Computers & Operations Research ■ (■■■■) ■■■–■■■

Contents lists available at ScienceDirect

Computers & Operations Research

journal homepage: www.elsevier.com/locate/caor

Bounded confidence opinion dynamics with opinion leaders and environmental noises

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ARTICLE INFO

Keywords:
Bounded confidence
Heterogeneous confidence levels
Opinion leaders
Environmental noises

ABSTRACT

Opinion dynamics is a kind of collective decision-making process and focuses on the study of evolution and formation of opinions within a human society. Particularly, bounded confidence rule is one of intrinsic interaction principles in the opinion dynamics. In this paper, a leader–follower opinion dynamics model is built, with the help of the bounded confidence rule, to consider the opinion formation of a community, which is constituted of opinion leaders and opinion followers. At the same time, environmental uncertainties are considered in the opinion formation and called as environmental noises, which are modeled as Gaussian stochastic processes. All the agents are assumed to have heterogeneous confidence levels. Then the impacts of the opinion leaders and the environmental noises on the final opinions of the opinion followers are analyzed. Finally, some simulation results are presented to demonstrate the collective opinion evolution in three cases: no opinion leader, single opinion leader and multiple opinion leaders.

1. Introduction

As an individual living in the complex and polytropical modern society, people generally have tocommunicate with othersbya variety of ways or obtain information from different mass media, and then, based on the personal knowledge or experience, make an autonomous decision and form an independent opinion on a certain issue. In most normal scenarios, individuals analyze the common issue and try to make a reasonable judgmenton the basis of some criteria formed by their own knowledge and experience or the influence of other individuals and mass media. In the field of Multiple Criteria Decision-Making (MCDM), a decision is generally made, for each individual, by evaluating a set of criteria, which can be conflictive [21–24]. In the field of Opinion Dynamics,a collective decision-making evolves on an interaction network associated with a community, where individuals communicate opinions with some others. In this context, recent years have witnessed that opinion dynamics is becoming an important research issue in social systems and management science [20,28,29,32].

The interest in opinion dynamics is to study the collective opinion formation, such as opinion fragmentation, polarization or consensus, of a population. When opinions are represented by variables or vectors, the challenge is to find an adequate set of mathematical rules to describe the underlying mechanism in opinion evolution. Many models so far have been developed to investigate the mechanisms in the collective opinion formation process. In sociology and economics, various “threshold” or “critical mass” models have been developed to explore the underlying mechanisms of individuals’ attitudes and behaviors in collective decision-making [4,14], which shows that individuals tend to obey a majority rule in the group. Galam et al. built a majority rule model for opinion dynamics [12,13]. Some social influence models were proposed to provide the early disciplinary treatments on the underlying mechanisms of opinion spreading from the sociological and social psychological perspectives, such as French’s social power model [11] and Latane's social impact model [26]. In decision-making science, opinion dynamics is closely related with the inquiries on consensus building, which was initially studied in DeGroot model [7]. Recently, some scientists investigated a bounded confidence situation, where individuals interact or communicate each other only if they have sufficiently close opinions. The Deffuant–Weisbuch (DW) model [10] and the Hegselmann–Krause (HK) model [15] are two representative bounded confidence models. The bounded confidence models can be classified into agent-based and density-based models, if the number of agents is finite or infinite, respectively; orheterogeneous and homogeneous models, if the confidence levels are uniform or agent-dependent, respectively. Furthermore, according to the mathematical description of opinions, all opinion dynamics models can be classified into two big categories: discrete opinion

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http://dx.doi.org/10.1016/j.cor.2015.07.022
0305-0548/

dynamics and continuous opinion dynamics. The bounded confidence models belong to continuous opinion dynamics.

This paper will investigate opinion dynamics in the framework of HK model. Our purpose is to analyze the opinion evolution for a variant of HK model, which includes opinion leaders and suffers from environmental uncertainties. The motivation for the consideration is twofold. First, the research perspective is closer to real social phenomena. A real communication environment is full of uncertainty. For example, [27] considered a risk decision-making problem in a disaster, where the emergency response of each decision-maker was uncertain and the values of potential response results were calculated by using cumulative prospect theory. Second, the opinion leader-following strategy can be easily implemented as soon as leadership is available in a community. A strong evidence has been demonstrated in Fukushima disaster. In March 2011, a panic buying of iodized salt was triggered by some rumors in many regions in China in the Fukushima Daiichi nuclear accident. The natural emergency easily gives illegal sellers the opportunity to spread rumors and undermine the stability of market. Herein, the emergency can be regarded as a kind of environmental uncertainty and illegal sellers plays the role of opinion leaders.

The contribution of the paper is the quantitative investigation of opinion formation systems based on HK model with opinion leaders and environmental uncertainties. A mathematical model is presented for opinion evolution under such a scenario. Then, the impacts of the leader on the opinion evolution is analyzed. An optimal fraction of opinion leaders is studied for the influence power of the leadersthrough computer simulations. Simultaneously, we also investigate the impacts of the environmental uncertainties on the opinion evolution.

The rest of this paper is organized as follows. Section 2 gives some preliminaries on the collective opinion modeling in the paper. A leader–follower opinion formation model with heterogeneous confidence levels is proposed based on a bounded confidence rule in Section 3. Section 4 presents some computer simulation results to study the impacts of opinion leaders and environmental uncertainties on the opinion propagation with the proposed heterogeneous opinion dynamics. Section 5 concludes the paper.

2. Some preliminaries

2.1. Environmental noises

In this paper, environmental uncertainties are modeled by stochastic processes. The concept ‘uncertainty’ has distinct definitions or understanding in different fields. In the Economics field, the famous economist, Knight thought that the uncertainty refers to a lack of knowledge of some basic properties of an object or event, which makes people difficult to analyze quantitatively and predict effectively the evolution of the event with their own knowledge or experience in [19]. Uncertainty is also an important concept in the organization theory and mainly manifested in the interaction relationship between an organization and the environment it is situated [8,41]. Uncertainty is a significant characteristic of an organization and its external environment. Milliken defined an uncertainty in [30] as follows: an individual cannot predict the external environment around his organization since he has no enough information or ability to distinguish the related or unrelated data. Priem et al. paid much attention to the dynamics of environmental uncertainties in [31] and defined the environmental uncertainty as an unpredictable variation, which includes two other concepts, risk and fuzzification, in decision-making science.

The environmental uncertainties have complex influence on the collective decision-making. In the middle of 20th century, Simon pointed out in his bounded rationality theory that when a decision-maker lies in an uncertain environment and thus, he cannot find all alternatives to maximize his own benefits [33,34]. When environmental uncertainties exist or emergency happens, individuals are hard to make rational decisions. In recent years, collective behaviors in the uncertain environment have been investigated extensively from different viewpoints. For instance, a number of sports disasters were examined in [10], which concluded that massive injuries and deaths were caused due to panics without complete information in the emergency environment. Helbing built a confirmed crowding dynamics with a series of computer simulations when a fire occurs in a building that people show a tendency towards mass behavior and alternative exits are often overlooked or not efficiently used in escape situations [16]. A study was given in [1] to investigate a large scale collective behavior on the WWW when internet users faced an information burst. A research was contributed to the collective reactions in some extreme events (e.g., September 11, Fukushima nuclear accident) with the help of risk assessment and risk management in [35]. In fact, many examples of the collective opinion formation under various emergencies, such as the panic buying of salt and bank run mentioned above, can be found in real world. However, few results so far have been obtained for opinion formation under uncertain environment. In this paper, Gaussian stochastic process or Gaussian noises are used to model the environmental uncertainties and an opinion propagation model with environmental noises will be developed.

2.2. Opinion leaders

There are many studies on leadership in various fields and the definition of a leader is also distinct in different fields. However, a common characteristic of a leader is having special influence on other individuals. In the field of opinion dynamics, an opinion leader is referred to an individual having prominent influence on the decision-making of other individuals in the opinion communication process [37]. Krause et al. defined leadership as the initiation of new directions by one or more individuals, which are followed easily by other group members [25]. Using a simple agent-based model, Couzin et al. demonstrated that leadership is effective in animal groups on the move or forage and the final behavior of group will reach consensus, even if there are only a few informed individuals, who do not know whether they are in a majority or minority, how the quality of their information compares with that of others, or even whether there are any other informed individuals [5]. In addition, a series of computer simulations showed that the larger the group is the smaller the proportion of informed individuals needed to reach consensus is. Dyer et al. held a viewpoint that leadership may either be inherent or emerge spontaneously due to individuals' possessing qualities or experience in certain situations, or because they are of a personality type that is generally more inclined to lead [9].

Some opinion dynamics models have been built and various experiments have been employed to analyze the function of opinion leaders in the evolution of the collective opinion. Lazarsfeld and Katz et al. had a profound contribution on the theory of public opinion formation. They built an important model, called “two-step flow”, which involves information influence “flows” from the media through opinion leaders to their respective followers, based on analysis on various decision-making scenarios [17,18]. In a two-step flow model, compared with the rest of the population, opinion leaders were found to be considerably more exposed to the radio, the newspapers and magazines, that is, to the formal media of communication. For a long time after the introduction of the

Please cite this article as: Zhao Y, et al. Bounded confidence opinion dynamics with opinion leaders and environmental noises. Computers and Operations Research (2015), http://dx.doi.org/10.1016/j.cor.2015.07.022