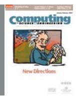
In IEEE Computing in Science and Engineering, **7** (**1**):65-70, Jan-Feb 2005.



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SOCIAL INFLUENCE AND WATER CONSERVATION: AN AGENT-BASED APPROACH

By Ioannis N. Athanasiadis and Pericles A. Mitkas

EVERY DAY, CONSUMERS ARE EXPOSED TO ADVERTISING CAMPAIGNS THAT ATTEMPT TO INFLUENCE THEIR DECISIONS AND AFFECT THEIR BEHAVIOR. YET EVEN WHEN MASS-MEDIA MESSAGES DIRECTLY REACH A LARGE AUDIENCE, THEY AREN'T ALWAYS effective at achieving their goals—in fact, some have the opposite effect. Word-of-mouth communication—the informal channels of daily interactions among friends, relatives, coworkers, neighbors, and acquaintances—plays a much more significant role in how consumer behavior is shaped, fashion is introduced, and product reputation is built.

Macrolevel simulations that include this kind of social parameter are usually limited to generalized, often simplistic assumptions. In an effort to represent the phenomenon in a semantically coherent way and model it more realistically, we developed an *influence-diffusion mechanism* that follows agent-based social simulation primitives. The model is realized as a multiagent software platform, which we call Dawn (*d*istributed *a*gents for *w*ater simulatio*n*). Dawn consists of a community of interacting, autonomous, consumer agents (CAs). In a virtual social network environment, these agents simulate social interactions, and through the influence-diffusion mechanism, they persuade each other and ultimately make decisions.

In generic simulation environments, researchers use the notion of an *agent* to represent physical drivers, system stakeholders, natural entities, public organizations, and several other diverse entities. Agent-based social simulation applies to several different domains (including ecology, social sciences, robotics, environmental assessment, and computer games), either for exploring methods to achieve a common goal or for explaining common behavior.[1] In this respect, agent-based social simulation seems suitable for assembling microlevel experiments that explore the way consuming habits form as a result of ad campaigns.

Among the microlevel models developed for simulating interpersonal communication and opinion dynamics are the Sznajd-Weron models for price formation and opinion evolution.[2] These models simulate social responsiveness to mass-mediasignals and the effects of word-of-mouth communication in competitive environments such as presidential elections, duopoly or oligopoly markets, and new product penetration. The urban water supply-demand cycle reflects an unusual monopoly market of a natural resource whose value includes both an economical and an environmental dimension. Indeed, an individual's water consumption isn't related solely to price—it also has connections to his or her generic behavior related to environmental awareness and social responsibility. Consequently, even if several people share similar opinions about environmental values, they won't behave in the same way or willingly modify their water consumption habits uniformly. For such a peculiar market, our agent-based social simulation model helps explore the effects of a public conservation campaign on residential water demands.

Social Communication Models

The simplest influence model for simulating the public's response to mass-media messages is the *stimulus-response model*, which suggests that mass media can influence people directly and uniformly by stimulating them with the appropriate messages to trigger a desired response. This model, which considers people as passive receivers, was abandoned in the 1960s after Elihu Katz and Paul Lazarsfeld introduced their *two-step flow-of-communication model*.[3] In this new model, mass-media signals don't affect the entire society directly. Instead, they permeate the grid of social connections within a community, stressing individual behavior. Media messages spread in the social network via contagious individuals, known as "opinion leaders," who are supposedly respected by their acquaintances. Given that the latter's behavior is influenced indirectly by the opinion leaders, they're called "opinion followers." This theory views the opinion leader as a middleman between the impersonal mass media (advertiser) and the rest of society (consumers).[4]

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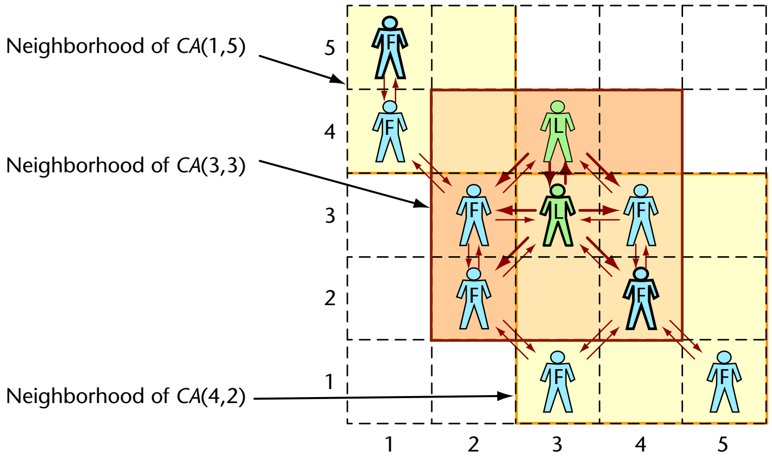

Figure 1. Virtual agent neighborhoods and influencing power. In this social grid, consumer agents (CAs) exchange messages to simulate word-of-mouth communication. Opinion leaders are marked with Ls and thick arrows; opinion followers have Fs and thin arrows.

People have criticized the two-step theory because it implies that all opinion leaders are active recipients and that all followers are passive consumers.[5] Recent research shows that the diffusion of ideas is not a simple two-step process. A *multiple-step model* is now more generally accepted because it combines both direct and indirect means of social influence at multiple levels. Although criticized, the communication-flow models still remain relevant and fundamental to the diffusion of influence throughout a social community; they have led to the development of the *idea-virus model*[6] and the widely used *diffusion-of-innovations model*.[7]

Social Grid and Agent Interaction

A public advertising campaign reaches society as a whole and initiates word-of-mouth communication among individuals, but each consumer is affected in a dissimilar way through the indirect channels of social interactions. We use Dawn to simulate social interaction—and the propagation of social influence—among individuals.

Dawn's virtual environment randomly distributes software agents, representing actual consumers, over a square lattice as a social grid. Neighboring CAs exchange messages to simulate word-of-mouth communication, with each CA implementing two behaviors (roles) in parallel. An agent can act as:

- a *consumer*, a role that involves decision-making about consumption. Consumer behavior is based on the agent's perception of its virtual environment, which further enables the agent to be influenced by its neighbors.
- a *neighbor*, meaning it has the power to influence its social neighbors (as an opinion leader affecting its followers). The neighboring role empowers agents to persuade their acquaintances.

Figure 1 shows an example of Dawn's artificial neighborhood setting. CAs are randomly situated over a 5 × 5, two-dimensional, social grid and form Moore's neighborhoods (defined elsewhere[8]) of a range equal to one. Each CA can have up to eight neighbors—for example, $CA(1,4)$ is the sole neighbor of $CA(1,5)$, whereas $CA(3,3)$ is neighbored by $CA(2,2)$, $CA(2,3)$, $CA(3,4)$, $CA(4,2)$, and $CA(4,3)$. Similarly, each CA_i defines a neighborhood, within which we can use agent messaging to get a complex communication-flow model. Notice that the grid represents social, not geographical, proximity and that the platform could easily be extended to support other types of networks for modeling social connections.[9]

Numerical "social" weights (*sw*) represent people's amount of influence in exchanges among CAs—opinion leaders have large social weights, whereas followers have low ones. In Figure 1, CAs acting as opinion leaders are marked with Ls, and thick arrows represent their influencing power; similarly, opinion followers are marked with Fs, with thin arrows representing their influencing power.

Influence-Diffusion Mechanism

Within Dawn's virtual grid of autonomous agents, influence is diffused among neighboring consumers. In practice, however, each consumer comprehends the signals it receives from its neighbors differently: some are more receptive and willing than others to change their consuming habits. To simulate individuals' different reactions to social influence, CAs are designed to diversify their responses to the signals by using a diffraction function. Because social influence has cumulative effects, each CA sums all the social weights received from its neighbors, thus representing the degree to which it is influenced by them. Analogous to actual consumer behavior, each CA_i determines a social variable $S(i, t)$ at time interval t as

$$S(i,t) = D_i \sum_{j=1}^{N_i} (sw_j), \qquad (1)$$

where sw_j is the social weight the CA_i receives from its jth neighbor, N_i is the number of agents residing in CA_i's neighborhood, and D_i is a diffraction function for adjusting the sum of social weights. Function D_i represents a consumer's ability to comprehend social signals and describes the agents' influence behavior. In this respect, those CAs using a quickly rising diffraction function represent consumers who are more willing to listen and perhaps modify their consuming behavior (called "opinion seekers" by advertisers). On the other hand, socially apathetic consumers are represented by CAs with low slope functions D_i. Consider $CA(1,4)$ and $CA(3,1)$ in Figure 1: they experience the same amount of influence, because two followers reside in each one's neighborhood—specifically, $CA(1,4)$ is neighbored by $CA(1,5)$ and $CA(2,3)$, and $CA(3,1)$ is neighbored by $CA(2,2)$ and $CA(4,2)$—yet they comprehend it differently. Consequently, $CA(1,4)$ and $CA(3,1)$ revise their consuming practices in dissimilar ways, a behavior made possible by the use of nonidentical diffraction functions D_i.

Urban Water-Consumption Models

Urban water is a vitally important natural resource, and water utilities are constantly preoccupied with estimating future water demands. Simulation tools used in this field help model current water-management dynamics and forecast future needs.

The simulator's overall goal is not to forecast the modeled system's exact state but rather to explore how the system will evolve due to specific policies. Conventional approaches use price to help control water demand, but pricing water in urban areas is a complicated task because it must incorporate economic, social, and political constraints as well as water resources' availability. (An in-depth review of the models used for estimating water demand appears elsewhere.[10])

Usually, we can estimate water demand by using a generic econometric model,

$$Q_p = \boldsymbol{f}(P, Z), \tag{2}$$

which relates the average consumer's water consumption Q_p to price measures P and other variables Z, such as income, weather conditions, housing characteristics, household composition, and indoor/outdoor water use. For an urban area, we calculate the total consumption (Q_{tot}) as

$$Q_{tot} = RQ_p, \tag{3}$$

where Q_p is average consumption per capita or per household, and R is the total number of inhabitants or households (respectively). Such models are based on data from water utility accounts or consumer questionnaires.[10]

Consumer Behavior and Water Demand

In addition to individual consumption habits, consumers' awareness of environmental issues in general and water issues in particular have a positive effect on water conservation. Consumer awareness as a result of a public campaign becomes a social parameter in the econometric models as a variable of type Z.[11] Elasticities for variables related to consuming habits or the degree of awareness range between –0.04 and –0.19 in the literature, which is a rather significant magnitude, compared with the elasticities of water price (typically ranging from –0.01 to –0.7).

In trying to interpret these numbers, we could argue that water-conservation campaigns can have a sizeable impact on total consumption, but conventional econometric models don't account for the social behavior of individual consumers; rather, they reflect society as a whole. That said, a public campaign's effectiveness is highly related to individual behaviors. The actual phenomenon involves the propagation of water-conservation signals among individual consumers, who then influence each other through their social relationships. In this respect, the use of an econometric model such as the one in Equation 2 misrepresents the actual factors that drive the formation of a water-aware social consensus.

A Hybrid Agent-Based Approach

To simulate the social behavior of individual consumers, we combined the conventional econometric model with Dawn's agent-based social-simulation model. We changed Equation 2 to a hybrid:

$$Q_p = \boldsymbol{f}(P, Z, S), \tag{4}$$

which introduces the social variable S (as defined in Equation 1). In this respect, we extend the conventional econometric model with an agent-based social model to estimate future water demands and simulate water-conservation signals among consumers. In this extended form, we use Dawn to include consumer behavior primitives and their effects on the propagation of water-conservation signals.

Water Demand in Thessaloniki

We validated the hybrid model by looking at the metropolitan area of Thessaloniki, Greece. Prior studies in the region used a logarithmic function for estimating water demand,[11] which was induced from field questionnaires and the water utility's accounts data. We calculated an individual's water demand for time interval t by using a logarithmic form of Equation 2:

$$\ln Q_p(t) = \sum_i e_i \ln[f_i P(t)] + \sum_j e_j \ln[f_j Z(t)], \tag{5}$$

Table 1. Consumer types.

Consumer type	Population (%)	Power to influence others	Tendency to be influenced by others
A, opinion leaders	10	High	Low
B, socially apathetic	20	None	None
C, opinion seekers	30	Low	High
D, opinion receivers	40	Low	Low

Table 2. Pricing scenarios evaluated for the period 2004 to 2010.

Scenario	Action
A	Water price is adjusted to the real price without implementing any education or information policies; the water tariff increases with the inflation rate.
B	Water price is increased by 5 percent without any education or information policies.
C	Water price is increased by 7.5 percent without any education or information policies.
D	Water price is adjusted to the real price with the implementation of a medium-scale education or information policy.
E	Water price is adjusted to the real price with the implementation of a major-scale education or information policy.

where f_i are functions of the price measures P, f_j are functions of other factors Z affecting water demand, and e_i and e_j are the corresponding elasticities. The empirical model for Thessaloniki[12] involves one social variable: well-informed, or aware, consumers (*wic*), which are included in vector Z, following the conventional econometric approach. According to the empirical model's assumptions, *wic*'s power increases by an average of 6 percent every three years, following the relation

$$wic(t) = 0.06\frac{(t-t_0)}{36}wic(t_0) + wic(t_0), \quad (6)$$

where t is expressed in months. Instead of using this relation for our simulation experiments, we used Dawn's agent society and the hybrid model in Equation 4 to get

$$\ln Q_p(t) = \sum_i e_i \ln[f_i P(t)] + \sum_{j'} e_{j'} \ln[f_{j'} Z'(t)] + \underbrace{e_k \ln[f_k S(t)]}_{wic}, \quad (7)$$

where Z' is the vector Z of Equation 5 excluding variable *wic*, which is calculated using agent-based social simulation and is represented as the third term in Equation 7. To simulate *wic*, we introduce a social variable S that uses Equation 1 and follows the influence diffusion mechanism.

Experiments and Results

To assess the impact of public conservation campaigns on water demands in Thessaloniki, we evaluated five alternative scenarios for the period 2004 to 2010. We used an artificial society of interacting CAs to simulate individual consumers and their water-consumption habits, with 100 CAs simulating the consumer population. We then clustered these CAs into the four consumer groups presented in Table 1 and defined consumer types according to the results of a questionnaire study.[12] Agents of type A (opinion leaders) have a strong power to persuade their neighbors but are less likely to be influenced by others. A CA of this group corresponds to an environmentally aware consumer who supposedly

- has already altered his or her consumption habits and conserves water, thus having a low probability of being further influenced, and
- is willing to actively propagate water-conservation signals in his or her social communications.

In contrast, we use CAs that neither promote nor comprehend water-conservation signals to represent socially apathetic consumers who have negative attitudes about water conservation (type B). However, most of the population is socially sensitive and open to influence (as types C and D). Opinion seekers (type C) represent people who are aware of the need to conserve water but still require some encouragement before changing their habits. Opinion receivers (type D) adopt an "effortless" behavior about water conservation: their attitude is passive, because they need to be heavily influenced by their social contacts before they change their habits.

Having specified the CA types, we used Dawn to evaluate the five elective water-policy scenarios presented in Table 2. We first distributed 100 CAs randomly over a square lattice with side lengths equal to 12. We set the low social weights communicated by type C and D CAs to be equal to

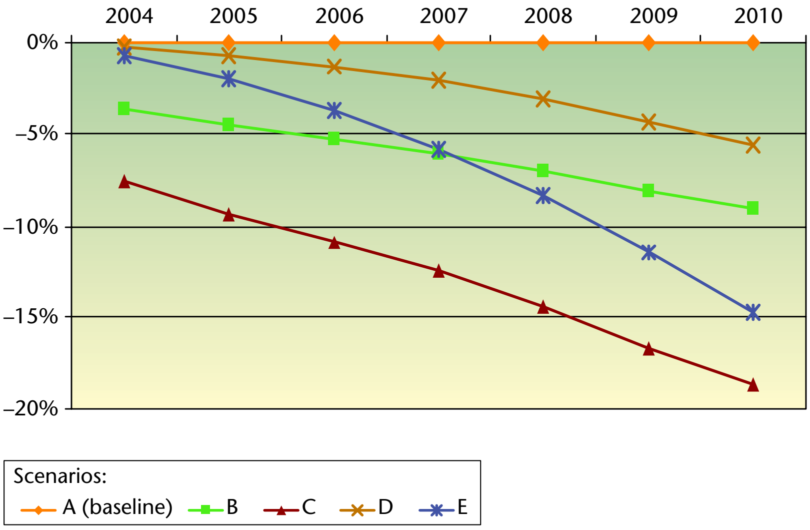

Figure 2. Per capita reduction. By implementing the Dawn model and the scenarios from Table 2, we can trace the reduction in water use from the baseline (scenario A) to a major campaign (scenario E).

$$\frac{0.06}{36} wic(t_0),$$

which is empirically induced in Equation 6. Social weights communicated by type A CAs were twice this value, whereas type B CAs didn't communicate any social weights. Similarly, we selected linear, low slope-diffraction functions for type A and D CAs, whereas the slopes for type C CAs were doubled. For type B CAs, we set the diffraction function to be equal to zero. We obtained the remaining variables and all the elasticities used in our experiments with the hybrid model (Equation 7) from a prior study of the Thessaloniki region.[11]

Our model generated quantitative estimations that illustrate the proportional reduction in per capita water consumption. Scenario A—preserving the real water price—is the baseline scenario. Figure 2 plots the percentage reduction of per capita water consumption for the remaining four scenarios. We use *water price* in scenarios B and C and *public campaigns* in scenarios D and E to control water demands. The implementation of an information and education campaign (scenarios D and E) seems to require more time for people to respond, but the impact is more intense.

The results we get with Dawn, without implementing any education or information policy (meaning the social model was not applied), resemble prior studies that used contemporary econometric models. Dawn's value is that it supports scenarios involving public campaigns. A first reading of the quantitative results points to two conclusions:

- The implementation of a medium-scale education and information policy, in conjunction with adjusting water prices by inflation (scenario D), has similar effects to increasing water price by 5 percent (scenario B).
- The effects of a public campaign proliferate through time, and a major conservation policy could yield water savings of more than 5 percent of total demand in a time frame of six years.

With Dawn, water decision-makers can better understand the quantitative implications of hybrid approaches that combine public awareness campaigns and price adjustments for controlling water demand. Adding to its usefulness, Dawn has been implemented in Java by using software agents.[13]

Our future efforts with Dawn will build on the current framework to extend its competence. Our intention is to further investigate the individual behavior formulation and study the impact of microlevel social parameters (such as social influence) on macrolevel variables (such as the total consumption estimation). We'll also focus on issues related to model complexity, including three-dimensional grids or scale-free networks, for example, as well as more complex consumer behaviors.

Acknowledgments

We express our gratitude to Panagiotis Vartalas for his assistance in developing the Dawn platform with Java, and Yiannis Mylopoulos, Alexandros Mentes, and Dimitra Vagiona for their help demonstrating the Dawn model for Thessaloniki.

References

1. N. Gilbert and K.G. Troitzsch, *Simulation for the Social Scientist*, Open Univ. Press, 1999.
2. K. Sznajd-Weron and J. Sznajd, “Opinion Evolution in a Closed Community,” *Int'l J. Modern Physics C*, vol. 11, no. 6, 2000, pp. 1157–1165.
3. E. Katz and P. Lazarsfeld, *Personal Influence*, Free Press, 1955.
4. L. Schiffman and L.L. Kanuk, *Consumer Behavior*, 8th ed., Prentice Hall, 2004.
5. G. Mersham and C. Skinner, *New Insights into Communication and Public Relations*, Heinemann, 1999.
6. S. Godin, *Unleashing the Ideavirus*, Simon and Schuster, 2002.
7. E.M. Rogers, *Diffusion of Innovations*, 4th ed., Free Press, 1995.
8. E.W. Weisstein, *Moore Neighborhood*, Wolfram, 2004; http://mathworld.wolfram.com/MooreNeighborhood.html.
9. A.-L. Barabási and E. Bonabeau, “Scale-Free Networks,” *Scientific Am.*, May 2003, pp. 50–59.

10. F. Arbues, M.A. Garcia Valinas, and R. Martinez Espineira, “Estimation of Residential Water Demand: A State-of-the-Art Review,” *J. Socio-Economics*, vol. 32, no. 1, 2003, pp. 81–102.
11. Y.A. Mylopoulos, A.K. Mentes, and I. Theodossiou, “Modeling Residential Water Demand Using Household Data: A Cubic Approach,” *Water Int’l*, vol. 29, no. 1, 2004, pp. 105–113.
12. E. Kolokytha, Y. Mylopoulos, and A. Mentes, “Evaluating Demand Management Aspects of Urban Water Policy: A Field Survey in the City of Thessaloniki, Greece,” *Urban Water*, vol. 4, no. 4, 2002, pp. 391–400.
13. I.N. Athanasiadis, P. Vartalas, and P.A. Mitkas, “DAWN: A Platform for Evaluating Water-Pricing Policies Using a Software Agent Society,” *Int’l Environmental Modeling and Software Soc. 2004 Int’l Congress: Complexity and Integrated Resources Management*, C. Pahl et al., eds., Int’l Environmental Modeling and Software Soc., 2004, pp. 643–648.

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