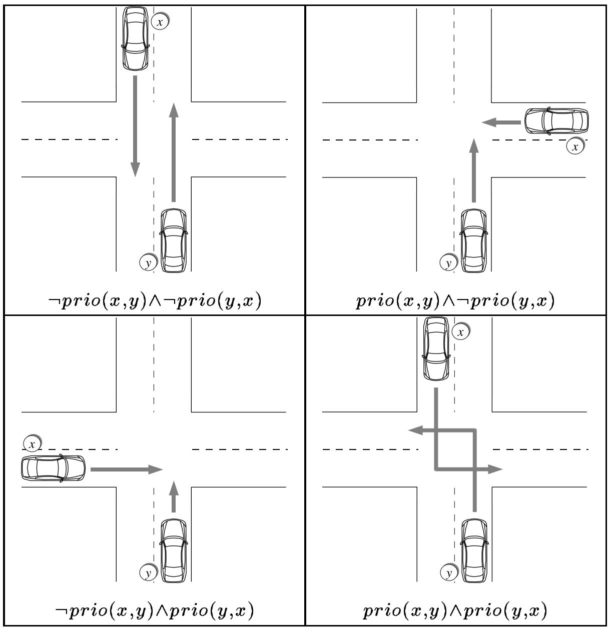

Fig. 1. Elementary situations in crossroad

The coordination mechanism runs at each time step of the simulation. Each agent in conflict situation tries to recognize the current situation by identifying the priority relation it shares with the other agents. Based on this recognition, it chooses the decision matrix and then the action which has the best payoff.

In this context, the most simple way to introduce non-normative behaviour is by modifying for the agents their priority recognition. Indeed, it is possible to consider that the priority relation used in the previous model is in fact an aggregation of different types of priority.

It is clear that in reality, the Highway Code is not always respected. In fact, drivers develop personal informal rules of driving [19]. Several informal priorities can be considered for example:

- priority relating to speed: a driver arriving with code priority at an intersection tends to lose his priority if he perceives a vehicle approaching with a high speed
- priority relating to impatience: a driver stopped for a long time tends to consider he has priority on the other vehicles

- priority relating to the entry in the conflict zone: a driver near the conflict zone has priority on vehicles less close

In the figure 2, we present our rules possibility of aggregation (the aggregated priority is $prio_A$). Six predicates are defined:

- $codePrio$ which stands for the normative priority relating to the Highway Code,
- $physicalPrio$ which represents the priority relating to an entry in the conflict zone,
- $impatience$ which expresses an impatience state of the agent,
- $moveOffAgain$ which indicates if the agent accelerates after having stopped,
- $turnBehind$ which means that two vehicles turn behind each other,
- $distConflict$ which represents the distance between a vehicle and the conflict point, for example $distConflict(x, y)$ expresses the distance from x to the conflict point between x and y.

For example, the rule 8 expresses that if a simulated driver is impatient and its distance to conflict gives a sufficient margin of safety, then it can consider it has priority.

Without being explicitely expressed, this aggregation takes the priority relating to the speed into account. When the speeds are near from zero, distances ($distConflict$) are considered instead of speed (rules 5,6,7,8,9). On the other hand, when the speeds are significant, all boolean using $distConflict$ are replaced by a time to conflict.

To illustrate this aggregation of priority relations, let us consider a simulated driver waiting at a stop sign. If the conflictual flow has a high density, it is very difficult for it to cross the intersection with respect of the Highway Code. With the rule 8, it can consider it has priority if it is sufficiently impatient[4] and if it can reach the conflict point before the other vehicles (possibly considering that the other vehicles will have to brake).

$$physicalPrio(x,y) \rightarrow prio_A(x,y) \wedge \neg prio_A(x,y) \quad (1)$$

$$codePrio(x,y) \wedge codePrio(y,x) \wedge turnBehind(y,x) \rightarrow \neg prio_A(x,y) \wedge prio_A(y,x) \quad (2)$$

$$codePrio(x,y) \wedge codePrio(y,x) \wedge \neg turnBehind(x,y) \rightarrow prio_A(x,y) \wedge \neg prio_A(y,x) \quad (3)$$

$$codePrio(x,y) \wedge \neg codePrio(y,x) \wedge impatience(x) \rightarrow prio_A(x,y) \wedge \neg prio_A(y,x) \quad (4)$$

$$codePrio(x,y) \wedge \neg codePrio(y,x) \wedge \neg impatience(x) \wedge (distConflict(x,y) < distConflict(y,x)) \rightarrow prio_A(x,y) \wedge \neg prio_A(y,x) \quad (5)$$

$$codePrio(x,y) \wedge \neg codePrio(y,x) \wedge \neg impatience(x) \wedge (distConflict(x,y) \geq distConflict(y,x)) \wedge moveOffAgain(y) \rightarrow prio_A(x,y) \wedge \neg prio_A(y,x) \quad (6)$$

$$codePrio(x,y) \wedge \neg codePrio(y,x) \wedge \neg impatience(x) \wedge (distConflict(x,y) \geq distConflict(y,x)) \wedge \neg moveOffAgain(y) \rightarrow \neg prio_A(x,y) \wedge prio_A(y,x) \quad (7)$$

$$\neg codePrio(x,y) \wedge codePrio(y,x) \wedge (moveOffAgain(x) \vee impatience(x)) \wedge (distConflict(x,y) < distConflict(y,x)) \rightarrow prio_A(x,y) \wedge \neg prio_A(y,x) \quad (8)$$

$$\neg codePrio(x,y) \wedge codePrio(y,x) \wedge (moveOffAgain(x) \vee impatience(x)) \wedge (distConflict(x,y) \geq distConflict(y,x)) \rightarrow \neg prio_A(x,y) \wedge prio_A(y,x) \quad (9)$$

$$\neg codePrio(x,y) \wedge codePrio(y,x) \wedge \neg moveOffAgain(x) \wedge \neg impatience(x) \rightarrow \neg prio_A(x,y) \wedge prio_A(y,x) \quad (10)$$

$$\neg codePrio(x,y) \wedge \neg codePrio(y,x) \rightarrow \neg prio_A(x,y) \wedge \neg prio_A(y,x) \quad (11)$$

Fig. 2. Example of aggregation of priority relations

C. Effects of non-normative behaviour

The introduction of non-normative behaviour has some effects that it is important to control. When an agent decides to violate the High Code because it feels impatient at a stop road sign: for example, it has to verify that it will not create an accident. In other words, the agent has to test if its moving is authorized.

In our context, we have introducted for critical situations an estimation of braking time. When an agent decides to violate the priority, it checks that the vehicle, which it is in conflict with, can brakes with security margin.

A second type of effects concerns the deadlocks. A rule of Highway Code says that a driver mustn't enter into a junction if it not sure to be able to go out. This rule has not been implemented in our model since it is barely applied by real driver. Consequently, when simulating high density of vehicles, agents tend to store themselves in the inner center of the crossroad and consequently create a deadlock. An exemple of such a situation is presented on figure 3.

In real life, even if drivers perform individual and non-normative practices, deadlocks situations are quite uncommon since drivers anticipate.

D. Anticipation to ensure free deadlock non-normative practices

Anticipation is a general concept and many definitions exist. Rosen's one seems well adapted to our issue. *An anticipatory system is a system containing a predictive model of itself and / or of its environment that allows it to change current state at an instant in accord with the model predictions pertaining to a later instant* [20]. Our idea is to use anticipation in order to ensure that actions performing by an agent will not induce a deadlock.

The model we have introduced [21] consists in partionning the environment representation of an agent in two parts:

[4]this parameter vary from the agents

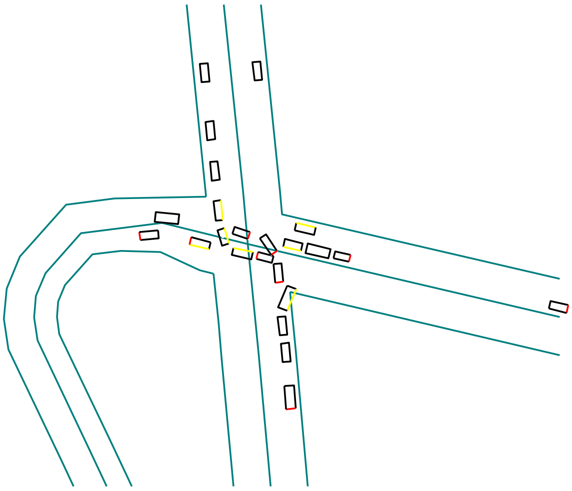

Fig. 3. Deadlocks occuring in an intersection due to non-normative practice

desired and undesired states. Deadlocks are considered as undesired states. With this background, the anticipation process consists in building a forecast of the current environment in the future and testing the existence of undesired states.

To realize this anticipation task, agents need to construct a mental representation of what happens in the center of an intersection. The architecture of ARCHISIM allows agents to get, at each step of the simulation, a symbolic description of their environment with information about other perceived vehicles: position on the road, current speed, acceleration, etc. We enrich this symbolic vision by considering three blocking relations between two vehicles:

- $bph_z(x, y) \equiv$ *"x is physically blocked by y from the point of view of agent z"*
- $bpha_z(x, y) \equiv$ *"z perceives that x will be physically blocked by y"*
- $bpr_z(x, y) \equiv$ *"y has priority over x from the point of view of agent z"*

A conjunction set of these relations allows to describe easily the contextual traffic situations in a crossroad.

To be able to infer undesired states from the previous relations, the mental representation of each agent is expressed as a constraint network. Such a formalism describes a set of variables taking their value in a domain and constrained by binary relations. The mental representation of each agent is constructed with vehicles present into the intersection (variables) and having one or many blocking relations with each other (constraints). Each of these vehicles is associated to a temporal domain that can be reduced by performing propagation on constraints. For example, if an agent z has in his mental representation $dom(x) = [1, 4] \cup [8, 10]$, this means that z has infered that x will be blocked during the interval $t + 5$ to $t + 7$.

The first step of the anticipation algorithm consists in constructing the mental representation of the agent. A first constraints propagation is performed on the built network. This allows to reduce the domain of each variable of the mental representation. Then for each possible actions of the agent, the algorithm determines the possible effects of it. These effects entail the addition or the eliminating of blocking relations. When all the effects of an action have been estimated, the algorithm makes an update of the network and performs a new propagation. The final step consists in searching undesired states like for example a nil domain for the current agent. Each action inducing such a state is eliminated.

E. Discussion

To sum up, the introduction of non-normative behaviour in our multi-agent coordination issue has the need for the adjunction of some agent abilities and in particular anticipation ones. This seems logic since the several rules of the Highway Code aim to ease the moving of the driver. When real driver violate several rules, they make their driving task more difficult and need to develop a more intense mental activity.

In the next section, we present the benefits of the use of non-normative behaviour in the traffic simulation.

IV. Experimental results

The evaluation of our multi-agent model has been led in two parts. The first one consists in tests and visual analysis of individual behaviours. Different scenarii have been used: crossroad with and without traffic sign [21]. Such an evaluation is quite subjective and only allows to verify that behaviours are sound. To be more accurate in our evaluation, we have tried to simulate the traffic on a real crossroad and compare the traffic data obtained by simulation with real measures.

The intersection used for this evaluation is located in the city of Reggio Calabria in Italy. This intersection makes the junction between a main road going from north to south and a secondary street (from east to west). It is signalized by two stop signs installed on the secondary trunk road. Each arm of the junction has two lanes and the inner center is large enough to allow storage of vehicles.

The traffic data was measured manually by the University of Reggio Calabria within the intersection between 12:30 AM and 1:30 PM on a normal weekday. For each arm of the intersection, the entry flow is expressed in a number of vehicles per hour and pourcentage of turning movement (right or left turn, straight ahead).

From this data, we have generated a traffic demand which has been used in ARCHISIM to generate simulated vehicles two hundred meters before the intersection. Virtual sensors have been used to measure the flow of vehicles.

Simulations were carried out according to two experimental conditions. In the first experiment, agents used a reference behaviour which is quite normative [18], whereas non-normative practices and anticipation are performed in the second one.

The figures 4 to 7 draw the comparison between the simulated flows obtained with or without anticipation and the real flow measured. For all graphs, the time is expressed as five minutes' period. The figures 4 and 5 relate to the principal axis. The figures 6 and 7 describe the flows of the secondary axis.

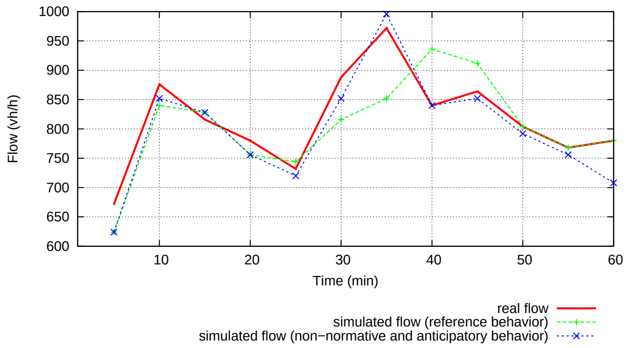

Fig. 4. Simulated flow (South-North axis)

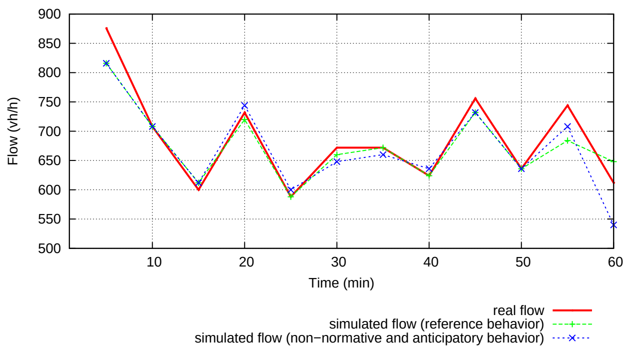

Fig. 5. Simulated flow (North-South axis)

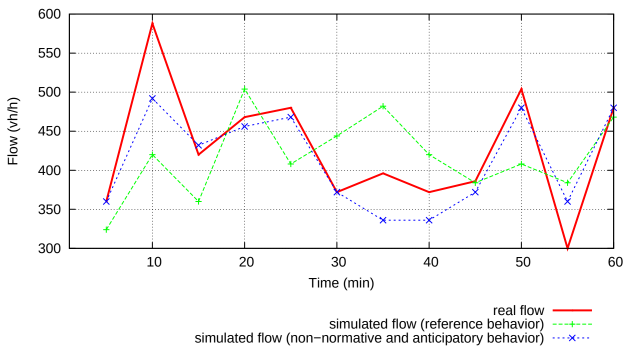

Fig. 6. Simulated flow (East-West axis)

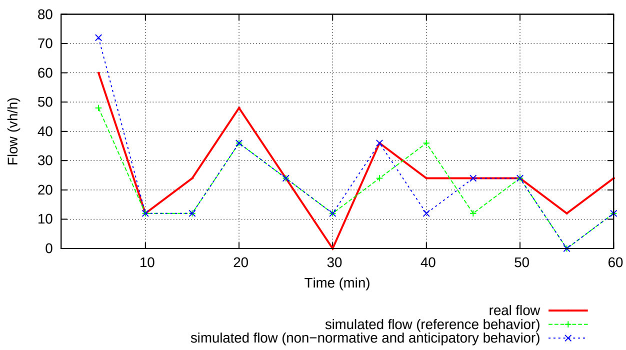

Fig. 7. Simulated flow (West-East axis)

In all cases the best results are obtained by using anticipatory agents. To qualify more precisely these results, we use a well known indicator in traffic simulation: RMSE. It corresponds to the root mean square error between the real flow y_i and the flow simulated x_i and is expressed by the following formula:

$$RMSE = \sqrt{\frac{\sum_i (x_i - y_i)^2}{\sum_i {y_i}^2}}$$

The values obtained are, for three out of the four axis, lower than 0,1 what corresponds to an error lower than 10% (table I). In the litterature, a good simulation of traffic often offers an error rate lower than 15%. The results of the curve of the figure 7 are not very representative since the simulated flows are weak and not very significant.

	RMSE		Flow (vh/h)	
	reference behaviour	anticipatory and non-normative behaviour	Min	Max
North/South	0,06	0,04	600	900
South/North	0,03	0,03	680	980
East/West	0,15	0,06	300	600
West/East	0,32	0,30	0	60

TABLE I
VARIATION IN RMSE WITH REFERENCE AND ANTICIPATORY/NON-NORMATIVE BEHAVIOUR

V. CONCLUSION

In this article, we have presented a practical case study of using non-normative agents in a multi-agent simulation. In litterature, the violation of norms is usually mentioned but barely used in practical terms. We have studied the impact of such a concept on a traffic simulation at junction issue.

Our aim is to provide a simulation which gives a realistic traffic from a visual and statistical point of view. As non-normative behaviours seem to be relevant with the driving task, we have improved the autonomy of agents by giving them violation of norms abilities. In order to avoid accident or deadlock, we have completed the coordination model of our agent by an anticipation algorithm.

The experimental results obtained and compared to real data confirm the relevance of the use of non-normative behaviour for the traffic simulation issue. We are now working on a generalization of our approach to be applied to other issues.

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