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Public Opinion Transmission of Corporate Crisis Events Based on Improved SEIR Model

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Abstract

In the era of the digital economy, public opinion transmission about corporate crisis events has become an important topic that needs urgent attention. In this paper, we propose an improved SEIR model applicable to the evolution of online public opinion transmission of corporate crisis events, and reveal the key nodes of public opinion transmission by solving the steady state solution and the transmission threshold R0. To identify the core factors affecting public opinion transmission, the influence mechanism of each parameter on public opinion transmission is analyzed. The reasonableness and reliability of the model are verified by simulation experiments using the Tesla "Brake Failure" crisis event. We find that the change of immunity rate β has a significant effect on the speed, scope and depth of public opinion transmission, which provides an important theoretical basis and practical guidance for enterprises to deal with crisis events.

Keywords

Public Opinion Transmission; Corporate Crisis Events; SEIR model; Transmission Mechanisms; Tesla Brake Failure

1. Introduction

With the rapid development of the Internet and social media, public opinion has become an important carrier for the transmission of corporate crisis events. Although public opinion can bring attention to an enterprise in normal times, it can easily damage its reputation in crisis times. Facing corporate crisis events, every decision of an enterprise may become an online storm, driving the incident from some dissatisfaction to a mass crisis. At this time, if the enterprise still follows the traditional crisis response method, it is easy to expand the crisis and affect the survival and development of the enterprise. Therefore, it is important to study the transmission mechanism of public opinion in corporate crisis events.

This paper examines the public opinion transmission mechanism of corporate crisis events from multiple dimensions, including transmission subject, transmission state, transmission node, and transmission effect. Meanwhile, we innovatively introduce the SEIR model to quantitatively portray the diffusion characteristics of crisis at different transmission stages. The research questions include: What are the key influencing factors of public opinion on corporate crisis events? What are the key nodes of public opinion transmission? and how to intervene most effectively? By addressing these questions, this paper not only helps enterprises respond to public opinion quickly and appropriately, but also helps to deepen the understanding of public opinion transmission.

2. Literature Review

Corporate crisis events are potential threats to a company's operations, development, or even survival of the events (Janssen et al., 2015). Public opinion is a wide-ranging discussion based on online platforms that reflects collective views, attitudes and emotions around hot social events (Dong et al., 2024). Public opinion transmission is not limited to a closed single network (Zhang et al., 2018). Faced corporate crisis events, it is difficult for consumers to distinguish true from false. And Prospect theory states that consumers are more sensitive to losses than gains (Kahenman D., 1979). Negative public opinion spread faster and wider than factual information (Yin et al., 2022). If the relevant departments handle it improperly, it will affect the trends of public opinion and even endanger social harmony and stability (Wang et al., 2021). Therefore, corporate crisis events are often accompanied by the emergence of negative public opinion, and the transmission of public opinion in turn affects the event situation (Sandra Oliver, 2008).

The process of information transmission is relatively abstract, scholars have widely discussed the mechanism. Nekovee et al. (2007) studied the transmission mechanism of public opinion from the perspective of systematics, constructed a kinetic model of online opinion diffusion, and carried out simulation analyses. Liu and Maning (2014) constructed a hypernetwork model and explored the regularity of message diffusion. Hansen et al. (2018) discussed the time of opinion diffusion. Due to the spread of infectious diseases and the transmission of information have similarities, scholars have successively used epidemic models and their improved models to study the laws of information transmission (Zhang and Pan, 2021, Ma et al., 2022, Ran and Chen, 2021). With the rise of complex network research, the combination of infectious disease models and complex network theory is widely used by scholars. For example, Wu et al. (2018) introduced a SAR model to study the spreading of sudden events. Li et al. (2019a) established an I2S2R model to analyze the impact of model parameters on rumor propagation.

3. SEIR Model

Kermack and Mckendrick constructed the SIR contagion model with a kinetic approach. Sudbury (1985) used the SIR contagion model to study the transmission mechanism of rumours. Chen et al. (2011) proposed the SEIR model considering information spreading behaviour, and simulated it in scale-free network and regular network. Thus, this study introduces the SEIR model to construct the transmission model for public opinion of corporate crisis events.

3.1. Traditional SEIR Model

- Model Assumption

Hypothesis 1: The total number of people remains constant, and the entire population is divided into three categories: Susceptible refers to uninfected person who is susceptible to infection by infected person; Exposed refers to person who has already been infected but are not yet symptomatic; Infectious refers to sick person who can infect others; Recovered refers to person who has been isolated or is immune to the infection.

Hypothesis 2: The ratios of various types of people to the total number of people at time t are denoted as s(t), e(t), i(t), r(t), and the numbers of various types of people are S(t), E(t), I(t), and R(t), respectively. At the initial moment t=0, the initial ratios accounted for by the number of people in each category are s(0), e(0), i(0), r(0).

Hypothesis 3: λ is the average number of susceptible effectively exposed to each diseased person per day (referred to as infection rate); α is the ratio of latents who become Infectious to the whole latents per day (referred to as incidence rate); and β is the ratio of diseased persons to the whole patients per day (referred to as cure rate).

- Model Building

According to the Hypothesis, each infected person can infect λs(t) people to become infected per day in period t after disease onset, and the diseased person is Ni(t), so that λs(t)Ni(t) people become infected per day. The exposed Ne(t) per day includes αNe(t) that develops the disease. The diseased Ni(t) each day includes βNi(t) that cured and becomes a recovered person. The traditional SEIR model illustrated in Figure 1.

$$\text{Susceptible} \xrightarrow{\lambda s(t)Ni(t)} \text{Exposed} \xrightarrow{\alpha Ne(t)} \text{Infectious} \xrightarrow{\beta Ni(t)} \text{Recovered}$$

Figure 1. The Traditional SEIR Model.

The differential equation as follows:

$$\begin{cases} N\dfrac{ds(t)}{dt} = -\lambda s(t)Ni(t) \\ N\dfrac{de(t)}{dt} = \lambda s(t)Ni(t) - \alpha Ne(t) \\ N\dfrac{di(t)}{dt} = \alpha Ne(t) - \beta Ni(t) \\ N\dfrac{dr(t)}{dt} = \beta Ni(t) \end{cases}$$

After simultaneous about N, get:

$$\begin{cases} \dfrac{ds(t)}{dt} = -\lambda s(t)i(t) \\ \dfrac{de(t)}{dt} = \lambda s(t)i(t) - \alpha e(t) \\ \dfrac{di(t)}{dt} = \alpha e(t) - \beta i(t) \\ \dfrac{dr(t)}{dt} = \beta i(t) \\ s(0) = s_0, i(0) = i_0, e(0) = e_0, r(0) = r_0 \\ s_0 + i_0 + e_0 + r_0 = 1 \end{cases}$$

3.2. Improved SEIR Model

This paper makes corresponding structural improvements to the traditional SEIR model based on the real situation. It mainly involves the following points: (1) The traditional SEIR model does not take into account the fact that some exposed people after coming into contact with infected ones, may not spread the information but instead become immune directly. (2) Some susceptible people may become infected directly after being exposed to crisis events without going through the latent stage. (3) After being exposed to a similar public opinion event again, recovered people may continue to be caught up in the public opinion event and spread it again, i.e., transform from recovered people to infected person.

- Model Assumption

Hypothesis 1: there are four states of Internet users in the process of online public opinion transmission: Susceptible who have not yet viewed the public opinion information on the Internet; Exposed who have obtained relevant public opinion information and are still waiting to see whether to spread it; Infectious who have obtained public opinion information and are spreading it; Recovered who have withdrawn from the transmission of information.

Hypothesis 2: The overall number of public opinion is N. The proportions of susceptible (S), Exposed (E), Infectious (I), and Recovered (R) in the total number of people N at the moment t are denoted as s(t), e(t), i(t), and r(t), and s(t)+e(t)+i(t)+r(t)=1, s(t)+e(t)+I(t)+R(t)=N.

Hypothesis 3: λ is the ratio of being influenced by the information to enter the latent state (referred to as latent rate), δ is the ratio of being influenced by the information to spread the information (referred to as direct transmission rate); α is the ratio of going from observation to transmission after a period of latency (referred to as transformation rate), μ is the ratio of losing interest in the public opinion information and no longer paying attention to it in the latent stage (referred to as forgetting rate); β is the ratio of being immune to the information after spreading the information (referred to as immunity rate), and γ is the ratio that the recovered person transforms into a communicator again (referred to as rekindling rate).

- Model Building

According to the Hypothesis: when the current state is susceptible, there is a probability of being exposed or infectious; when a exposed, there is a probability of transforming into a infectious or becoming an recovered directly; when an infectious, there is a probability of becoming a recovered to withdraw from spreading; when a recovered, there is a probability of being re-involved in the spread of the public opinion and becoming an infectious again. The improved SEIR model is illustrated in Figure 2.

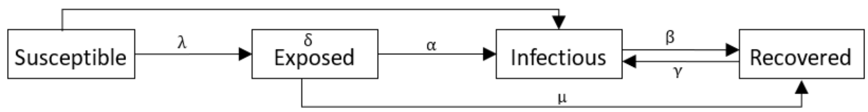

Figure 2. The Improved SEIR Model.

The differential equation as follows:

$$\begin{cases} \dfrac{ds(t)}{dt} = -\lambda s(t)i(t) - \delta s(t)i(t) + \gamma r(t) \\ \dfrac{de(t)}{dt} = \lambda s(t)i(t) - \alpha e(t) - \mu e(t) \\ \dfrac{di(t)}{dt} = \delta s(t)i(t) + \alpha e(t) - \beta i(t) \\ \dfrac{dr(t)}{dt} = \beta i(t) + \mu e(t) - \gamma r(t) \\ s(0) = s_0, i(0) = i_0, e(0) = e_0, r(0) = r_0 \\ s_0 + i_0 + e_0 + r_0 = 1 \end{cases}$$

4. Stability Analysis

4.1. The Steady State Solution s*, e*, i*, r*

① The improved SEIR model is analysed numerically by letting the values at the right end of the model be zero to obtain the system of equations:

$$\begin{cases} -\lambda s(t)i(t) - \delta s(t)i(t) + \gamma r(t) = 0 & (1) \\ \lambda s(t)i(t) - \alpha e(t) - \mu e(t) = 0 & (2) \\ \delta s(t)i(t) + \alpha e(t) - \beta i(t) = 0 & (3) \\ \beta i(t) + \mu e(t) - \gamma r(t) = 0 & (4) \end{cases}$$

② From equation (2) get $e = \dfrac{\lambda si}{\alpha + \mu}$, bringing e into equation (3):

$$\delta si + \alpha(\frac{\lambda si}{\alpha + \mu}) - \beta i = 0$$

$$\Rightarrow i\left[\delta s + \frac{\alpha\lambda s}{\alpha + \mu} - \beta\right] = 0$$

Case 1: i=0 (no information transmission steady state), substituting into the other equations gives e=0, r=0, s=1.

Case 2: i≠0 (continuous information transmission steady state), solved:

$$s = \frac{\beta(\alpha + \mu)}{\delta(\alpha + \mu) + \alpha\lambda} \triangleq s^*$$

③ Solve for e∗and r∗.

Substitute s∗into the expression e, get:

$$e^* = \frac{\lambda s^* i}{\alpha + \mu}$$

From equation (4), it is obtained: $r^* = \frac{\beta i + \mu e^*}{\gamma}$

④ Using the conservation condition s + e + i + r = 1, denote s∗, e∗, and r∗as functions i, and solve the nonlinear equations i:

$$s^* + \frac{\lambda s^* i}{\alpha + \mu} + i + \frac{\beta i + \mu(\frac{\lambda s^* i}{\alpha + \mu})}{\gamma} = 1$$

The numerical solution results in:

$$i^* = \frac{1 - s^*}{1 + \frac{\lambda s^*}{\alpha + \mu} + \frac{\beta + \mu(\frac{\lambda s^*}{\alpha + \mu})}{\gamma}}$$

4.2. The Transmission Threshold R0

The threshold condition is derived by calculating the basic regeneration number.

① Jacobian matrix of infected subsystems (e, i):

Infection F and Transfer V $F = \begin{bmatrix} \lambda si \\ \delta si \end{bmatrix} \square V = \begin{bmatrix} (\alpha + \mu)e \\ -\alpha e + \beta i \end{bmatrix}$

Derived at the uninformative steady state (s=1, e=0, i=0):

$$F = \begin{bmatrix} 0 & \lambda \\ 0 & \delta \end{bmatrix} \square\ V = \begin{bmatrix} \alpha + \mu & 0 \\ -\alpha & \beta \end{bmatrix}$$

② Calculate R0 = ρ(FV-1) (spectral radius):

$$V^{-1} = \frac{1}{\beta\ (\alpha + \mu)} \begin{bmatrix} \beta & 0 \\ \alpha & \alpha + \mu \end{bmatrix} \square\ FV^{-1} = \begin{bmatrix} \frac{\lambda\alpha}{\beta\ (\alpha + \mu)} & \frac{\lambda}{\beta} \\ \frac{\delta\alpha}{\beta\ (\alpha + \mu)} & \frac{\delta}{\beta} \end{bmatrix}$$

The threshold R_0 is the maximum eigenvalue of the matrix FV^{-1}:

$$R_0 = \frac{\delta}{\beta} + \frac{\lambda\alpha}{\beta(\alpha+\mu)}$$

③ The threshold condition:

If $R_0 > 1$, the message transmission continuously (there is a non-zero steady state);
if $R_0 \leq 1$, the message fades away (steady state $i^* = 0$).

4.3. Intrinsic Mechanisms of Transmission Threshold R0

Transmission threshold R0 is a key indicator to measure the spread ability of public opinion. When R0>1, it means that public opinion has a tendency of self-amplification and continuous spreading; while R0<1, it indicates that public opinion is difficult to spread on a large scale. Figure 3 gives the curve of R0 changing with α, β, λ , γ, δ, and μ, which is analysed as follows:

As the value of α increases, R0 also increases gradually, which indicates that individuals are more likely to convert information into actions (e.g., retweeting, commenting); As β increases, R0 decreases rapidly, means that the stronger the individual's immunity to the information, the weaker the propagation ability of public opinion; As λ increases, R0 grows linearly, indicating that the longer the information is latent in an individual, the greater the scope and depth of public opinion transmission; As δ increases, R0 increases gradually, which indicates that the more efficient the direct transmission of information is, the faster the public opinion spreads; As γ increases, R0 decreases, indicating that the higher the rate of re-activation of information, the scale of public opinion transmission may be suppressed instead; As μ increases, R0 decreases slightly, indicating that the faster the individual forgets the information, the weaker the effect of opinion transmission.

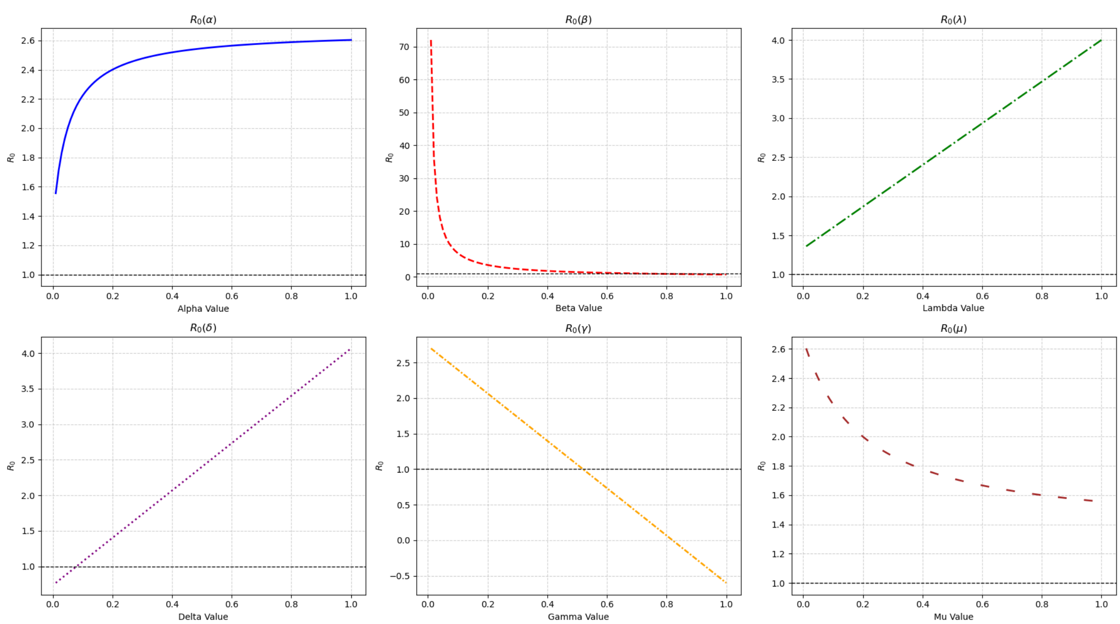

Figure 3. The Curve of R0 Changing with α, β, λ , γ, δ, μ

5. Simulation Experiment

5.1. Case Selection

This paper chooses the Tesla “brake failure” public opinion incident as the data source for the simulation experiment. The cause of the incident is: many Tesla owners in China complained about “brake failure” in 2020, but Tesla did not make a reasonable response until consumers stood on the roof of Tesla cars to defend their rights at the Shanghai Auto Show in 2021. The incident quickly triggered a hot debate on the Internet and formed a public opinion storm in a short period. The case exhibits characteristics of rapid proliferation, continuous controversy, and long-term rekindling, making it suitable for quantitative analysis of public opinion evolution use the improved SEIR model.

5.2. Parameter Setting and Model Simulation

The paper uses Python software to simulate and analyse the improved SEIR model. Assuming the number of users N=1000, 5 nodes are randomly selected as infected, with the remainder being classified as unknown. At the moment of t=0, set S(0)=N-1/N, E(0)=0, I(0)=1/N, R(0)=0. Based on the real data of the event, set the following parameters: λ=0.5, δ=0.25, α=0.15, β=0.2, μ=0.08, γ=0.03. The test result shown in Figure 4. Only γ to R0 is different from the original model setting, due to the case lasted for a long time and had a large influence scope after rekindling in 2021.

5.3. Key Node Analysis

As illustrated in Figure 4, the immunity rate β is identified as the key node in the context of corporate response crisis public opinion. The effect of altering β on the transmission curve is illustrated in Figure 5.

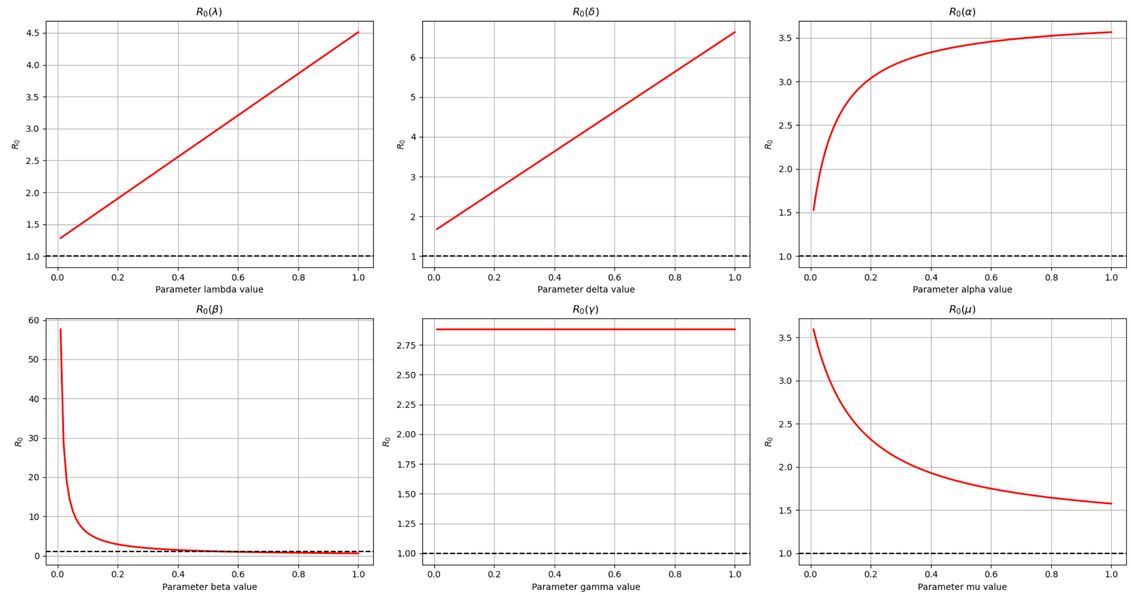

Figure 4. Sensitivity of R0 to Model Parameters in Tesla Case

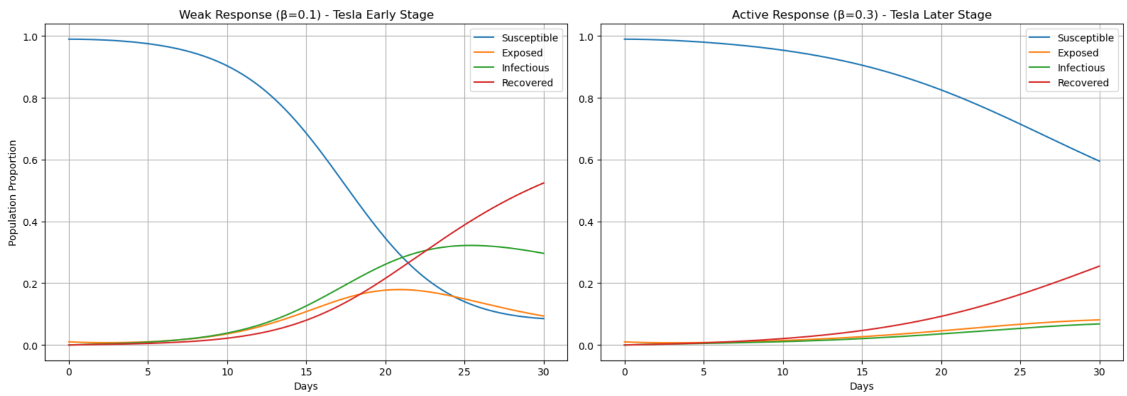

Figure 5. SEIR Simulation under Different Response Strategies

Figure 5 shows the effect of different immunity rate β on the public opinion transmission curve in the Tesla “brake failure” crisis. By comparing the simulation results of the SEIR model in the weak response (β=0.1) and positive response (β=0.3) scenarios, we can analyse the impact of immunity rate on public opinion transmission. The results show that a higher immunity rate β not only slows down the transformation of susceptible people to the state of exposure and infection, thus reducing the speed of public opinion transmission; it also significantly reduces the proportion of exposed and infected people, limiting the scope and depth of public opinion transmission. Enterprises can effectively manage and guide public opinion and safeguard their reputation by enhancing the public's immunity to crisis events (e.g., by improving media literacy, enhancing discernment, etc.).

6. Conclusion and Future Outlook

Based on the improved SEIR model, this paper deeply analyzes the characteristics of public opinion transmission when a corporate crisis event occurs. Firstly, we propose an improved SEIR model that is more suitable for the evolution of public opinion transmission in corporate crisis events. Secondly, we solve the steady state solution of the model and the transmission threshold R0, and construct the curves of R0 with the changes of α, β, λ, γ, δ, and μ. Finally, we choose the public opinion transmission of Tesla "brake failure" crisis as a simulation case to verify the reasonableness and reliability of the model, and explore the influence of different parameters on public opinion transmission. We find that the change of immunity rate β has a significant effect on the speed, scope and depth of public opinion transmission, which provides an important theoretical basis and practical guidance for enterprises to response crisis events.

However, this study still has some limitations. Firstly, the values of each parameter in the model are set empirically, which may affect the accuracy and generalization of the model. Secondly, more complex factors can be considered in the future, such as user behavioral characteristics and emotional polarity, to reflect the dynamic process of public opinion transmission.

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