Modeling, simulation, and case analysis of COVID-19 over network public opinion formation with individual internal factors and external information characteristics

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Abstract
With the development of information technology, the Internet has become an important channel of public opinion for expressing public interests, emotion, and ideas. Public emergency usually spreads via network. Due to the temporal and spatial flexibility and the information amplification of network, the opinions from different regions and background are easy to be represented as network public opinion, and have important impact on social and economic life. Thus, studying the formation mechanism of network public opinion has important theoretical and practical significance. Taking the formation process of network public opinion under emergencies as the research object, this paper first identifies the key factors influencing the formation of network public opinion, namely the internal characteristics (include individual education level, individual stubbornness, individual initial opinion, and so on) and external information of individuals (include external information intensity). Second, information intensity is introduced to describe the influence of external information feature on the formation of network public opinion. Individual education level, individual stubbornness, and individual initial opinion are analyzed to describe the influence of individual internal factors on the formation, and then its model is constructed. Through the simulation experiments, this paper analyzes the influence of external information intensity, individual education level, individual stubbornness, individual initial opinion, and other factors on the formation of network public opinion. The simulation results show that: (1) the greater intensity of public emergency reporting causes the easier formation of network public opinion; (2) the higher individual education level leads to the shorter time for completing the final formation and stable state of online public opinions, and after the formation of online public opinions, the opinion of the event is mainly neutral; (3) the greater individual's stubbornness makes the shorter formation time of online public opinion. When online public opinion reaches a stable state, the neutral opinion group dominates and firmly controls the development trend of public opinion; (4) the difference of opinions among individuals is the most important factor affecting the formation of network public opinion. Finally, the rationality and validity of the proposed model are verified by a real case. Compared with previous studies on the formation mechanism of network public opinion, this paper divides the formation process of network public opinion into three stages: individual information perception, individual decision...
making, and individual opinion transmission. Meanwhile, the influence of individual internal factors and external information characteristics on the formation process of network public opinion is also considered.

**KEYWORDS**
external information features, individual internal factor, network public opinion formation, public emergencies

### 1 | INTRODUCTION

With the continuous popularization of the Internet, it has become an indispensable part of people's daily life. More and more people take part in the online world and actively use various platforms to express opinions, exchange views and find information they are interested in. Compared to the offline communication, Internet is an easier platform to express people's views because of its freedom and convenience. When an incident is reported on the Internet, the information will spread immediately and spread to all over the country, triggering the national public opinion field, becoming the hot public topic, forming network "opinion free market", and contributing to the formation of public opinion. In public emergencies, it is helpful to strengthen the guidance of public opinions by studying the formation process of online public opinions, finding the source of their outbreak, discovering the rules of formation, and driving the force of development and evolution, so as to provide scientific basis for the emergency decision-making of relevant government departments.

At present, the research on the formation mechanism of network public opinion mainly focuses on two aspects: first, from the macro-level, the formation process of network public opinion is divided into stages, and the influencing factors of network public opinion formation in each stage are studied. Typical literature is as follows: By studying the formation and influencing factors of the network public opinion of unexpected events, Yu established the differential equation model of its evolution, identified the three characteristics timing points of the diffusion process and the four phases of public opinion development, and explored the corresponding measures in government's responses. The outcomes provided an effective reference for governmental decision-making in emergency management of the network public opinion. Lan and Deng analyzed the diffused characteristic of public opinion derived for network emergencies. Based on the Lotka-Volterra model of public opinion for network emergencies, they carried out research on public opinion derived character for network, built derived public opinion monitoring and early warning model through describing the extent of public opinion derived and making the definition of derivative rate. The feasibility of the theoretical analysis was verified by an example, and it could provide reference for the government to realize network management of public opinion. Second, from the micro-level, scholars study the generation conditions and development trend of network public opinion based on viewpoint dynamics model. Many researchers use Sznajd model and French-DeGroot model for their analysis. Sznajd model believes that people have only two kinds of opinions, namely support and opposition. However, in real network, the opinion has various evolution mode, which is not equipped with fixed structure as general community network structure, so the typical Sznajd model is not suitable for the evolution of research on individual's view over network. However, the French-Degroot model assumes that the weights of edges in the network are fixed values that do not change with time, which cannot truly reflect the closeness and time-varying characteristics of the connections between nodes. Zaller first proposed RAS (Receipt-Accept-Sample model) in 1992, and Kułakowski expressed opinion of Zaller formation theory again, further optimizing RAS model through studying the formation of network public opinion based on individual dynamic change of viewpoint and development trend. Compared to other individual dynamic change model, the model proposed by Kułakowski is more in line with actual condition. At present, macro-level researches rarely consider the evolution process of individual opinions in the formation process of network public opinion, while micro-level researches lack the analysis of influencing factors for the formation of network public opinion. In other words, the viewpoint dynamics model is rarely incorporated into the formation process of network public opinion, and the factors affecting its formation are rarely involved. Based on this, this article introduced the individual internal factors and external characteristic information to study the influence of network public opinion, and then based on the opinion dynamics RAS model to describe the inner mechanism of the individual opinion interaction and Lotka-Volterra model for the analysis of individual viewpoint, thus constructing a network public opinion formation model.

In previous literature, researches on the formation mechanism of network public opinion include qualitative analysis combined with psychology, and quantitative research through modeling and simulation. However, qualitative methods are subjective to some extent based on personal experience. The quantitative method mostly uses external factors to analyze the influence on the formation of public opinion, but lacks the mechanism to consider the formation of network public opinion from the perspective of individual internal characteristics. Also, the analysis of the formation process of network public opinion includes life cycle theory, system dynamics, evolutionary game theory, and so on. In the process of exploring the formation of network public opinion, this paper subdivides it into three stages: individual information perception, individual decision making, and individual opinion communication. Also, the impacts of the perspective of individual internal factors and external information on the formation mechanism of network public opinion are studied. The formation process of network public opinion not only considers the game competition
relationship between individuals but also considers the formation cycle of network public opinion formation. More importantly, it is analyzed by combining qualitative and quantitative methods.

The structure of this paper is as follows: Section 2 is literature review; Section 3 divides the formation process of network public opinion into three stages: individual information perception, individual decision making, and individual opinion communication. Also, the factors affecting each stage are quantitatively described, so as to build a network public opinion formation model. Section 4 discusses the influence of some key factors on the formation of public opinion through simulation experiment; Section 5 verifies the model proposed in this paper with practical cases. Section 6 is the summary of the whole paper and the prospect of the future work.

2 LITERATURE REVIEW

At present, there are three different streams of research on the formation of network public opinion, which explained the formation of public opinions from different perspectives. First, the structural stream, mainly represented by Howard Childs, is focused on the research on the factors affecting the formation of public opinions. Second, the law stream, represented by Hudler Kaname, studies the law of public opinion formation. Third, the procedure stream, mainly represented by Clyde King, Davidson W. P., and Jackson Ball, studies the specific procedures and steps of public opinion formation.

Many scholars in the structural stream have conducted in-depth studies on the factors of the formation of public opinion, and the representative results are as follows: Fatas-Villafranca et al. sought to shed new light on the social process of public opinion formation. The assumption of nonreactiveness on the part of agents gave core values, enduring general needs, social interaction, and the combination of the citizens intuition and occasional deliberate reasoning a key role in the dynamics of public opinion formation. Drake believed controversial issues might be hard for some individuals because they feared they might become isolated. In addition, Spiral of silence, a communication theory set forth by Elisabeth Noelle-Neumann could be used to explain why some individuals would publicly express their opinion of the Iraq War while others would not. This study investigated public opinion expression through interactive forms of media such as discussion forums, blogs, and Websites. Wang et al. took the identification of multidimensional influential factors of social media information dissemination as the research object and comprehensively sort out the influencing factors of public opinion. To improve the scientific basis and accuracy of the research, multidimensional factors, including information characteristics, dissemination network structure, and user-level attributes, were selected to analyze the effect of influential factors in different dimensions on the dissemination of social media public opinion information using econometric models.

Scholars in the law stream studied the formation model of public opinion. Typical literatures are as follows: Yin et al. proposed an agent-based online opinion formation model based on attitude change theory, group behavior theory, and evolutionary game theory in the perspective of sociology and psychology. In this model, there were three factors influencing the persuasion process, including credibility of the leaders, characteristic of the recipient, and situation. Galam reviewed a sociophysics two-state model for opinion forming that has proven heuristic power. The dynamics were driven by repeated small-group discussions; within each group, a local majority rule was applied to update the opinions of agents. Iterating the dynamics leads toward one of two opposite attractors at which every agent shares the same opinion. While odd-sized groups yield a threshold at 50%, even-sized groups, which allow the inclusion of doubt in the case of an opinion tie, produce a threshold shift toward either one of the two attractors, giving rise to minority opinion spreading. Hong and Liu studied the characteristics of public sentiment on mobile Internet represented by mobile phones varied in each period of the whole life cycle. The supervision department was supposed to pay close attention to dynamic participation of public sentiment from mobile terminations like mobile phone in order to grasp the law of public sentiment development.

In order to explore the main body of the online public opinion formation stage, Dong combined the system dynamics and the evolution of the dynamic equations effectively, and established the evolutionary game model based on System Dynamics through the simulation system, identified the impact of public opinion formation stage of the game results of key variables. Gao and Xie combined Elisabeth Noelle-Neumann’s spiral of silence and Mary Douglas’ cultural theory with the help of game theory, proposed a framework that can explain under which circumstances people voice deviant opinions. It suggested that this decision was based on the individual’s perception of the social group within which the opinion is voiced.

In order to study how the individual opinion conversion coefficient and how the structure of the social net affects the public opinion formation and evolution, Ruan et al. constructed a nonlinear differential equation model. The local stability of the model was analyzed theoretically by linearization in the light of its trait. Chen et al. analyzed the process of information diffusion. On the basis of Susceptible Infected Recovered Model (SIR) model, the change of public opinion in the formation of public opinion polarization was studied.

At present, most of the studies on the formation of public opinion belong to the procedure stream, and the representative literature is as follows: Chen et al. combined external information and individual characteristics to study the impact on public opinion reversal. Xu described network of public opinion formation from four aspects: formation of network issues, formation of the public opinion field, formation on the axis, and formation of three-dimensional communication. Based on the life cycle theory, Liu and Tian analyzed the formation path of network public opinion, and discussed its formation mechanism. After that, they analyzed the evolution mechanisms of network public opinion, including the evolution direction mechanism of topics and mutation mechanism of network public opinion. Xiang and Xu conducted in-depth analysis on the evolution factors, life cycle and propagation effects of network public opinion of mass events, which was an important premise for the effective guidance of network public
opinion and efficient response to mass events. Public events, Internet users and mass media were the basic evolution elements of public opinion of mass events. The life cycle of network public opinion of mass events includes formation period, diffusion period, fluctuation period and dissipation period, and each stage has its own unique communication logic. Combined with the gray statistic method and Analytic Hierarchy Process (AHP) analysis method, Liang and Ju made researches on each stage of network public opinion evolution period with the risk index system, and made analysis and calculation on each risk index weight coefficient.

From the above three types of literature, for the study of formation of network public opinion although there are from the public opinion formation model and system dynamics, the dynamic equation of evolution is analyzed, individual internal factors and external information to influence public opinion are rarely considered. Especially, the information intensities of these factors and individual education level have important effect on network public opinion formation. In addition, in the process of exploring the formation of network public opinion, few researches subdivide it into individual information perception, individual decision making, individual opinion communication and other stages, and discuss the influence of individual internal factors and external information on different stages. Based on this, this paper divides the formation process of network public opinion into the above three stages, considers the influence of individual internal factors and external information characteristics, constructs a network public opinion formation model, and then explores the action mechanism of different factors in the formation process through experimental simulation.

3 | MODEL CONSTRUCTION

This paper introduces individual internal factors and external information characteristics, and studies the formation process of network public opinion based on RAS model and Lotka-Volterra model of population competition. Generally speaking, public emergencies are spread through various media, and individuals will form their own opinions with regard to the events. When an individual perceives others’ opinions on an event, people first choose whether to accept others’ opinions or not. After the above decisions are made, their viewpoints are further interacted with the viewpoints of others, thus forming the diffusion of information. With the passage of time, various opinions clash violently and dominant opinions emerge gradually. Due to the spiral effect of silence, dominant opinions inhibit the development of other opinions and firmly control the direction of public opinion, while opinions become more and more sharp. Finally, online public opinions are formed, and the specific formation process is shown in Figure 1. Based on this, this paper divides the formation process of public opinion into three stages: individual information perception, individual decision making, and individual opinion communication. The main variables and parameters involved are shown in Tables 1 and 2.

In order to quantitatively describe the network public opinion formation process, there will be individual views with attitude value in the interval, and different individual viewpoint is divided into three categories, namely positive, negative, and neutral viewpoint. Regarding individuals with the attitude value of \( [1,0.3) \) as negative, attitude value of \( (0.3,1] \) as positive, the attitude value of \( [0.3,0.3] \) as neutral.

3.1 | Information perception stage

Campbell and Key pointed out that a major influence of education on viewpoints lies in the fact that education carries various influences of a person throughout life. With the continuous expansion of educational experience, a person is more likely to be exposed to the discussion of issues during his growth, and these educational conditions will have a certain influence on the direction of public opinion, meaning the education level of an individual has an important influence on the initial formation of individual views. The RAS model discusses the dynamic change process and development trend of an individual’s own views under the influence of external information, and describes the evolution process of views as: an individual may perceive or miss an external view, and may adopt or ignore the perceived views. By referring to the probability formula of information being perceived by individuals in the evolution rules of RAS model and integrating with individual education level to study their perception degree of other people’s information, the probability formula of individual information perception is expressed as follows:

\[
P_r (W_i; \text{Inf}, a_i) = 1 - \frac{1}{1 + e^{(\text{Inf} - a_i) W_i}}
\]
TABLE 1  Related variables of the model

| Variable | Description |
|----------|-------------|
| $P_r$   | Perceived probability of individual information |
| $P_a$   | The probability that an individual adopts others’ views |
| $P_{att}$ | Probability of individual attitude change |
| $W_a$   | Individual education level |
| $k_1$   | The correlation coefficient between individual perceptions of minimum perceived ability and educational level |
| $\text{Inf}$ | Information intensity of an event |
| $RI$    | The intensity of relationship between individual education level and $P_r$ |
| $X$     | Credibility of perceived information |
| $Y$     | Influence of individual education level on $P_a$ |
| $z$     | Individual stubbornness |
| $L_a$   | The existing tendency of an individual’s initial opinion |
| $X_i(t)$ | The number of individuals holding the $i$th opinion at time $t$ |
| $K_i$   | The upper limit of the number of individuals holding the $i$th opinion |
| $r_i$   | The rate of increase in the number of individuals holding the $i$th opinion |
| $X_{i0}$ | Initial value for the number of individuals holding the $i$th opinion |

TABLE 2  Related parameters of the model

| Parameter | Description |
|-----------|-------------|
| $i/j$     | An individual holding an $i$ or $j$ opinion (Individuals with positive, negative, and neutral views are represented by 1,2,3, respectively) $i,j = 1,2,3, i \neq j$ |
| $t$       | Time |
| $W_i$     | Values of individual attitudes that hold the $i$th opinion |
| $W_j$     | Values of individual attitudes that hold the $j$th opinion |
| $W_{ij}$  | The absolute value of the difference of individual attitude between the $i$th opinion and the $j$th opinion |
| $\alpha$  | The coefficient of competition between individuals with positive and negative views |
| $\beta$   | The coefficient of competition between individuals with negative and neutral views |
| $\gamma$  | The coefficient of competition between individuals with positive and neutral views |

where $\text{Inf}$ represents the information intensity of an event, that is, the intensity of media reports after the event occurs. $l$ represents the understanding degree of the individual to the perceived information. $l$ represents the minimum perceived ability of an individual. $W_c$ represents the view coefficient of an individual, indicating the individual’s understanding of the information related content. According to individual information perception stage, individual education level will have an effect on whether to read others’ views, and the different levels of education will form the subjective viewpoint, which can form a minimum perception of each individual $l$, meaning minimum awareness $l$ and education level $W_a$ are linearly related: $l = k_1 \times W_a$, including $k_1$ as correlation coefficient in the range of $(0,1)$. The probability of individual information perception can be represented by the formula (2).

$$P_r = 1 - \frac{1}{1 + k_1 \times W_a + e^{\text{Inf} + RI \times W_c}}$$  (2)

where different education levels are divided into different categories from 1 to 10 levels. The higher level indicates the higher individual’s education level, the stronger individual’s ability to receive the opinions of others, and the higher probability that the individual perceives the opinions of others. The $RI$ represents intensity of relationship between individual education level and $P_r$, which is set in the range of $(0, +\infty)$. $\text{Inf}$ is the information intensity of an event, similar to the intercept of standard regression, and is defined in the range of $(0,1)$.

3.2  Decision-making stage

In the RAS model, individuals may adopt or ignore others’ views, that is, there are different selection strategies. Assume that a new information has been perceived by an individual, according to Equation (1), the probability of an individual adopting the idea of this information decreases with the
increase of \( W_c \). The probability that an individual adopts others’ views is \( P_x \), which is represented by formula (3).\(^7\) The probability of individuals’ attitude change when they perceive a piece of information and change their own views is expressed by Formula (4).\(^7\)

\[
P_x(W_x, P_x; b_0, b_1, b_2) = \frac{1}{1 + e^{b_2 - b_1 \times W_x - b_2 \times P_x}} \tag{3}
\]

\[
P_{ab} = P_x(W_x; a_0; a_1) \times P_x(W_x, P_x; b_0, b_1, b_2) \tag{4}
\]

where the parameter \( b_0 \) describes the difficulty or reliability of information, \( b_1 \) indicates the influence coefficient between inherent thought and the probability that individuals adopt others’ views. \( b_2 \) indicates the influence coefficient between individual’s perception and the probability that individuals adopt others’ views. \( P_x \) indicates the tendency of individuals to adopt information, which depends on the degree of information awareness.

It can be seen from the RAS model that whether an individual adopts others’ views and changes his/her own views is in the individual decision-making stage, which is divided into two sub-stages. The first is whether an individual chooses to adopt the views, and the second is whether an individual changes his/her own views after adopting the others’ views.

### 3.2.1 The sub-stage in which an individual adopts others’ views

When an individual perceives the information of others, the existing tendency of the individual, namely the degree of individual stubbornness, will have an influence on the choice of his strategy. According to the theory of “Spontaneous Symmetric Deviation”\(^29\) once a persuasive opinion can be understood and quickly adopted by an individual, the individual’s opinion will skew, and within a certain period of time, conform to the same opinion as his original one. Therefore, it can be seen that the attitude difference between individuals will affect the decision-making process of individuals, and the attitude difference between individuals exists in three situations as shown in Table 3. Setting \( W_i \) and \( W_j \) \( (i, j = 1, 2, 3, i \neq j, i \) and \( j \) respectively) to represent the three groups of people with positive, negative and neutral views) as individual attitude values from the two groups of views. When the information of other party is perceived, the probability of individuals adopting the opinions of the other party is related to the attitude difference between them, that is, the greater attitude difference between two different types of individuals represents the smaller probability of the other party’s opinions being adopted.

According to Table 3, attitude difference values in different situations have different decisions. By integrating individual attitude difference and individual stubbornness into the probability formula of their viewpoint adoption, Formula (3) is further rewritten into Formula (5) shown as follows:

\[
P_x = \frac{e^x}{e^x + e^{-x \times W_x \times W_x - b_1 \times W_x \times P_x \times W_x}} \tag{5}
\]

where \( x \) represents the credibility of the information after the individual perceives the information of others, whose range is within interval \((0,1)\). The more credible an individual perceives the information of others, the more likely it is to be accepted. \( \gamma \) represents the negative effect of individual education level on the probability of individual opinion adoption. \( L_x \) represents the existing tendency of an individual’s initial opinion, and its positive and negative values depend on whether the individual’s initial opinion and the perceived opinion of others are of the same type. In other words, if the initial attitude value is both positive, it is of the same type. If it is the same attitude value, the value of \( L_x \) is positive, whereas the value of \( L_x \) is negative. Referring to the value obtained by Torgerson\(^30\) through questionnaire and test theory, the value range of \( L_x \) is set at \([-5,5]\). The parameter \( z \) represents the degree of individual stubbornness and is within the range of \((0,1)\).

Since the individual views are divided into three classes, attitude difference also has three conditions after individuals with different viewpoints perceive others view. From formula (5), there are several conditions whether individuals with different viewpoints to accept others views, as shown in Table 4.

### TABLE 3 Types of different attitudes

| \( i \) (An individual holding the \( i \)th opinion) | \( j \) (An individual holding the \( j \)th opinion) | \( W_{ij} \equiv |W_i - W_j| \) (Attitude difference) |
|---|---|---|
| 1 | 2 | \( W_{12} \) represents the absolute difference between the individual attitude value with positive view and the individual attitude value with negative view |
| 1 | 3 | \( W_{13} \) represents the absolute difference between the individual attitude with a positive view and the individual attitude with a neutral view |
| 2 | 3 | \( W_{23} \) represents the absolute difference between the individual attitude with a negative view and the individual attitude with a neutral view |

\( W_{ij} \) represents the absolute difference between the individual attitude value with positive view and the individual attitude value with negative view. \( W_{12} \) represents the absolute difference between the individual attitude with a positive view and the individual attitude with a neutral view. \( W_{23} \) represents the absolute difference between the individual attitude with a negative view and the individual attitude with a neutral view.
### Types of individuals’ opinion adoption probability

| i (An individual holding the ith opinion) | j (An individual holding the jth opinion) | $P_{ij}$ (i,j = 1,2,3, $i \neq j$, the initial view is the ith opinion, after perceiving the jth opinion information, the probability of its idea being adopted) |
|-----------------------------------------|-----------------------------------------|---------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| 1                                       | 2                                       | $P_{12}$ represents individuals whose initial view is positive, perceiving individual information with a negative opinion, the probability of a negative opinion being adopted |
| 1                                       | 3                                       | $P_{13}$ represents individuals whose initial view is positive, perceiving individual information with a neutral opinion, the probability of a neutral opinion being adopted |
| 2                                       | 1                                       | $P_{21}$ represents individuals whose initial view is negative, perceiving individual information with a positive opinion, the probability of a positive opinion being adopted |
| 2                                       | 3                                       | $P_{23}$ represents individuals whose initial view is negative, perceiving individual information with a neutral opinion, the probability of a neutral opinion being adopted |
| 3                                       | 1                                       | $P_{31}$ represents individuals whose initial view is neutral, perceiving individual information with a positive opinion, the probability of a positive opinion being adopted |
| 3                                       | 2                                       | $P_{32}$ represents individuals whose initial view is neutral, perceiving individual information with a negative opinion, the probability of a negative opinion being adopted |

Note: $P_{12} = P_{21}, P_{13} = P_{31}, P_{23} = P_{32}$.

### The sub-stage in which an individual changes the views

From formula (4), the probability of acceptance of the message and henceforth change of attitude is equal to the product $P_{ub} = P_i \left( W_i; a_0, a_1 \right) * P_o \left( W_i, P_i; b_0, b_1, b_2 \right)$. When individuals adopt others’ views to a certain probability, the probability of individual idea change also has three conditions, namely $P_{ub12} = P_{ub21}, P_{ub13} = P_{ub31}, P_{ub23} = P_{ub32}$.

### Individual opinion communication stage

After the occurrence of public emergencies, individuals with positive, negative, and neutral views will change their attitude values after adopting others’ views, and further interact with others, thus spreading the information. When the communication stage of individual viewpoints reaches a stable state within a certain period of time, the network public opinion forms. The Lotka-Volterra model adopted by Lan3 in the process of information spread is used to model the interactive process of viewpoints. At the initial moment, not all individuals in the network participate in the discussion of public emergencies, but with the spread of information, more and more individuals participate in the process of view interaction. However, cyberspace does not allow unlimited individual expression, that is, the number of individuals that can accommodate different views should have limit, so the spread of public opinion stage in essence is the individuals with positive, negative, and neutral viewpoints competing for limited cyberspace resources (as shown in Figure 2). It is similar to the evolution mechanism in ecological science theory that species compete for limited resources: when the number of each type of species in a certain time period remains the same (balance), the individuals achieve the optimal state of competition in cyberspace. Based on the Lotka-Volterra model of population competition in ecological science, the interaction process between individuals is studied through differential equations, and the communication of three different viewpoints is described.

### Constructing communication model of individual views

Individuals’ views at time $t$ may change, and the number of people with positive, negative and neutral views at time $t$ is set as $X_1(t), X_2(t), X_3(t)$, that is, the groups with different views form a competitive relationship. Set the competition coefficient of three kinds of people as $\alpha$ (The coefficient of competition between individuals with positive and negative views), $\beta$ (The coefficient of competition between individuals with negative and neutral views), and $\gamma$ (The coefficient of competition between individuals with positive and neutral views). According to the analysis process of the individual decision-making stage, the probabilities of attitude change of three views are $P_{ub12}, P_{ub13}, P_{ub23}$, whose meanings are the same as the competition
First, the “residual” space of individuals holding positive viewpoints changes, from \((1 - X_1(t))\) to analyze the problem of mixture. There are three kinds of conditions: negative and neutral views respectively, and their values are set within the range of \((0,1)\). \(K_1, K_2,\) and \(K_3\) represent the upper limit of the number of individuals holding three different viewpoints respectively, which is determined according to the number of netizens in the existing network. The number of three types of individuals at initial time \((t = 0)\) is \(X_{10}, X_{20},\) and \(X_{30}\), respectively.

When there are individuals with only one single view (no competition relations), the number of individuals holding the \(i\)th opinion at time \(t\) is \(X_i(t)\), “residual” space of other individuals (the space of public opinion spread) is \((1 - \frac{X_i(t)}{K_i})\), as shown in below\(^{10}\):

\[
\begin{align*}
\frac{dX_1(t)}{dt} &= r_1X_1(t) \left(1 - \frac{X_1(t)}{K_1}\right) \\
X_1(0) &= X_{10}
\end{align*}
\]

After a sudden incident, three types of individuals holding different viewpoints coexist in the Internet space. Therefore, it is necessary to expand the single viewpoint competition model based on formula (6) to analyze the problem of mixture. There are three kinds of conditions: first, the “residual” space of individuals holding positive viewpoints changes, from \((1 - \frac{X_{1n}}{K_1})\) to \((1 - \frac{X_{1n}}{K_1} - a\frac{X_{2n}}{K_2} - \gamma\frac{X_{3n}}{K_3})\); second, the number of individuals holding negative viewpoints is \(\frac{dX_2(t)}{dt} = r_2X_2(t) \left(1 - \frac{X_2(t)}{K_2} - a\frac{X_{2n}}{K_2} - \gamma\frac{X_{3n}}{K_3}\right)\); third, the number of individuals holding neutral viewpoints is \(\frac{dX_3(t)}{dt} = r_3X_3(t) \left(1 - \frac{X_3(t)}{K_3} - a\frac{X_{2n}}{K_2} - \gamma\frac{X_{3n}}{K_3}\right)\).

The initial numbers are \(X_{10}, X_{20}, X_{30}\) respectively. By integrating the above three equations, the number of individuals with different views can be obtained as follows:

\[
\begin{align*}
\frac{dX_1(t)}{dt} &= r_1X_1(t) \left(1 - \frac{X_1(t)}{K_1} - a\frac{X_2(t)}{K_2} - \gamma\frac{X_3(t)}{K_3}\right) \\
\frac{dX_2(t)}{dt} &= r_2X_2(t) \left(1 - \frac{X_2(t)}{K_2} - a\frac{X_1(t)}{K_1} - \gamma\frac{X_3(t)}{K_3}\right) \\
\frac{dX_3(t)}{dt} &= r_3X_3(t) \left(1 - \frac{X_3(t)}{K_3} - a\frac{X_2(t)}{K_2} - \gamma\frac{X_3(t)}{K_3}\right) \\
X_1(0) &= X_{10} \\
X_2(0) &= X_{20} \\
X_3(0) &= X_{30}
\end{align*}
\]

### 3.3.2 Model equilibrium point and its stability

In the stage of individual opinion communication, when the number of individuals with positive, negative, and neutral opinions reaches a stable state within a certain period of time, it indicates that network public opinion has formed. In order to clearly know the formation time of network public opinion and the main advantages of which views are in the stable state, it is necessary to discuss the stability of the equation set (7), and the time of reaching the stable state. In general, the stability problem is discussed by solving analytic solutions of differential equations. However, the differential equation proposed in practical problems is often very complex, so it is impossible to find the exact analytic solution. We need to judge its stability from the zero solution of the differential equation. The relevant definitions are discussed below:
Definition 1. The differential equation without explicit independent variable \( t \) at the right end of the equation is called autonomous equation, as shown in Equation (8):

\[
x'(t) = f(x)
\]

Definition 2. If the real root \( x = x_0 \), then \( x = x_0 \) is called as the equilibrium point of the differential Equation (8).

After the equilibrium point of differential equation is obtained, it is necessary to judge the stability of the equilibrium point in order to analyze whether the equilibrium point will remain stable and unchanged in the following period of time. The following two methods for judging the stability of equilibrium point are introduced: one is the indirect method; the other is the direct method.

1. Indirect method:
   Starting from any value of some neighborhood of \( x_0 \), the solution \( x(t) \) \( \lim_{t \to \infty} x(t) = x_0 \) in the differential Equation (8) can be satisfied, then \( x_0 \) is stable, otherwise it is unstable.

2. Direct method:
   If \( f(x) \) is expanded at \( x_0 \) and only one term is taken, the differential Equation (8) can be approximately expressed as:

\[
x(t) = f'(x_0)(x - x_0)
\]

Equation (9) is the approximate linear equation of Equation (8), and \( x_0 \) is the equilibrium point of Equation (9), and the general solution of Equation (9) is:

\[
x(t) = x_0 + Ce^{f'(x_0)t}
\]

Since \( \lim_{t \to \infty} x(t) = \begin{cases} x_0, & f'(x_0) < 0 \\ +\infty, & f'(x_0) > 0 \end{cases} \), the stability of the equilibrium point of differential Equation (9) can be concluded as follows:

1. If \( f''(x) < 0 \), \( x_0 \) is the stable balance point of Equations (8) and (10);
2. If \( >0, f''(x) > 0 \), \( x_0 \) is the unstable balance point of Equations (8) and (10).

As Equation set (7) is an autonomous equation, the stable state of individual viewpoint communication cannot be determined by analytic solutions, but only by solving the equilibrium point and analyzing the stability of the equilibrium point. Based on this, it is necessary to first find the equilibrium point of the equation set (7), and then use the equation set (7) to describe the trend of the numerical solutions of \( X_1(t), X_2(t), \) and \( X_3(t) \), so as to find the stable value of \( X_1(t), X_2(t), \) and \( X_3(t) \) over time. Finally, it judges whether the equilibrium point satisfies the stability condition. If so, the equilibrium point is stable, that is, the value of the stable state is equal to the equilibrium point value, and this equilibrium point is also the formation state of network public opinion. If the equilibrium point value is not equal to the value in the stable state, the equilibrium point at this time cannot represent the formation state of network public opinion, then the individual numerical trend in a longer period of time should be simulated to obtain the stable value.

According to the solution method of competitive population model in the literature, as time goes by, the number of the three species tends to a stable value, and in order to achieve ecosystem balance, one of the three species does not become extinct. It is of practical significance only if the number of the three species in the equilibrium point is all greater than zero. The following will solve the equilibrium point of the equation:

To facilitate the solution of the dynamic differential equation, the equation set (7) is rewritten into the difference equation form as follows:

\[
\begin{align*}
\Delta X_1(t) &= r_1 X_1(t) \left( 1 - \frac{X_1(t)}{k_1} - \alpha \frac{X_1(t)}{k_2} - \gamma \frac{X_1(t)}{k_3} \right) \\
\Delta X_2(t) &= r_2 X_2(t) \left( 1 - \frac{X_2(t)}{k_2} - \alpha \frac{X_2(t)}{k_1} - \beta \frac{X_2(t)}{k_3} \right) \\
\Delta X_3(t) &= r_3 X_3(t) \left( 1 - \frac{X_3(t)}{k_3} - \gamma \frac{X_3(t)}{k_1} - \beta \frac{X_3(t)}{k_2} \right)
\end{align*}
\]

where \( \Delta X_i(t) = X_i(t) - X_i(t-1), i = 1, 2, 3, X_i(t) \) is the number of Internet users holding a certain view. When will the number of people with positive, negative and neutral views reach a stable state? What happens to the number of views when they reach a stable state? They are the key points to study the formation of network public opinion. Now, the balance point of the formation of network public opinion is found from the difference equation of the number of people among the three. Let the values of the difference equations (11) all be 0, and the equations (12) are expressed as follows:
so the following simulation part only discusses a certain type of views completely disappears. and the relationship between the competition coefficient and the individual viewpoint decision probability is defined in the model hypothesis as 

\[
\begin{align*}
    r_1 X_1(t) \left(1 - \frac{X(t)}{K_1} - \alpha \frac{Y(t)}{K_2} - \gamma \frac{Z(t)}{K_3} \right) &= 0 \\
    r_2 X_2(t) \left(1 - \frac{X(t)}{K_4} - \alpha \frac{Y(t)}{K_1} - \beta \frac{Z(t)}{K_2} \right) &= 0 \\
    r_3 X_3(t) \left(1 - \frac{X(t)}{K_5} - \beta \frac{Y(t)}{K_4} - \gamma \frac{Z(t)}{K_3} \right) &= 0
\end{align*}
\] (12)

Seven non-zero equilibrium points can be obtained from the above Equation (12), which is represented by \(P(X, Y, Z)\). The specific value is shown in Equation (13):

\[
\begin{align*}
    P_1 (K_1, 0, 0) \\
    P_2 (0, K_2, 0) \\
    P_3 (0, 0, K_3) \\
    P_4 \left(0, \frac{K_1}{1 + \alpha}, \frac{K_2}{1 + \beta} \right) \\
    P_5 \left(\frac{K_1}{1 + \alpha}, 0, \frac{K_3}{1 + \gamma} \right) \\
    P_6 \left(\frac{K_1}{1 + \alpha}, \frac{K_2}{1 + \beta}, 0 \right) \\
    P_7 (1 - \beta) \left[1 + \beta - (\gamma + \alpha) \frac{K_1}{(1 + 2\alpha \beta \gamma - a^2 - \gamma^2 - \beta^2)} \right, \\
    (1 - \gamma) \left[1 + \gamma - (\beta + \alpha) \frac{K_2}{(1 + 2\alpha \beta \gamma - a^2 - \gamma^2 - \beta^2)} \right, \\
    (1 - \alpha) \left[1 + \alpha - (\gamma + \beta) \frac{K_3}{(1 + 2\alpha \beta \gamma - a^2 - \gamma^2 - \beta^2)} \right)
\end{align*}
\] (13)

After solving the equations of equilibrium, because direct method needs to illustrate the stability state of the equations by the stability of the analytical solutions, the indirect method is adopted to determine the stability of the equilibrium point, that is: if the balance \(P(X, Y, Z)\) meet \(\lim_{t \to \infty} X_1(t) = X, \lim_{t \to \infty} X_2(t) = Y, \lim_{t \to \infty} X_3(t) = Z\). \(P(X, Y, Z)\) is called as stable equilibrium. And the balance at this moment is the time for forming network public opinion. In addition, in reality, the ecosystem equilibrium conditions in the Volterra model must be satisfied, that is, \(X_1(t), X_2(t), \) and \(X_3(t)\) in the equilibrium point must all be greater than zero to have practical significance. According to the above indirect method and the premise of \(X_1(t) > 0, X_2(t) > 0,\) and \(X_3(t) > 0\), the conditions for the seven equilibria to reach a stable state are solved, as shown below:

1. If the equilibrium point \(P_1\) reaches a stable state, it shall meet \(a > 1, \gamma > 1\).
2. If the equilibrium point \(P_2\) reaches a stable state, it shall meet \(a > 1, \beta > 1\).
3. If the equilibrium point \(P_3\) reaches a stable state, it shall meet \(\beta > 1, \gamma > 1\).
4. If the equilibrium point \(P_4\) reaches a stable state, it shall meet \(0 < \beta < 1, 1 + \beta < a + \gamma\).
5. If the equilibrium point \(P_5\) reaches a stable state, it shall meet \(1 + \gamma < a + \beta, 0 < \gamma < 1\).
6. If the equilibrium point \(P_6\) reaches a stable state, it shall meet \(0 < a < 1, 1 + a < \gamma + \beta\).
7. If the equilibrium point \(P_7\) reaches a stable state, it shall meet

\[
\begin{align*}
    &0 < a, \beta, \gamma < 1 \\
    &1 + a > \gamma + \beta \\
    &1 + \beta > a + \gamma \\
    &1 + \gamma > a + \beta
\end{align*}
\]

Based on the above analysis, the sufficient conditions for reaching the stable state of individual viewpoint communication stage are obtained, and the relationship between the competition coefficient and the individual viewpoint decision probability is defined in the model hypothesis as \(a = P_{ab12}, \beta = P_{ab13}, \gamma = P_{ab23}\). Generally speaking, the decision probability of individual opinions ranges from \([0,1]\), so the prerequisite for the competition coefficient between the three opinions is \(a, \beta, \gamma \in [0,1]\). Among the seven equilibrium points obtained above, only \(P_7\) satisfies this condition, so the following simulation part only discusses \(P_7\). According to the value of \(P_7\), when the network public opinion is formed and reaches a stable state, individuals with positive, negative, and neutral views coexist in the network, and there is no situation that the number of individuals with a certain type of views completely disappears.

**4 | SIMULATION EXPERIMENT**

This section discusses the influence of external information intensity, individual education level, individual stubbornness, and individual initial opinions on the formation process of network public opinion, so as to reveal its internal evolutionary mechanism. In addition, the initial attitude value
of the individual was set to be within the range of \([-1,1]\) and to follow the normal distribution of \(N \sim (0,0.03876)\). The sum of the three individuals with positive, negative, and neutral views at the initial time is \(N = 500\). In the individual information perception stage, the relationship strength \(RI\) between education level and information perception probability \(P_k\) is set as 1. In addition, the correlation coefficient \(k_2\) of minimum information perception ability and education level was set as 0.1. Only the interaction of two different categories of views is considered, that is, the views of each two categories of individuals are different. For example, if the individuals with a positive view and the individuals with a negative view interact, the existing tendency of the initial views of these two types of individuals is different, one is positive, the other is negative. In this paper, it is defined that the existing tendency of the initial views of the same class is positive, and the existing tendency of the initial views of different classes is negative. The interaction of two different types of initial views is discussed, so the existing tendency of the initial views of the local individuals is negative. Based on literature,\(^{4}\) the value range of \(L_a\) is \([-5,5]\), the initial viewpoint tends to be negative, the value range of \(L_a\) is \([5,0]\). In the initial state, the value of \(L_a\) only has minor influence on the result of the final public opinion formation with its initial set value as 2. The perceived confidence level \(\kappa = 0.1\), the negative function of individual education level for the adoption probability of the individual viewpoint is \(\gamma = 0.1\). Set \(K_1 = 6000, K_2 = 4000, K_3 = 10000\), to ensure that the group with neutral viewpoints accounts for the majority. While reflecting opinion distribution in the real world, the most initial viewpoint is neutral and only a small group of people holding extreme viewpoints. In addition, other parameters are set as follows: \(r_1 = 0.5, r_2 = 0.8, r_3 = 1\). It should be noted that in this section, in addition to Section 4.4, which discusses the influence of individual opinion differences on the formation process of network public opinion, Sections 4.1–4.3 fix the difference between the three types of attitudes, and make \(W_{12} = W_{23} = W_{13} = 0.6081\) according to the range of the three types of attitudes. In the simulation results, \(X_1(t), X_2(t), X_3(t)\) \(X_1, X_2,\) and \(X_3\) mentioned below are equal to \(X_1(t), X_2(t),\) and \(X_3(t)\) respectively represent the number of individuals with positive, negative, and neutral views.

The equilibrium point \(P_r\) described above reached a stable state under the conditions of \([0 < a, \beta, \gamma < 1; 1 + a > \gamma; 1 + \beta > a + \gamma; 1 + \gamma > a + \beta]\), the competitive coefficients of, and satisfy the conditions \([0 < a, \beta, \gamma < 1; 1 + a > \gamma + \beta; 1 + \beta > a + \gamma; 1 + \gamma > a + \beta]\) indicates that \(P_r\) is in a stable state, and the value of its equilibrium point is consistent with that of \(X_1(t), X_2(t),\) and \(X_3(t)\). Based on this, the value of equilibrium \(P_r\) is used to represent the stable state of network public opinion formation in the following content of this paper.

### 4.1 The impacts of information intensity of public emergency on the formation of public opinion

After reporting public emergency by mass media or the Internet, media’s coverage intensity of events will affect individual’s perception of information, that is, the intensity of information affects the probability of individual information perception, which in turn affects the change of individual’s viewpoint, and change the competition coefficient between the individual factors, which affects the final formation of network public opinion. Based on this, the influences of information intensity on the formation process of network public opinion under 0.1, 0.3, 0.5, 0.7, and 0.9 are respectively discussed below. Other parameters are set as: individual education level \(W_a = 1\). The simulation results are shown in Figures 3-6.

The simulation results show that the higher information intensity promises the higher individual information perception probability under the same education level. With the improvement of individual education level, the probability of individual information perception is also higher. In real life, generally speaking, the higher an individual’s education level is, the broader his mental state and vision are, the easier he is to accept others’ opinions, the more willing he is to listen to others’ opinions and opinions, and the more comprehensive he is in his view. On the contrary, the less educated an individual is, the more closed his mind is, the less he communicates with others, and the more extreme and biased his views on events are. Therefore, with the increase of information intensity, the number of people holding positive, negative and neutral opinions decreases when network public opinions are formed, and the time required for the final formation of network public opinions also decreases accordingly.

**FIGURE 3** The change of individual information perception probability under different information intensity
FIGURE 4  The variation trend of the number of individuals holding the positive view under different information intensity

FIGURE 5  The variation trend of the number of individuals holding a negative view under different information intensity

FIGURE 6  The change trend of the number of individuals holding a neutral view under different information intensity
4.2 The impacts of individual education level on the formation of public opinion

In the stages of individual information perception and individual decision making, the change of individual education level will affect the probability of individual opinion change, that is to say, changing competition results among individuals with positive, negative, and neutral views. Also, the change of competition process will affect the formation time of network public opinion and the number of individuals with three views. Based on this, this section discusses the influence of \( W_a \) of different individual education levels on the formation process of public opinion, and sets the value of \( \text{Inf} \) of information intensity as 0.1. The simulation results are shown in Figures 7-9.

It can be seen from Figure 7 that the higher an individual’s education level is, the greater the probability of information perception is, showing an “S-shaped” increase. It can be seen from Figure 8 that the probability of an individual adopting the views of others decreases with the increase of individual education level, and the overall trend of monotony decreases. As can be seen from Figure 9, the greater level of individual education makes the probability of individual opinion first increase and then decrease. In other words, if the education level of an individual is at a low level, the more likely an individual is to change his or her viewpoint. If the education level of an individual is at a high level, the probability of his or her viewpoint changing gradually decreases, and he or she will not change own viewpoint easily. According to the relationship between the competition coefficient and the individual opinion change probability in the above model hypothesis in Section 3.3.1, it can be seen that \( \alpha = P_{\text{nb12}}, \beta = P_{\text{nb13}}, \gamma = P_{\text{nb22}}, \) the individual opinion change probability will affect the competition coefficient among the three types of individuals. Therefore, the following simulation is conducted for the variation trend of the number of individuals with different opinions, and the results are shown in Figures 10-12.

In Figures 10-12, different education levels \( W_a \) (\( W_a \in [1, 10] \)) describe the change trend of three kinds of individuals, different colors of curve in the graph represent the different trends of \( X_1, X_2, X_3 \). From Figures 10-12, it can be seen that when the individual education level is \( W_a = 3 \),
the number of individuals $X_1$, $X_2$, and $X_3$ of three viewpoints approaches to the equilibrium point $P_7$ (4928, 3286, 8214). The number of individuals with positive view gradually tends to be stable when $t = 35$, and the overall trend is monotonously increasing. The number of individuals with negative view tends to be stable after $t = 40$. The number of individuals with neutral viewpoint tends to be stable after $t = 40$. When the maximum value of individual education level is $W_a = 10$, the number of three types of individuals reaches the equilibrium point $P_7$ (5059, 3373, 8433) when the network public opinion is formed. The number of positive, negative and neutral individuals tends to be stable after $t = 53$, 47, and 46, respectively.

From the above simulation, it can be seen that the higher the individual education level is, the longer the formation time of online public opinion will be, and the more individuals with positive, negative and neutral opinions will be formed when public opinion is formed.
4.3 The impacts of individual stubbornness on the formation of public opinion

Due to significant differences in personality characteristics, behavioral intention and other aspects, different individuals will have different degrees of acceptance for new matters, new information, and new ideas. Therefore, individual stubbornness will have an impact on the formation of network public opinion. By simulation experiment, the impact of different individual stubbornness \( z \in [0.1, 0.9] \) on network public opinion formation process is discussed with the setting for the initial state of \( \text{Inf} \) is 0.1, \( W_a \) is 1.

When the individual’s stubbornness changes, it will have an impact on the probability that the individual adopts others’ opinions and the probability that the individual’s opinions change. The following part analyzes the influence of individual stubbornness on individual decision-making stage by simulating individual’s adoption probability of others’ opinions. Assumes that the initial condition of information intensity \( \text{Inf} \) is 0.1, the individual education level \( W_a \) is defined as 1. When the value of individual stubbornness is in the range of \([0.1, 0.9]\), the values of individual viewpoint changing probability will change, but individual viewpoint changing probability will influence the competition between the individual coefficient, so that the individual views tend to be stable. In addition, the views held by three types of individuals are defined as positive, negative and neutral respectively, and the probability of change of individual views is also divided into three types, including the transformation between positive and negative views, the transformation between negative and neutral views, and the transformation between positive and neutral views. Based on this, the three cases are discussed respectively, and the simulation results are shown in Figures 13-15.

Figures 13-15 discuss the influence of individual stubbornness on individual decision-making process. When the individual’s stubbornness increases from 0.1 to 0.9, the probability of the change among positive, negative and neutral views decreases, which means that it is more difficult for individuals to adopt the views of others.

In addition, from the description of the three stages of the formation of network public opinion in Section 3, it can be seen that the individual decision-making process will have an impact on the communication process of individual opinions, thus affecting the formation of network public opinion. In order to further analyze the influence of individual stubbornness on the communication process of individual opinions, and further affect the time required for the formation of network public opinions, the influence of individual stubbornness on the communication process of individual opinions is simulated as shown in Figures 16-18 below.
FIGURE 14  The probability of changing between negative and neutral views changing under different individual stubbornness.

FIGURE 15  The probability of changing between positive and neutral views changing under different individual stubbornness.

FIGURE 16  The change trend of the number of individuals holding positive views under different individual stubbornness.
When the individual stubbornness is 0.1, $X_1$, $X_2$, and $X_3$ reach the equilibrium point $P_7 (4874, 3249, 8123)$. Among them, the number of individuals with positive, negative and neutral views gradually tends to be stable after $t = 18$, 40 and 30 respectively, and shows a monotonously increasing trend. With the increase of individual stubbornness from 0.1 to 0.9, the number of individuals from three viewpoints $X_1$, $X_2$, and $X_3$ increases to $P_7 (4928, 3286, 8214)$. The time for individuals with positive views to reach a stable state changed from $t = 18$ to $t = 33$, that is, the duration for the number of individuals with positive and neutral views to reach a stable state is longer, while the duration for the number of individuals with negative views to reach a stable state is shorter. To sum up, with the increase of individual stubbornness, it takes longer time for network to form public opinion, and more people take part in discussion when it reaches a stable state, that is, more and more individuals participate in the process of viewpoint interaction and gradually form network public opinion.

4.4 The impacts of initial viewpoint difference on the formation of public opinion

If the differences of opinions between individuals are too large, people may not participate in the communication, and there will be no fierce collision of various opinions. Instead, they will only have scattered discussions, which cannot form online public opinions. This shows that initial opinion differences among individuals have an impact on the formation of network public opinions. In order to further analyze the relationship between individual opinion differences and the formation process of network public opinions, this section simulates individual opinion differences with positive, negative and neutral opinions, and sets individual stubbornness $z = 0.1$. The simulation results are shown in Figures 19-21.

From Figures 19-21, it can be seen that the greater difference in initial attitude values among individuals with positive, negative and neutral views means the smaller probability of individuals choosing to change their own views in the decision-making process. In addition, from the model hypothesis, competition coefficient and the relationship between the individual opinion change probability, it shows: 

$$a = P_{ab12}, \beta = P_{tb13}, \gamma = P_{nb23},$$

and individual opinion change probability will influence coefficient of three kinds of competitions. Therefore, the
individual quantity trends are divided into four parts: one kind is with all changes of $W_{12}$, $W_{13}$, $W_{23}$; the second type is with fixed $W_{12}$ value and changed values of $W_{13}$ and $W_{23}$. The third is with fixed $W_{13}$ value and changed values of $W_{12}$ and $W_{23}$. The fourth is with fixed $W_{23}$ value and changed values of $W_{13}$ and $W_{12}$.

The simultaneous changes of $W_{12}$, $W_{13}$, $W_{23}$ will affect the individual's competition coefficient. The simulation results of the corresponding network public opinion formation process is shown in Figure 22: the blue shaded part represents the change of $X_3$ when $\alpha \in [\min P_{\text{prob12}}, \max P_{\text{prob12}}]$. The red shaded part represents the change of $X_1$ when $\beta \in [\min P_{\text{prob13}}, \max P_{\text{prob13}}]$. The green shaded part represents the change of $X_2$ when $\gamma \in [\min P_{\text{prob23}}, \max P_{\text{prob23}}]$. It can be seen from the figure that the blue shaded part is much larger than the other two types, indicating that when three types of individuals compete with each other, the number of individuals holding a neutral view changes greatly. That is because the individuals holding a neutral
The influence of simultaneous changes of $\alpha$, $\beta$, $\gamma$ on the trend of $X_1(t)$, $X_2(t)$, and $X_3(t)$

view are more likely to be influenced by other individuals’ views, thus making their own views biased. When the initial viewpoint difference of the three types of individuals all takes the minimum value, the number tends to be $P_7$ (4913, 3276, 8041). Among them, the number of positive, negative, and neutral individuals gradually tends to be stable after $t = 37, 30$, and $26$ respectively, and generally increases monotonically. When the initial opinion difference among the three types of individuals gradually increases to the maximum value, the number tends to be $P_7$ (5094, 3421, 8306), that is, when the network public opinion forms and reaches a stable state, the number of people participating in the discussion of public emergencies increases, and the time required for the formation of network public opinion also increases.

When $W_{13}$ gradually increased from minimum to maximum value, and $W_{23}, W_{12}$ values were fixed at 0.6081 ($\beta$ changed from small to large), trends of three kinds are shown in the simulation results in Figure 23(A-C): the difference between green shaded area and blue shaded area represents the impact of $\beta$ on the formation of public opinion. If the difference is large, the change of $\beta$ will have large impact. As shown in Figure 23(A-C), when $\beta$ decreases, the number of individuals with negative and neutral views increases, while the number of individuals with positive views decreases. According to the area difference, the change of $\beta$ has a great impact on individuals with neutral views, and the formation time of network public opinions is shortened.

When $W_{23}$ gradually increased from minimum to maximum value, and $W_{13}, W_{12}$ values were fixed at 0.6081 (changed from small to large), trends of three kinds are shown in the simulation results in Figure 24(A-C): the difference between green shaded area and blue shaded one represents the impact of $\gamma$ on the formation of public opinion. If the difference is large, the change of $\gamma$ will have large impact. As shown in Figure 24(A-C), when $\gamma$ decreases, the number of individuals with negative and neutral views decreases, while the number of individuals with positive views increases. According to the area difference, the change of $\gamma$ has a great impact on individuals with negative views, and the formation time of network public opinions is shortened.

When $W_{12}$ gradually increased from minimum to maximum value, and $W_{13}, W_{23}$ values were fixed at 0.6081 ($\alpha$ changes from small to large), trends of three kinds are shown in the simulation results in Figure 25(A-C): the difference between green shaded area and blue shaded represents the impact of $\alpha$ on the formation of public opinion. If the difference is large, the change of $\gamma$ will have large impact. As shown in Figure 25(A-C), when $\alpha$ decreases, the number of individuals with negative, neutral and positive views increases. According to the area difference, the change of $\alpha$ has little impact on three kinds of individuals.

To sum up, the change of $\alpha$ has minor influence on the communication process of individual opinions or the formation time of network public opinion. Compared with the change of $\gamma$, the change of $\beta$ has greater impact on the communication process of individual opinions and the formation of network public opinion. Compared with the influence of external information intensity, individual education level and individual stubbornness on the formation of online public opinion, according to the change of the number of individuals and the time when the online public opinion reaches a stable state, it can be known that the difference of individual initial opinions has the greatest influence on the time needed for the formation of online public opinion.

5 | CASE STUDY

In this section, in order to verify the network public opinion formation model established in this paper, a typical case is selected: Under the COVID pandemic, on February 19, 2020, The Ministry of Culture and Tourism of China issued the tourism revitalization policy—to successively open the national scenic spots events.
The outbreak of COVID in late 2019 has seriously affected China’s economic and social development and people’s lives. Tourism is the industry that has been hardest hit. The impact of the epidemic on tourism includes not only the direct losses of many tourism enterprises and related employees, but also the indirect losses of related industries of tourism. During the Spring Festival, the direct economic loss caused by the shutdown of China’s tourism industry is around RMB 400 billion to 500 billion Yuan, resulting in the annual expectation to change from “year-on-year growth of 10% to” negative growth of 14%–18%. According to statistics, 450 million people have canceled or postponed their Spring Festival travel by February 1, 2020. Until May 2020, China’s epidemic prevention and control situation has been in a stable state. However, on February 14, 2020, Zhejiang Province Government issued the relevant guidelines on the orderly opening of tourist attractions under the control of COVID. The West Lake in Hangzhou was opened on February 19, and other sight spots around the country were also opened in succession. As soon as this policy was released on the Weibo, it aroused positive responses from netizens. Some netizens believed that the government acted too quickly and it was irresponsible to open the sight spots before the epidemic was stabilized. Some netizens think the tourism industry will return to normal sooner or later, and it is better to resume business as soon as possible. Later, on April 4, Huangshan scenic area was crowded and closed operation immediately, which was blamed and doubted by public. Within 1 month, network public opinion was formed, forcing the government to issue subsequent policies so as to make up the deficiency.

**FIGURE 23** The influence of changed $\beta$ on the number of individuals with different view. (A) The influence of changed $\beta$ on the number of individuals with a positive view. (B) The influence of changed $\beta$ on the number of individuals with a negative view. (C) The influence of changed $\beta$ on the number of individuals with a negative view.
In order to analyze network public opinion formation process of sight spots open policy during COVID, this paper took up Weibo comments under 6 official media on February 19, 2020 and March 19. A total of 60,000 Weibo comments and likes are collected, among which 6228 comments data is scored through JIEBA and emotional dictionary. The emotional values of each comments are obtained within the range of \([-1, 1]\). At the beginning of February 19, 2020, the number of people with positive, negative and neutral views was 30, 80 and 118, respectively. After the release of relevant information about the policy by 6 official media, it caused heated discussions on the Internet. Finally, it was found that the number of people holding positive views was 330, with an attitude value in \((0.3043, 1)\). The number of people holding negative views was 880, with an attitude value in \([-1, -0.3043)\). The number of people holding neutral views was 5018, with an attitude value in \([-0.3043, 0.3043]\). All conformed to the fact that majority was netizens holding neutral views. In spite of limited data, based on Six Degrees of Separation Theory, these data can reflect general user behavior to a great extent, as shown in Figure 26.

In this paper, the data after processing were analyzed, the comments from 10:00 February 19 to 0:00 February 23 were ranked according to time order, and the change trend of three types of individuals was formed, as shown in Figure 27.

As can be seen from Figure 27, when the government released the policy of opening tourist attractions on February 19, 2020, netizens held more neutral views, and some also held negative views. Under stable state, the number of individuals with positive, negative, and neutral views was equal to $P_r (330, 880, 5018)$. At this time, online public opinions were formed. In the process of its formation, the number of individuals holding neutral views increased first and then decreased, while the number of individuals holding negative and
positive views increased slightly. On the whole, the number of individuals holding negative views was more than that of individuals holding positive views.

The following is the simulation of the public opinion evolution process of the event according to the model constructed in this paper, and the trend of the three types of individual are obtained. The results are shown in Figure 28. Parameter setting is as follows: $r_1 = 0.5, r_2 = 0.8, r_3 = 1, K_1 = 330, K_2 = 880, K_3 = 5018, \text{Inf} = 0.1, W_{12} = 1, k_1 = 0.1, L_1 = -2, x = 0.1, y = 0.1, W_{13} = W_{23} = W_{12} = 1.2$.

It can be seen from the comparison between Figures 27 and 28 that, although there is a slight difference between them, the change trend of online public opinion formation process is basically the same on the whole, and when it reaches a stable state, the proportion of positive, negative and neutral individuals is basically the same.

In addition, the Lotka-Volterra model mentioned in literature was used to simulate the public opinion evolution process of the "Open Scenic Spot Policy" during COVID, and the results are shown in Figure 29.

From Figure 27, the formation of network public opinion trend in literature is not consistent with the actual reality, network public opinion formation process model in Figure 29 speeds up sharply and then slows down. This is because the competition coefficient in literature takes high value, and the competition coefficient in the model cannot adjust according to the stages of network public opinion formation, so the model proposed in literature cannot fully reflect the true formation process of network public opinion. Therefore, the model established in this paper is more reasonable to simulate the formation process of network public opinion.
FIGURE 26  The Weibo contents of tourism policy in the context of COVID pandemic

FIGURE 27  The number of individuals for the opening policy

FIGURE 28  The simulation of public opinion evolution process
6 | CONCLUSIONS

This paper introduces the individual internal factors and external information, and analyzes network public opinion formation process through the RAS formation model and population competition model, which can be divided into: individual information perception stage, individual decision-making stage, and communication stage. Then the article discusses the impacts of external information strength, individual education level, individual stubbornness, initial individual opinion difference on network public opinion formation process. Through simulation analysis, the following conclusions can be drawn:

1. The greater the intensity of media coverage of public emergencies is, the stronger the interaction between network individuals is, and the easier they are to adopt other people's views and change their own views. Online public opinions are easier to form within shorter time.

2. The higher an individual's education level is, the higher his/her perception probability of information will be, and the probability of changing an individual's opinion will first increase and then decrease, thus shortening the time for the final formation of online public opinion and reaching a stable state. In addition, the number of individuals with positive, negative, and neutral opinions will increase in the network.

3. When the degree of individual stubbornness decreases, the probability of individual opinion change will increase. It will take longer time for network public opinion to finally form and reach a stable state. The number of individuals holding neutral opinions is greater than the number of individuals holding positive and negative opinions.

4. The competition coefficient between positive and negative opinions has the greatest influence on the formation of online public opinion, while the attitude difference between negative and neutral opinions has minor influence on the formation of online public opinion.

5. Compared with the influence of information intensity, individual education level and individual stubbornness on the formation of online public opinion, the attitude differences among individuals with different views have the greatest influence on the formation and stable state of online public opinion. The larger difference in opinions among individuals encourage more netizens to participate in the discussion of the event, and it takes longer time for the online public opinion to form and reach a stable state.

There are still some deficiencies in this paper:

1. The undiscussed issues in this paper, such as psychological change of Internet users, the leading role of the media, and the mood of opinion leaders will all affect the formation of network public opinion, but they are difficult to be quantified. Therefore, future work needs to be further integrated into the model, and studies the effect of three factors on the network public opinion formation.

2. In the simulation analysis, the influence of relevant parameters on the formation of network public opinion is highly discussed from the macro-level. Consequently, the discussion on the interaction mechanism of the formation of network public opinion from the micro-perspective is very limited. Therefore, it is necessary to discuss various interaction mechanisms in the formation of network public opinion.
3. The influence of network dynamics and node increment and regression mechanism\textsuperscript{41,42} on individual decision making and individual opinion communication is not considered in this paper, and the influence of dynamic network on the formation of network public opinion needs to be considered in subsequent studies.

**CONFLICT OF INTEREST**
The authors declare that they have no competing interests.

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