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An optimized evolutionary Multi-agent approach for Regulation of disrupted urban transport

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ABSTRACT: *For a sustainable people and goods mobility, CISIT (The International Campus on Safety and Intermodality in Transportation) has the objective to realize an optimal management of multimodal chains. In this context, this paper discusses the real-time regulation of traffic in a transportation system disruption.. In fact, the increase in the network size and the presence of multiple transportation modes had made the task of managing the transportation system more complex and more difficult for regulators especially during a disturbance. Hence, we propose a decision support system based on an evolutional multi-agent approach. This system is able to detect perturbations, analyze, propose and evaluate solutions using Choquet integral.*

Keywords: *Choquet integral, Genetic algorithm, Multi-agent system, Regulation Support System.*

I. Introduction

Seen an increase in the number of passengers and the development of various transportation modes, the great difficulty related to the traffic management is the respect of the planned departure and arrival times of the vehicles at the different stops in the network [1].

In fact, through an estimation of the demand, a travel time and traffic condition, a predictive scheduling was established [2]. This process consists in establishing different timetables describing the theoretical passage times of vehicles through the network stations. However, complex and random events can disrupt the network thus introducing considerable differences between the theory state and the real state, and subsequently causing deterioration in the quality of service provided. Hence the importance of a regulatory process that aims to generate fast and efficient solutions in real time. Therefore, to reduce the disturbances effects, the theoretical schedules have to be adapted to the real traffic conditions through regulation, or rescheduling tasks [3] [4] [5]. This process is then called reactive scheduling [3]. It results in the creation of new schedules that increase the level of service by undertaking operational decisions, such as, delay of one or everal vehicles, injection of an extra vehicle in the network or routes deviation of some vehicles …etc. Actually, it is a human operator, a regulator, who is responsible to manage and control the global network traffic. So, the regulator has to carry out difficult tasks that are often inaccessible at the human scale especially if many disturbances occur simultaneously, which involves the assistance of a RSS (Regulation Support System) [6].

Tools and regulatory approaches

Due to the imperfection of the data on which most mathematical models are based, fuzzy logic[7] has been introduced in various regulatory approaches[1][8]. Moreover, regulation is often seen as a real-time scheduling. Then it is a reordering of the following vehicles under real operating conditions [9].

Faced with the complexity of transportation problems, which requires the development of efficient and suitable solutions in a limited time, and noting the effectiveness of genetic algorithms for solving combinatorial optimization problems, several researchers have used these algorithms to optimize transportation networks [10][11]. Moreover, the problem of correspondence between different lines of a public transport network was also treated by approaches based on genetic algorithms [12], [13].

Due to the distributed nature of transportation systems, Laïchour in [14] proposed a decision support system to regulate a network of buses, based on Agent approach. Indeed, he proposed a multi-agent system capable of handling correspondence in real time.

Other researches had used hybrid approaches. In her doctoral thesis B.Fayech in [15] proposed an evolutionary multi-agents approach for the on-line regulation…

In this study, we propose a RSS which tries to assist the regulators to evaluate a pertinence of a disturbance and to choose the most efficient decision. We begin with a presentation of the mathematical formulation of the problem where the constraints and the regulation criteria are also stated. Then we propose decision support system that relies on cooperation between a multi-agent system [16][17],[18] and an evolutionary approach[3]. This system has to analyze disturbances, generate and evaluate solutions using Choquet integral. Some simulation results are finally shown in the last section.

II. Mathematical Formulation

A. Regulation horizon determination

In order to control the disturbances evolution, we have to search a set of network entities (vehicles and stations) involved in the detected disturbance $H = \{S^H \cup V^H\}$, where S^H is the set of the considered stops and V^H is the set of the vehicles. We note the k^{th} station of the line r by S_k^r .We also represent the i^{th} vehicle of the line l by V_i^l

To calculate the regulation horizon, MM.Ould Sidi [1] proposed a simple geometrical method which consists in a delay to be imposed on every vehicle during its passage in the terminus.

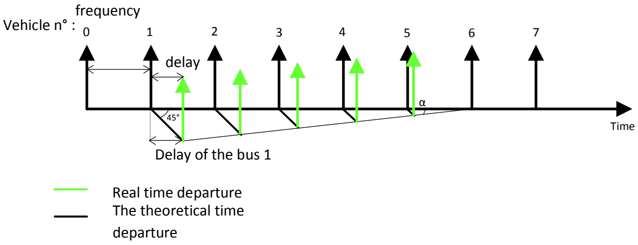


Figure 1. Principle of the regulation in terminus

The number of vehicles upstream expressed by the following formula:

$$N_{up} = (E(n_0) + 1) + 1 \quad (1)$$

The number of downstream vehicles expressed by using the following formula:

$$N_{down} = \begin{cases} N_{up} - 1, \ if \ 0 \prec N_{up} \leq 3 \\ N_{up} - 2, \ if \ N_{up} \succ 3 \end{cases} \quad (2)$$

Finally, the total vehicles number to consider is:

$$N_T = N_{up} + N_{down} + 1 \quad (3)$$

We note S_{up} the first station where a vehicle $(V_{distr} + N_{up})$ is going to serve after the moment of disturbance t_{distr}, and S_{down} the first station where the vehicle $(V_{distr} - N_{down})$ is going to serve after t_{distr}.

In the case of simultaneous disturbances, the determination of the horizon is even more complicated. To manage this complex incident, our proposed RSS must check whether these disturbances are overlapping or not.

- Separate disturbances: In this case, the RSS must identify the horizon associated with each disturbance and these will be treated separately.
- Overlapping disturbances: We note that H_1 is the horizon of the first disturbance and H_2 is the horizon of the second one. We assume that H_1 and H_2 are not disjoint. In this case more complex than the first, the RSS should determine the overall horizon H_{global} which is the union between H_1 and H_2.
- Generalization to m overlapping disturbances: We consider m perturbations simultaneous and overlapping, we note Hi horizon associated with each disturbance. The global regulation horizon H_{global} is the union of different horizons H_i.

B. Decision variables

The passage variable, a_{ij}^m associated to the vehicle V_i^m and to the stop S_j^m is equal to 1 if the vehicle V_i^m passes by this stop and 0 otherwise. The destination variable, x_{ijk}^m is equal to 1 when V_i^m goes directly from S_j^m to S_k^m and to 0 otherwise. We note ta_{ij}^m the arrival time of the vehicle V_i^m at the stop S_j^m and td_{ij}^m its departure time. Considering the initial duration, t_{ijk}^m of the vehicle V_i^m direct route between the stations S_j^m and S_k^m, we represent the route time modification between these two stops by δ_{ijk}^m. The variable ε_{ij}^m denotes the supplementary parking time of the vehicle V_i^m at the stop S_j^m.

C. Criteria

Through a comparison between the situation before regulation and that after the rescheduling, to conciliate the different aspects of the quality of service, we consider five criteria:

1. Regularity criterion:

The regularity criterion represents the time interval between the departure times of two successive vehicles at the same station. It concerns the waiting Time of the passengers at the different stops. The waiting time of all passengers in S_j^l is formulated as:

$$attente(S_j^l) = \sum_{V_i^l \in V^H} (a_{ij}^l \times \sum_{S_k \succ S_j} attente(ta_{i'j}^{l'} - td_{ij}^l, S_j^l, S_k^l)). \quad (3)$$

The total passengers waiting time at the different stops of the spatial horizon is formulated as

$$WT = \sum_{S_j^l \in S^H} attente\ (S_j^l) \quad (4)$$

2. Transfer criterion:

The transfer criterion is related to the Transfer Time at the different nodes of the network. It is then to calculate the duration of correspondence in the horizon H. This criterion can be formulated as follows:

$$TT = \sum_{V_i^l \in V^H} \sum_{V_{i'}^{l'} \in V^H} \sum_{S_j^l \in S^H} y_{ii'j}^{ll'} \times \omega_{ii'j}^{ll'} \times (td_{i'j}^{l'} - ta_{ij}^{l}) \quad (5)$$

Where $y_{ii'j}^{ll'}$ is equal to 1 if a connection is possible from V_i^l to $V_{i'}^{l'}$ at S_j^l and equal to 0 otherwise, $\omega_{ii'j}^{ll'}$ is the number of persons in transfer.

3. Route time criterion:

It consists in minimizing the total routes duration aboard the various vehicles according to their loads.

$$DT = \sum_{V_i^m \in V^H} \sum_{S_j^m \in S^H} a_{ij}^m \times C_{ij'}^m \times (td_{ij}^m - td_{ij'}^m) \quad (6)$$

where $C_{ij'}^m$ is the number of people who rise and fall of each vehicle at each station.

4. Commercial kilometers:

The commercial kilometers represent distance crossed in kilometers that the transport company has to assure.

$$KM = \sum_{V_i^m \in V^H} \sum_{S_j^m \in S^H} a_{ij}^m \times a_{ij'}^m \times d_i^m (S_j^m, S_{j'}^m) \quad (7)$$

With $d_i^m (S_j^m, S_{j'}^m)$ the distance crossed by a vehicle V_i^m between these two stations.

5. Service quality:

The quality of service can be expressed differently from one operator to another. It can be based on the number of not served stations, the number of vehicles and drivers changes, and the number of transshipments (Not to confuse with correspondences), by minimizing the maximum of three terms:

$$SQ = \max_{V_i^m \in V^H} (n\_change(V_i^m),\ n\_trans(V_i^m),\ n\_stat(V_i^m)) \quad (8)$$

D. Constraints

Several constraints should have to be considered during the real-time regulation of the traffic of a collective urban transport network. Therefore, we take into account the following constraints:

- Each vehicle V_i^m passing by a given point has a unique origin point and goes to a unique immediate destination point:

$$\sum_{S_k^m \in S^H} x_{ijk}^m = a_{ij}^m \quad (9)$$

-The minimal time interval between V_i^m and Vi'm its first successor at the stop S_j^m is stated as follow:

$$ta_{i'j}^m - td_{ij}^m \geq Inter_{\min}^m \quad (10)$$

-The limit on the stop time of V_i^m at the station S_j^m is represented by the following constraint:

$$td_{ij}^m - ta_{ij}^m \geq ts_{ij}^m \quad (11)$$

-The time limits on the connection or transfer durations are presented by the following inequality:

$$Trans_{\min} \leq y_{ii'j}^{ll'} \times (td_{i'j}^{l'} - td_{ij}^{l}) \leq Trans_{\max} \quad (12)$$

- The vehicle load can not exceed the allowed maximum load:

$$C_{ij}^m \leq C\max_i^m \quad (13)$$

Our regulation problem can be formulated as a multi-objective optimization problem; it can be stated as follow:

$$\begin{cases} \min \ \{ \Delta(WT), \Delta(TT), \Delta(RT), \Delta(KM), \Delta(SQ) \} \\ subject\, to: (15), (16), (17), (18)\ and\ (19) \end{cases} \quad (14)$$

With $\Delta(x)$ the variation of the concerned criterion between the theoretical and the regulated states of the network. We present in the following paragraph, a proposed decisions generation and evaluation module.

III. Indentations and Equations Decisions Generation and Evaluation

A. Decisions generation:

1. Regulation in terminus:

It consists in making departures advanced or delayed from a terminus to restore on-line regularity by acting on one or two downstream and upstream vehicles of a disrupted one, according to the importance of the delay of this one.

2. *On-line regulation*

For the decisions generation, we choose the *On-line regulation* class. This decision class is used by the regulators for 90 % of the disturbances cases, it is reliable and easy to implement. It consists in delaying some upstream and downstream vehicles of a disrupted one in order to avoid an excess load on this last one, to help it to not increase its delay and to restore the intervals regularity [3]. However, the calculation of these delays in a way to obtain an optimal solution is very difficult. Then, this problem was shown NP-hard Multi objective Optimization Problem (MOP)[3].

B. A proposed approach for the on-line regulation

During the recent past, multi-objective evolutionary algorithms are subject to an increasing attention among researchers and practitioners mainly because of the fact that can be suitably applied find a set of Pareto-optimal solutions in one single simulation run [19][20][1]. In addition, the trade-off between obtaining this set as a well-converged and well-distributed as possible and obtaining that in a small computational time is an important issue in multi-objective evolutionary optimization [21][22]. However, the solutions depend on the decision maker preferences, and not only the search of solutions but also the decision making is important. To reach these objectives, we developed an aggregative approach based on an evolutionary algorithm [23][24] using the Choquet integral concept.

C. Decisions evaluation: Aggregative approach based on the Choquet integral

The classical weighted arithmetic mean method is the most commonly used operator to aggregate criteria in decision making problems without further considering the interactions among criteria. On the other side, the discrete Choquet integral has proven to be an adequate aggregation operator that extends the weighted arithmetic mean method by taking into consideration the interactions among criteria [24]. The philosophy of the Choquet integral was first introduced in capacity theory and used as a (fuzzy) integral with respect to a fuzzy measure proposed by Murofushi and Sugeno [25].

In the beginning, we define a few concepts necessary for understanding the Choquet integral and essential mathematical tools.

***Definition 1*:** A fuzzy measure μ on N (the set of criteria) is a function $\mu : \mathrm{P}(N) \to [0,1]$, satisfying the two following axioms:

1. $\mu(\emptyset)=0$, (15)

2. $A \subset B \subset N \Rightarrow \mu(A) \leq \mu(B)$ (16)

We will assume here $\mu(N)=1$ as usual, although this is not necessary in general. $\mu(A)$ represents importance or power of the coalition A (group of criteria) for the aggregation problem in question. A fuzzy measure requires $2^n - 2$ coefficients to be defined, verifying the monotonicity conditions.

***Definition 2*:** Let μ be a fuzzy measure on N . The Choquet integral of a function $f : N \to \mathbb{R}^+$ with respect to μ is defined by:

$$C_\mu(f) = \sum_{i=1}^{N} (f(x_{(i)}) - f(x_{(i-1)}))\mu(A_{(i)}), \qquad (17)$$

Where $\cdot_{(i)}$ indicates that the indices have been permuted so that $0 \leq f(x_{(1)}) \leq .... \leq f(x_{(n)})$ and $A_{(i)} = \{x_{(i)}, ..., x_{(n)}\}$, and $f(x_{(0)}) = 0$.

Definition 3: Let μ an application (not necessarily a fuzzy measure) on C, the Möbius transform of μ is the set function defined by:

$$\mathrm{m(A)} = \sum_{\mathrm{B} \subset \mathrm{A}} (-1)^{|\mathrm{A \setminus B}|} \mu(B), \ \forall A \subset N \qquad (18)$$

Where A \ B is the set of elements of A not belonging to B, that is the compliment of B in A.

Definition 4: The fuzzy measure μ is called k-additive if its Möbius transform satisfies the following conditions:

$m(A) = 0,$ (19)

$\forall A$ such as $|A| > k$ and there is at least one subset of cardinality k such that : $m(A) \neq 0.$ (20)

The global importance of a criterion:

For reasons of simplification, let $\mu(c_i) = \mu_i = \mu(\{i\})$ .By definition, $\mu(\{i\})$ reflects the importance of criterion i. The global importance of this criterion c_i is not determined only by the number μ_i but by all measures μ_k of all coalitions K where $c_i \in K$. For example, we can have a criterion c_i such that $\mu_i = 0$ .The criterion c_i seems unimportant, but it is possible for several subsets K includes in C\{c_i}, the number $\mu(K\ \{i\})$ is more important than $\mu(K)$ which proves the importance of this criterion c_i . In this context, we can define the global importance of a criterion by its Shapley index:

$$I_i = \sum_{K \subset N \setminus i} \frac{(n-|K|-1)!|K|!}{n!}(\mu(K \cup \{i\}) - \mu(K)) \qquad (21)$$

Where n is the cardinality of N (set of criteria).

The Shapley index is interpreted as the average of marginal contributions of this criterion in all coalitions where he participates.

Interaction between two criteria:

There are three possible situations when we calculate the interaction between two criteria

- ✓ $\mu(\{i, j\}) > \mu(\{i\}) + \mu(\{j\})$: there is synergy of complementary between the two criteria.
- ✓ $\mu(\{i, j\}) < \mu(\{i\}) + \mu(\{j\})$: there is redundancy or negative synergy between these two criteria.
- ✓ $\mu(\{i, j\}) = \mu(\{i\}) + \mu(\{j\})$:the two criteria are independent.

Then, the interaction between two criteria can be defined by the following equation:

$$I_{ij} = \sum_{K \subset N \setminus \{i,j\}} \frac{(n-|K|-2)!|K|!}{(n-1)!}(\mu(K \cup \{i,j\}) - \mu(K \cup \{i\}) - \mu(K \cup \{j\}) + \mu(K)) \qquad (22)$$

It is possible to express the Choquet integral in case of 2-additive measures by using only the interaction index, as follows. Let $a_1, \ldots\ldots a_n$ be scores on criteria.

$$C_\mu(a) = \sum_{I_{ij} \succ 0} (a_i \wedge a_j) I_{ij} + \sum_{I_{ij} \prec 0} (a_i \vee a_j) |I_{ij}| + \sum_{i=1}^{n} a_i (I_i - \frac{1}{2} \sum_{j \neq i} |I_{ij}|) \qquad (23)$$

where $\wedge$ et $\vee$ represent respectively the minimum and maximum.

It can be seen that the Choquet integral for 2-additive measures can be decomposed in a conjunctive, a disjunctive and a additive part, corresponding respectively to positive interaction indices, negative interaction and the Shapley value. This makes clear the meaning of I_{ij} the framework of the Choquet integral:

- A positive I_{ij} implies a conjunctive behavior between *i* and *j*. This means that the simultaneous satisfaction of criteria i and j is significant for the global score, but a unilateral satisfaction has no effect.
- A negative I_{ij} implies a disjunctive behavior, which means that the satisfaction of either *i* or *j* is sufficient to have a significant effect on the global score.

The Shapley value I_i acts as a weight vector in a weighted arithmetic mean. This represents the linear part of Choquet integral. It will be small if interaction indices are large.

Interaction index and Shapley values determination

To be able to calculate the global score of each decision, We have to determine the Shapley values and interaction index between criteria (coefficients of Choquet integral). For reasons of simplicity, we suppose that the regulator can express, quantitatively or qualitatively, his preferences and it can give the interactions index once for quite independently of the current situation.

Decision-making related to the regulation may be likened to solving an optimization problem whose objective function to maximize the number of passengers served and satisfaction while minimizing the waiting time and travel time under different constraints related to transmission and available resources. To achieve these objectives, we propose a Multi-agent approach based on an evolutionary algorithm using the Choquet integral. This approach will be more detailed later.

V. Multi-Agent System Description

As a result, the complexity of the problem addressed and the distributed nature and dynamics of the system, a newly developed multi-agent technique was introduced to solve multi-objective optimization, and is combined with genetic algorithm to form an evolutional multi-agent system [25]. To resolve the problem described previously, we propose an optimized evolutionary multi-agent system based on the coordination of four kinds of reactive agents: AI, AH, AO and AE. Each agent must work and interact with other agents to achieve a common group goal.

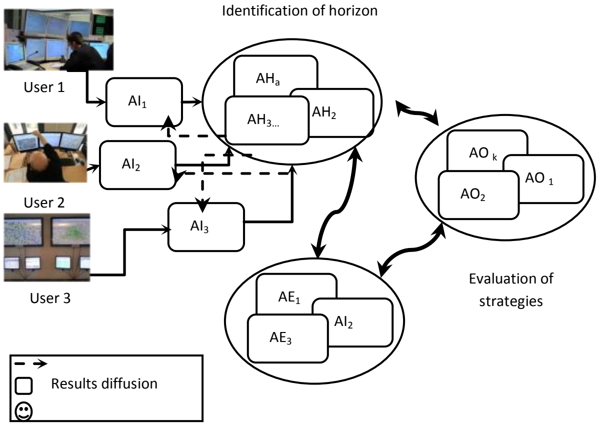
The system allows interacting with the regulator by indicating the area of regulation, the list of operations it can perform and evaluate each action chosen for each criterion separately and taken by an aggregation of criteria by the Choquet integral whose coefficients represent preferences. To simplify, we can consider that the regulator detects the disturbance. But if we put the system in contact with the system operating assistance (SOA) used by the operator, we can improve our system since it can directly detect the presence of disturbances and even alert the regulator.

D. Agents'behaviours

To describe better the behaviour of our system, we use a modeling software called UML (Unified Modeling Language).

1. Interface Agents (AI): these agents interact with the controller who inputs data of the disturbance, so they manage requests and then display results.

Figures and Tables



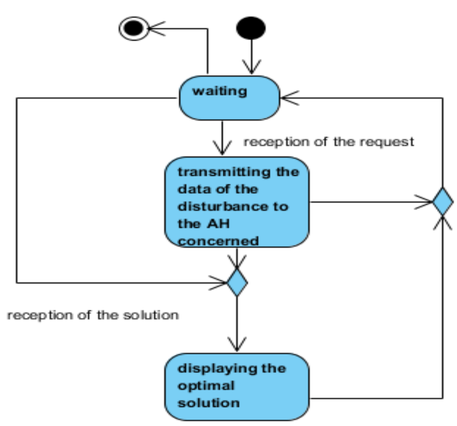


Figure 3. The AI's behaviour

2. Horizon agents (AH): The Horizon agent checks the nature of the disturbance and identifies his horizon using the geometrical method detailed previously.

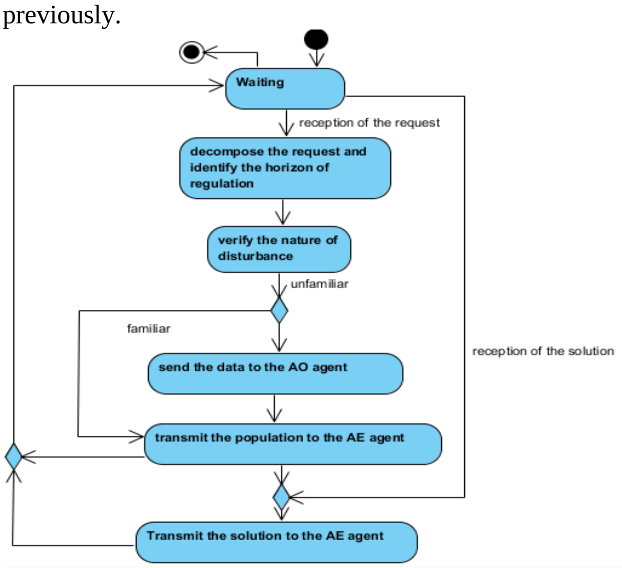


Figure 4. The AH's behaviour

3. Optimizer Agents (AO): To generate optimized solutions, we propose an evolutionary approach. In our approach, the Optimizer agent is loaded by the application of the genetic algorithm.

- ***Evolutionary approach***

The genetic regulation algorithm starts by constructing an initial population of solutions. The genetic regulation algorithm starts by constructing an initial population of solutions. A part of this population is built through a first strategic decision level processed by the multi-agent decision support system which also defines the constraints, other part is constructed randomly.

The decision concerned the variable ε_{ij}^{m} denotes the supplementary parking time of the vehicle V_i^m at the stop S_j^m .

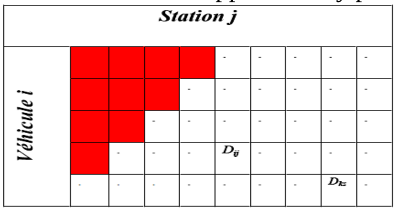


Figure 5. Example of coding

The evaluation of the initial population is effected by the AE agent.The selection procedure is based on the roulette principle [26]. The next generations are built through crossover and mutation operators.

Genetic algorithm Pseudo-code

-Initialize the population $P(0)$

-Calculation of the Choquet integral value for all $P(0)$

For i=1 until maximum number of iterations

-Selection depending on the effectiveness of individuals

-Crossover: Uniform crossing

-Mutation

-Evaluation: Calculation of the Choquet integral value for all individuals of the new population.

End for

Figure 6. Pseudo code of a genetic algorithm

✓ Selection

The selection is the issue of who will survive and reproduce a new generation. It is based on the value of the cost function of each individual. The deterministic selection operators keep only the best individual which is a disadvantage for the diversity of solutions and leads to premature convergence of the algorithm. So we decided to opt for a stochastic selection operator which is the technique of roulette.

In our approach, each individual i with fitness f_i is selected with probability:

$$p_i = \frac{f_i}{\sum_j f_j} \qquad (24)$$

✓ Crossover

For the implementation of our system, we used the uniform crossover of the lines. The masks on this operator are generated in a random manner at each intersection between two individuals.

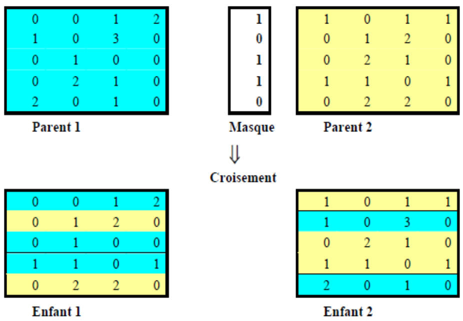


Figure 7. Example of uniform crossover

✓ Mutation

To increase the diversification of solutions, the alleles of individuals mutate with a probability of *pmut*. The behaviour of the optimizer agent is as follows:

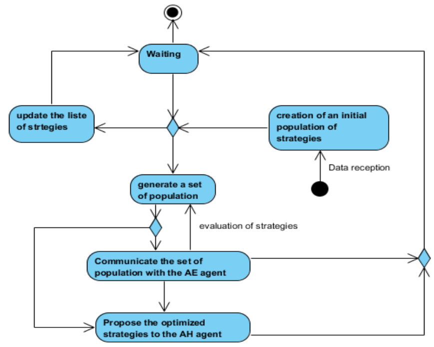


Figure 8. The AO's behaviour

4. Evaluator agents (AE): In other studies that have combined multi-agent systems and genetic algorithms, the procedure of evaluation of solution is integrated into the genetic algorithm [15]. But in our system, the multi-criteria evaluation is done by an independent agent. The AE agent evaluates the strategies by using an aggregative approach based on the Choquet integral. This design allows the regulator to evaluate strategies of regulation without going through the rest of the system.

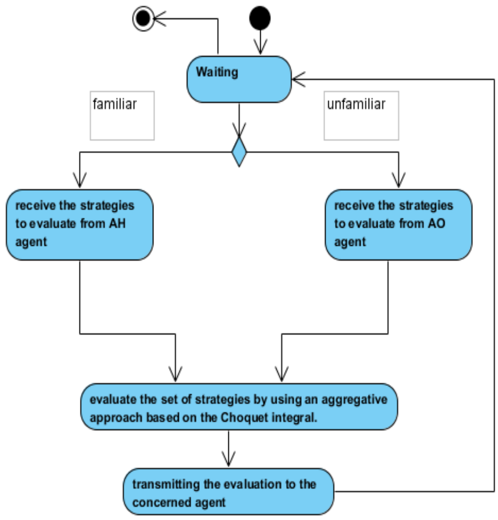


Figure 9. The AE's behaviour

E. The global behaviour of the system

After describing the individual behavior of different agents, we present a summary of the different interactions between entities of the system to better understand the regulatory process.

We illustrate the behaviour of system by a sequence diagram in UML. The sequence diagram expresses the dynamic structure modeling. It shows the communication and interaction between the different agents of the system.

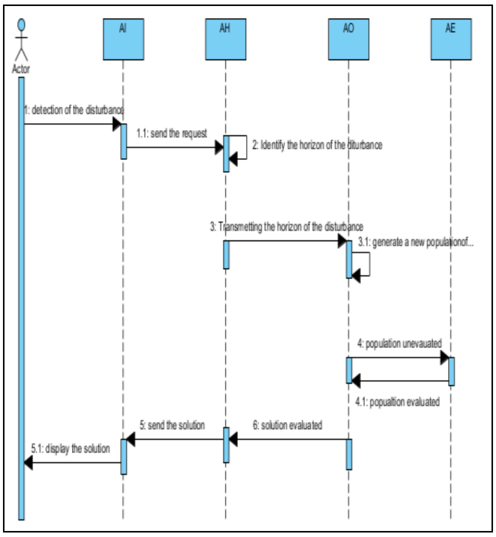


Figure 10. The global behaviour

VI. Simulation Results

Regulation is obtained thanks to communication, collaboration and negotiation between the agents; the programming is developed under the JADE platform (Java Agent Development Framework). This platform has several advantages. These benefits include:

- ✓ The distributed Processing
- ✓ The flexibility of Multi-Agent Systems communicating through effective transfer of messages ACL (Agent Communication Language).
- ✓ Write in JADE is like writing in JAVA

In order to evaluate the efficiency of the suggested approach, we present here a scenario of tow overlapping and simultaneous disturbances. Let's suppose that at 7:35am, a technical problem takes place on a section of the metro line with frequency of 1 metro / 2 minutes. This problem obliges the vehicle number 16, to stop during 4 minutes at the station number 12, and the vehicle number 20 to stop during 6 minutes at station number 8.

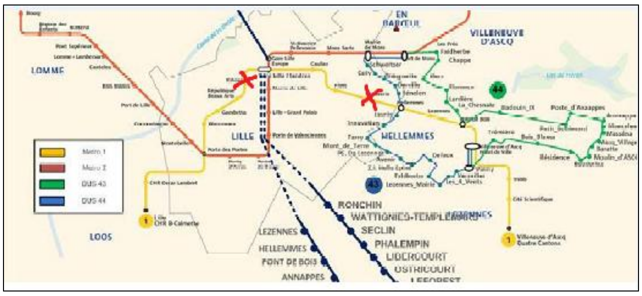


Figure 11. Tow overlapping and simultaneous disturbances.

F. Communication between different agents

The Sniffer agent visualizes the flow of communication between different agents in the system.

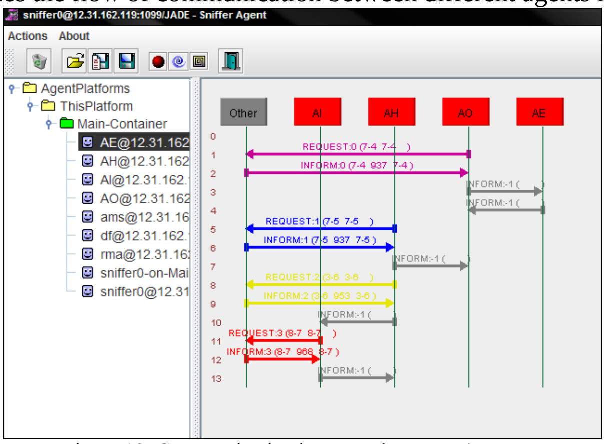


Figure 12. Communication between the system's agents

G. Determination of the regulation horizon

The first step of our regulation process consists of the determination of the regulation spatiotemporal horizon. So, the Horizon Agent uses the method explained in the paragraph II.A. Let us suppose that H1 is the horizon of the first disturbance, and H2 is the horizon of the second disturbance. So the global horizon HGlobal is the union between the two horizons. The following figure shows the solution presented by the Horizon agent.

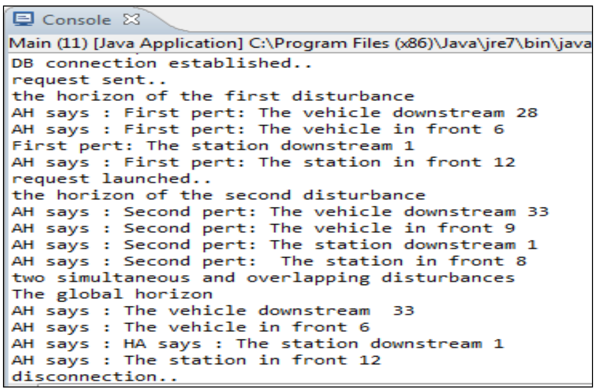


Figure 13. The global Horizon

H. Decisions construction

When the regulation horizon created, the Optimizer agent uses the collected data to build the solutions coding and execute our evolutionary approach explained in the last section. The chromosomes of our problem are coded as follows: for the metro-line, we use an array with 28 lines corresponding to the vehicles included in the disturbance zone and 12 colons for the stations. The chromosome cells illustrate the decisions (delays to be imposed) to undertake for the vehicles of V^H at different stops of S^H. Our approach will try to find the best combination of delays to be applied to two concerned lines. The crossover operates on the lines of chromosome; it acts only on the decision variable ε_{ij}^{lm} in the chromosome cells. Two breakpoints are chosen randomly and the exchange of the genes between the individuals is made only between the same vehicles. The crossover probability is set at 0.8. The mutation operates by random changes on the stops variables. The mutation probability is set at 0.005.

I. Decisions evaluation

After the generation of decisions, the Evaluator agent calls the module of evaluation to determine the best feasible decision by taking into account the importance of every criterion and the interaction between criteria. Let's suppose that the regulation strategy adopted by the regulator was modeled with the following matrix representing the weights of criteria and their interactions (coefficients of Choquet integral).

$$\begin{bmatrix} & WT & TT & RT & KM & SQ \\ WT & 0.1 & 0.15 & 0.2 & 0 & 0 \\ TT & 0.15 & 0.5 & -0.2 & 0 & 0.1 \\ RT & 0.2 & -0.2 & 0.1 & 0.1 & -0.1 \\ KM & 0 & 0 & 0.1 & 0.1 & 0.05 \\ SQ & 0 & 0.1 & -0.1 & 0.05 & 0.2 \end{bmatrix} = I_{ij}$$

Figure 14. Coefficients of Choquet integral

Values on the diagonal of this matrix represent the criteria importance (Shapley values), whereas the others represent the interaction index between criteria [5]. Based on these coefficients, the Evaluator agent will calculate the score of each criterion then the global score of Choquet obtained for every solution. The optimized solution is the solution that corresponds to the highest score of Choquet.

The scores obtained by the optimized solution are shown in the following figure:

```
Console
Main (11) [Java Application] C:\Program Files (x86)\Java\jre7\bin\javaw.exe (14 mars 2013 14:53:42)
AE says : scores obtained for each criterion: WT = 1.000021633783316 , TT = 1 , RT = 0.4 , KM = 1 , QS = 1
AE says : highest global score of Choquet corresponds to chromosome index 2 is 0.880004326756663
```

Figure 15. The Choquet scores

J. The optimized solution

For 10 generations and a population of 20 individuals, the optimized solution for the metro line is given in the following table, where columns represent the stations from 1 to 12 and the lines represent the vehicles from 6 to 33.

The values of the table correspond to the supplementary parking time of vehicles in each station.

The optimized solution

0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	4
0	0	0	0	0	0	0	0	0	3	3	4
0	0	0	0	0	0	0	0	0	4	2	2
0	0	0	0	0	0	0	4	0	4	0	2
0	0	0	0	0	0	2	2	4	0	2	3
0	0	0	1	3	2	4	0	2	4	1	2
0	0	2	0	4	4	1	3	0	0	3	1
0	2	0	4	3	3	2	1	1	0	2	2
0	2	3	4	4	2	1	1	4	0	2	1
0	2	3	0	3	3	4	4	1	4	1	3
0	2	2	4	1	2	1	2	2	0	2	4
0	3	0	2	3	1	1	4	3	2	0	0
0	1	0	1	4	1	3	3	3	0	0	1
0	0	4	3	3	4	4	2	4	1	0	1
0	2	2	1	3	1	4	0	0	3	2	1
0	2	4	0	1	2	2	1	2	0	0	4
0	1	2	2	1	3	0	1	3	4	0	0
0	1	4	4	3	1	2	4	3	3	3	3
0	1	1	3	0	4	2	4	0	3	3	0
0	3	4	0	1	1	2	2	2	0	3	1
0	0	3	0	3	4	1	0	1	2	1	1
0	1	3	0	0	0	1	4	0	4	2	3
0	0	2	3	1	3	3	1	3	3	3	4

Figure 16. Delays to impose on Metro

Finally, The distributed architecture, in conjunction with the Multi-Agent concept, helped to further reduce the initial problem's complexity thanks to the communication and the collaboration between the different agents of the system.

VII. Conclusion and Perspectives

The real-time regulation of an urban collective transport network is a very delicate problem, especially in the case of appearance of simultaneous disturbances (vehicle's breakdown, strike, demonstration.... etc). Our purpose in this paper, is to assist the regulators (decision-makers) and to propose to them effective solutions by taking into account their preferences and uncertainties related to these preferences.

At the end, we will try to introduce personal transportation such as carpooling and car sharing as other regulation modes to provide more flexibility in the transport network...

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