# *The impact of real time information on transport network routing through Intelligent Agent-Based Simulation*

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*Abstract*—**Advance Traveller Information Systems (ATIS) are considered a promising tool to alleviate traffic congestion and improve road network performance. They provide real time traffic information and route recommendation to road users, in order to increase their ability to choose the best alternative path. Though such systems have reached a high technical standard, their actual impact in traffic pattern and network performance is controversial. The methodology used is based on a Multi Agent Simulation to model how the presence of information influences the driver's reactive behavior and the network efficiency. The case study is the well known network of the Braess' paradox and the specific aim is to find the proper route recommendation strategy to avoid that adding a new road to traffic network may result in increasing the total travel time. Through a software platform able to simulate a virtual road network, where single drivers interact with each other and with the spatial environment according to a defined behavior, that is their reaction to external outputs, two behavioral patterns will be simultaneously considered. The first refers to the driver's path choice among those available for a fixed origin-destination pair; the second refers, once the path is chosen, to the microscopic motion of each vehicle as a function of the leader vehicle along each link of the network. To simulate the presence of drivers equipped with ATIS system and drivers who are not, or equivalently to simulate different reactive behavior to the information provided, it has been used a variable "probability of feedback". Pattern arrival vehicle flow can be varied together with speed and acceleration of the vehicles. The general purpose of the paper is to contribute to the analysis of the impact of ITS (Intelligent Transport Systems) technology in traffic pattern and network performance. The specific objective is modelling driver's behavior in road networks when real time traffic information is provided. The results show that a proper rate of provided information is able to reduce the effect of the Braess' paradox and that network performance increases when drivers' behavior is affected by their ability to see local traffic conditions.**

***Keywords: Multi-agent-system; road traffic control; Intelligent Transportation Systems; NetLogo; Braess' paradox; route choice model; cooperative traffic management.***

## I. Introduction and Literature Review

Traffic congestion is one of the most difficult problem to solve in our cities. Therefore a lot of work in network transport research is currently under continuous development. Network User Equilibrium [1] is today a widely used traffic assignment technique. It is based on the assumptions that, given a transport network represented by a set of nodes (road intersections or origin/destination of traffic zones) and a set of links (roads) connecting the nodes, users (drivers) traveling from origin to destination have a perfect knowledge of the costs they will incur in each available path and that they have a rational path choice behavior, trying to minimize the relative cost. On the other hand, in a congested network, each path cost is not constant, but is affected by how many users have chosen it. Then a competitive behavior is set up since, according to the first Wardrop principle [2], a stable configuration (in terms of link average flows) is reached when no user can unilaterally change the chosen path without incurring in higher costs: this state of the network is called User Equilibrium [1].

Of course, in real world, users do not have a stiff rationale behavior and do not have a perfect knowledge of path costs as well. To match the first problem, stochastic path choice models based on random utility theory [3] [4] have been developed and are now a well consolidated technique. To match the second one the development of Intelligent Transport Systems are considered a promising tool to provide real time current or predictive information to road users in order to increase their knowledge of the exact cost of each alternative path they can choose. Besides, dynamic route guidance systems, such as Advance Traveller Information Systems (ATIS), will umbersoon be available for a large number of drivers. Therefore underestimating drivers' response to these systems is critical to the design and operation of effective intelligent transport technologies.

Actually, the impact of ATIS in traffic pattern and network performance is controversial for several reasons:

1. even if all users had a perfect knowledge of the travel cost associated to each available path and User Equilibrium was achieved, this could be very far from an optimum configuration of the whole network in terms of total cost sustained by all users; the Braess' paradox is a well known example of that;
2. even if we find how to distribute traffic on the different paths and over time in order to minimize the total network cost, and provide the appropriate information, what will the driver reactions be to our suggestions?
3. how will the proportion of equipped and not equipped drivers with ATIS impact the network performance?
4. an overreaction can occur if too many drivers respond to the information, transferring congestion from one path to another, causing oscillations of traffic flows among alternatives.

Most of these considerations stress how relevant is to improve the modelling of the drivers' behavior. The scope of the paper is, therefore, to build a dynamic vehicle routing model that incorporates real time information on travel time. We use agent based simulation both to update travel times by a traffic micro-simulation algorithm and to reproduce the reactive behavior of drivers under the influence of travel time information. In the literature it is possible to find several different implementation of this approach.

Bazzan et al. [5] use agent simulation to divert from the classical view of route choice as an individual issue, and opt to study the social aspects of the problem to model decision making drivers within an intelligent transport system. Adler and Blue [6] develop a real-time approach to manage roadway network congestion based on cooperative multi-agent negotiation between agents that represent network managers, information service providers and drivers equipped with route guidance systems. Whale et al. [7] address a basic two-routes scenario with different types of ATIS information and study the impact of it using simulations. The road users are modelled as agents, and different ways of generating current information are tested, finding that the nature of the information very much influences the potential benefits of the ATIS.

Bazzan and Kugl [8], using a cellular automaton model of traffic, show that it is useful to manipulate the route information given to the drivers of a road network to avoid the Braess' paradox. In the following, we will extend the Bazzan-Kugl approach using the potential of the agent-based micro-simulation in order to evaluate how the performance of Braess network is affected by a mixture of local and ATIS information.

## II. AGENT-BASED SIMULATION AND NETLOGO PLATFORM

Agent-based simulation [9] is a computer technique simulating a system whose main components are agents. Agents are entities which, situated in some environment, are capable of autonomous action in order to meet their fixed objectives. Each agent is modelled by variables and algorithms which set his behavior and evolution over time is recorded both for each individual and for the overall system. Agents do not have a stiff behavior, but they are capable of reactive, proactive and social behavior. Reactive means they can perceive and respond to changes in their environment, proactive means they can take the initiative to achieve their goals, and social means they can interact with other agents to satisfy their objectives.

The consequence is that agent simulation has the capability of capturing emerging systems behaviors which cannot be described as a simple aggregation of individual behaviors and that often are very far from intuition and hardly foreseeable by experience and common sense. Ideally, each driver, with his/her knowledge, preferences, socio-economic characteristics and personal targets can be modelled using an agent. Traditional behavioral travel demand models (e.g. discrete choice models) are able to include detailed choice attributes based on socio-economic characteristics of the users and on relative attractiveness of the travel options, but the updating of driver's knowledge and decisions depend on a day-to-day approach. Agent simulation, instead, allows to model a dynamic choice behavior emerging from the mutual interaction of many individuals, which do not act according to a pre-defined set of rules, but as a consequence of the mutual interaction of many individuals, each with his own beliefs, goals and reaction to real time information coming from the environment [10].

In this paper we use agent simulation to evaluate the impact of real time information in a network scenario, taking into account different reaction behaviors. Besides, we will simulate how the mutual interaction of vehicles affects travel time in each link, through a microscopic model of the motion of vehicles rather than using theoretical flow-speed functions, as is done in current literature. There are different integrated development environments to assist agent-based simulation. They allow model development, code scripting and simulation running to be done all in the same graphical interface.

We use NetLogo Software [11], which is a programmable modelling environment designed for simulating complex systems developing over time. It runs on any platform that supports Java and is mainly used to simulate natural and social phenomena. NetLogo consists of two basic components: (1) a two dimensional grid of "patches" (World) that models the environment and (2) a set of agents ("turtles") with their own attributes and a number of procedures they can carry out. All independents "agents" move simultaneously in the "patch" environment and can read and react to the attributes attached to the patches in their

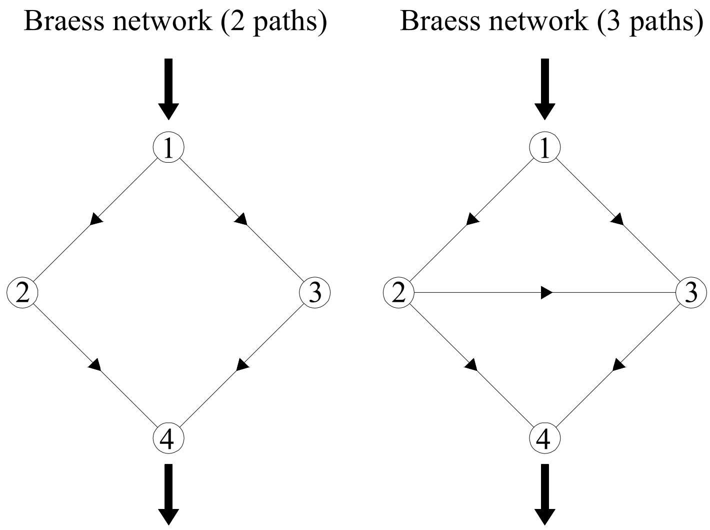


Fig. 1. Braess network topology

vicinity. Then the interaction among agents and among agents and the environment can be modelled.

NetLogo allows the creation of an interface for each model with commands in the form of procedures, activated by buttons on the interface, or entered directly in the command console. It provides many built-in tools to modify simulation parameters at runtime, including sliders, buttons and drop-down menus and allows output in the form of graphs and variable counters. Simulation is measured in discrete arbitrary time units, called "ticks". Speed simulation can be varied anytime by a slider.

NetLogo has already proved to be able to carry on traffic micro-simulation. Of course, like all multi-purpose simulation environment, the creation of a road network with NetLogo is not as easy as with built ad hoc traffic micro-simulation tools. On the other hand, it allows a very easy implementation of complex behavioral models, such as the capability "to see" a larger part of the network and the drivers' reaction to the combination of provided real time information, previous network experiences and personal characteristics.

## III. Case study – Braess' Paradox network simulation with NetLogo

The model was applied to a test road network. Our main aim is to analyse how route recommendations affect the network total travel time, therefore we decided to use the well known network of the Braess' paradox (Fig.1).

In 1968 Braess [13] [14], presented an example of an equilibrium assignment problem where the addition of a new link to the network determines the paradoxical results of an increasing of the total time on the network. Many analysis have shown that under certain flow and network conditions examples of Braess' paradox are likely to occur in sets of road network improvement [15].

Transport planners use Braess' paradox to highlight how transport networks are a complex system and proper improvement measures cannot be addressed by using common sense, but require a lot of mathematical modelling and simulation. Most of the research efforts has been up to now devoted to examine the conditions under which the paradox occurs, focusing on the range of demand, on the link travel time-volume relationship speed-flow or on network topology. But actually, the fundamental nature of the phenomenon is based on the competitive behavior of the users, each attempting to minimize his travel time, even if this may have a negative impact on other drivers.

### *A. Behavioral patterns and NetLogo interface*

As we already said, it is controversial to affirm that the provision of perfect information will automatically lead us to the most effective use of the transport capacity. Besides we are not sure that drivers have a rationale behavior and they all do not react the same to information. This is why agent simulation is a promising approach to deal with these kind of problems.

Two behavioral patterns have been modelled: the first refers to the users' path choice among those available for a fixed origin-destination pair; the second refers, once the path is chosen, to the microscopic motion of each vehicle as a function of the leader vehicle along each link of the network. To simulate the presence of drivers equipped with ATIS system and drivers who are not, or equivalently to simulate different reactive behavior to the information provided, it has been used the variable "probability of feedback". For instance, if the probability is 0.4, it means that 40% of drivers will adapt to follow the provided information, while

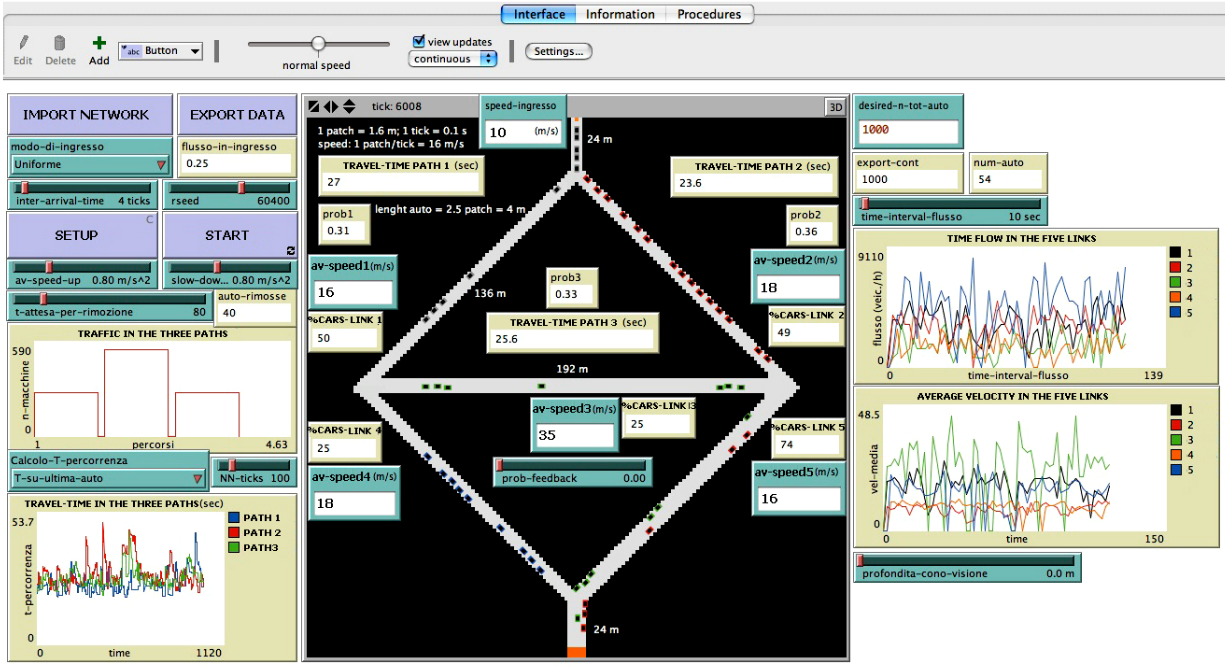


Fig. 2. NetLogo model interface

60% will choose their path randomly. Pattern arrival flow can be varied together with speed and acceleration of the vehicles.

Fig. 2 shows the NetLogo interface we have built to implement our simulation. In the central part of the interface is visible a snapshot of the Braess network, modelled over the NetLogo square grid (World). The size of the grid is 150x150 patches and the size of an agent vehicle is 2.5 patch. Assuming 4 m per vehicle, each patch corresponds to 1.6 m. In this scale, the four symmetric links of the network measure 136 m, while the central horizontal link 192 m.

The acceleration and deceleration rates of each vehicle are fixed by sliders on the left of the World, while the average speed allowed in each link is fixed by the correspondent input box visible near the link. Each time-step of the simulation (tick) is assumed to correspond to 0.1 sec and all the relevant dynamical quantities introduced before have been calibrated using this equivalence, in order to give them a real meaning and also to respect the Braess' paradox prescriptions (simmetry of velocities on the opposite links, and so on). In the left side of the interface are also visible the 'Setup' button, which launches a procedure to reset the model to its initial state, and the 'Start' button, which activates a procedure that carries out all actions for each time step. Several plots and output boxes allow to follow the real-time evolution of the interesting quantities (the travel time in the three paths, the percentage of vehicles passing through each link and their average speed, the flow in the different links, and so on).

### B. *Simulation features*

The simulation architecture is multi-agent with two layers: a tactical level controls the rules of motion of vehicles on the road where agents behave in a reactive way, and a strategic level models path choice where agents behave in a proactive way.

The hypotheses are that demand is rigid, average flow is constant over time, vehicles have the same length and own the same average performance.

Vehicles enter in node 1 (Fig. 1) with an uniform distributed inter-arrival time, then move on each link of the network at a speed normally distributed with mean equal to the average speed of the link and with a 20% standard deviation; if a slower vehicle is found ahead, they slow down their speed until it equals that of the preceding vehicle. Each driver can use different paths to reach node 4 from node 1. Path choice is random but it can also be affected by:

- information provided to drivers by an ATIS system and their attitude to follow external information which is modelled through an assigned "probability of feedback" *p;*
- what drivers "see" through their "radius of vision" in correspondence of each node where different paths can be selected.

If the option "radius of vision" is not activated, in each node where driver must choose among different paths vehicles receive the most updated information on relative travel times and a percentage *p* of drivers follow the suggestion, while the other *(1-p)%* choose randomly. If the option "radius of vision" is activated, drivers look at traffic on the links departing from the node within a fixed distance of vision and choose the less congested link; if both the links are equally congested, a percentage *p* of drivers makes a choice consistent with the information provided by ATIS, while the other *(1-p)%* drivers choose randomly.

The real time information provided by ATIS is based on two different strategies: (i) the best travel time experienced on each path by the last vehicle going out from node 4; (ii) the best travel time experienced by floating cars providing real-time data for each route. This information is updated each time a new vehicle covers its path. Each simulation run is launched using a different random seed and stops when 2000 vehicles go out from node 4. This traffic volume has proved to be optimal between lower values, which lead to results affected by the transitory phase of the simulation, and higher values leading to a highly congested network. The main outputs of the simulation are the evolution on time of the travel time on each path, the number of vehicle in the network, the amount of vehicles on each path, the total vehicles in the network, the link flows, the average link speed and the total average travel time in the network. At the end of each simulation, network performance has been measured by the total average travel time, calculated as the ratio between the sum of all vehicles' travel time and the total vehicles which passed through the network.

## IV. RESULTS

The main results are shown in terms of normalized total average travel time (Fig. 3), measured by running 10 simulations for each different value of feedback's probability varying from 0 to 1 with step 0.1 and for the five scenarios reported (see Tab.1 and Fig. 1). The coefficient of variation for each points (not reported) always less than 2%.

The first found result is that Braess' paradox occurs. In fact the line referred to scenario 1 (two paths' network, four links), is always lower than that of scenario 2 (three paths' network, five links) which has been obtained under the same dynamical conditions (ATIS information on the last vehicle without driver's eye). It is worthwhile to point out that,

TABLE I. FEATURES OF THE SIMULATED SCENARIOS

| Simulated scenarios | Description of scenarios | | | |
|---|---|---|---|---|
| | *Network config.* | *Number of paths* | *Path choice model* | *Ref.* |
| Scenario 1 | 4 nodes 4 links | 2 | Real time information based on last vehicles | Fig.3 |
| Scenario 2 | 4 nodes 5 links | 3 | Real time information based on last vehicles | Fig.3 Fig.4 |
| Scenario 3 | 4 nodes 5 links | 3 | Real time information based on floating cars | Fig.3 |
| Scenario 4 | 4 nodes 5 links | 3 | Real time information on last vehicles and local traffic condition within 50 m from the driver's eye | Fig.3 |
| Scenario 5 | 4 nodes 5 links | 3 | Real time information on last vehicles and local traffic condition within 25 m from the driver's eye | Fig.3 |

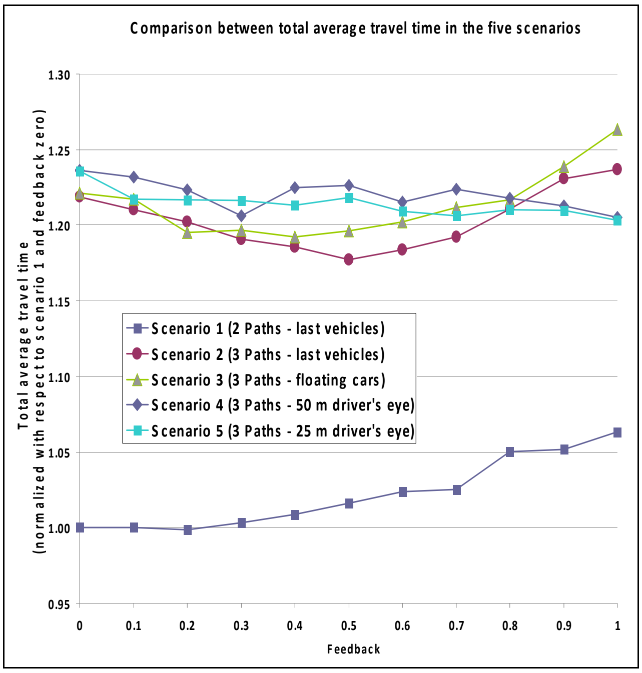


Fig. 3 Total average travel time (see text).

differently from Braess' work where travel times on links are calculated by theoretical cost functions, here they emerge dynamically by the agent-based micro-simulation of the traffic.

Second result is that the provided time information seems to have an impact on both the two and three paths networks, but while in scenario 1 the performance steadily decreases with rising feedback, in the three paths scenarios, an optimum feedback value has been observed. probably due the higher complexity of the network, In fact in scenario 2 the network presents a pronounced minimum of the total average travel time when the probability of feedback is around 0.5, rapidly increasing as far as feedback reaches the values 1.0. The reason is probably that, growing feedback implies that drivers comply more and more to provided information, but, at the same time the quality of information they receive is poorer. This happens because, if everybody follows the path suggested by the ATIS system (feedback 1.0), no further information is available on other paths that meanwhile could have become less congested. This effect is visible in the lower panel of Fig. 4, where long standing plateaux in the travel time can be observed. On the other hand, when the probability of feedback is zero (Fig. 4, upper panel), drivers randomly choose their paths: such a behavior, if frequently generates peaks in the travel time due to jams formation, also allows a more uniform exploration of all the paths. An intermediate level of feedback (Fig. 4, medium panel) seems therefore to realize the proper trade-off between these two situations, then justifying the behavior observed in Fig.3. In the same figure we show a scenario where feedback is due to the presence of floating cars providing real-time data with uniform frequency for each route (scenario 3). But, if on one hand this avoids lack of information due to seldom utilized paths, on the other hand

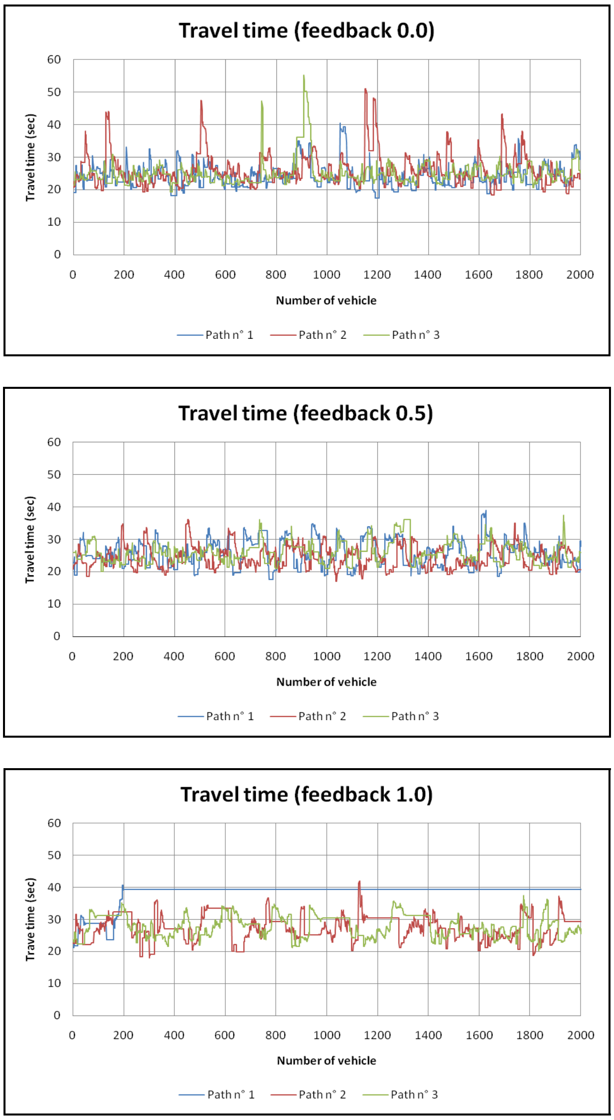


Fig. 4 Evolution of path travel time for three different feedback probabilities ( 0.0, 0.5, 1.0).

the frequency of the information received by the users is lower than in the previous case, so the resulting performance is globally worse. Finally, we explore what happens when path decision making is made combining local traffic perceived conditions with external real time information. This was realized in scenarios 4 and 5, where a different length of the drivers's radius of vision has been adopted, with values of 50m and 25m respectively. Both cases show that the total average travel time progressively reduces as feedback increases, , but with a lower extent than in the other scenarios. Only for high values of feedback (greater than 0.8) the performance of scenarios 4 and 5 is better than in the previous ones because the local mechanism of choice in some way restore the random exploration of all the paths.

## V. CONCLUSIONS

We built an agent based simulation model to measure the impact of giving real-time information on best paths in a road network. A Braess' paradox network has been tested as case study, using different network configuration, level of information through hypothetical advanced traveler information systems (ATIS) and drivers' behavior while choosing their path from origin to destination.

We used NetLogo agent-based modeling environment to implement a route choice model and a feedback probability mechanism in order to analyze how the overall cost of the Braess network varies according to the acceptance by the drivers of the information received. The results can be used to address a behavior space where optimal information strategies can be selected and a contribute to the basis for an intelligent agent approach to the on-line management and control of transportation networks. Future developments will involve the improvemenf of the realism of simulation by adding new psychological features to the agents in order to make them able to perform more complex choice strategies.

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