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Simulating the Impact of Blood Donation Policies on Donor Behavior in the Blood Supply Chain During the COVID-19 Pandemic

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ABSTRACT

The SARS-CoV-2 virus, which causes COVID-19, spread globally, disrupting various aspects of daily life and significantly affecting blood transfusion services and donation patterns. One of the primary factors contributing to the decline in donations was the fear and safety concerns of donors about contracting the virus at donation centres. This created immense pressure on blood transfusion facilities. To prevent a shortage of blood products, it became crucial to maintain donor engagement throughout the pandemic. This study investigates the impact of COVID-19 on blood donor behaviour and evaluates two strategies aimed at mitigating the decrease in donations: increasing public awareness through advertising and enhancing donation accessibility via mobile units. Using system dynamics modelling, a simulation was conducted with real data from 2018 to 2022. The results show a significant decline in first-time, sporadic, and repeat donors during the pandemic. While advertising policies initially increased donations, their effectiveness waned over time due to overcrowded donation centres and ongoing safety concerns. In contrast, the mobile unit strategy consistently increased donations, without experiencing a subsequent decrease. These findings underscore the importance of adaptive, context-sensitive policies to ensure a stable blood supply during public health crises.

Keywords

COVID-19, Blood donation incentive policies, Fear and safety concerns, Ease of donation, Advertising.

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1. Introduction

Blood donations tend to rise during short-term crises such as natural disasters, with many new donors registering in response to public appeals (Feeny and Clarke, 2007; Hess and Thomas, 2003).The COVID-19 pandemic severely disrupted blood supplies worldwide, with donations decreasing by 40–67% in areas with movement restrictions (Raturi and Kusum, 2020). In Iran, a 35% drop in blood donations was reported during the early phase of the pandemic (Moghimisfandabadi et al., 2023).

Beyond the fear of infection, logistical barriers such as travel restrictions and closure of donation sites had long-term effects on donor participation .Crises also shift donor motivations some people feel more socially responsible, while others avoid donating due to fear or inconvenience (Swanson, 2020). Most existing studies focus on short-term crises and immediate donor responses. However, there is limited research on the long-term effects of global health crises, like the COVID-19 pandemic, on donor behaviour. This gap is significant, as pandemics tend to cause extended disruptions in blood supply chains and alter donor motivations beyond the immediate aftermath.

Fear of infection and travel bans were major factors in the decline in donations during COVID-19 (Hakami et al., 2022). Sustaining donor motivation is essential, as the more time passes since the donation, the less likely the donor is to donate again (Kazemi Babaahmadi et al., 2023; Thomas et al., 2015). The main innovation of this study lies in employing a system dynamics approach to model long-term behavioural interactions among blood donors and to simulate the effects of various policies throughout a large-scale health crisis. One of them is the COVID-19 pandemic, an area that has received limited attention in previous research. To address this gap, this study seeks to answer the following research question: How can various policy interventions (e.g., awareness campaigns, mobile units) mitigate long-term donation decline among different donor types during pandemics?

This study aims to identify the most effective policy levers to mitigate donation decline during pandemics by simulating various scenarios. So, this study uses a system dynamics approach to analyse how COVID-19 and policies like advertising and mobile units affect donor behaviour over time, capturing interactions among fear, logistics, policy interventions, and supply chain disruptions. The system dynamics approach has been adopted because it effectively models complex interactions over time, including feedback loops, delays, and behaviour change patterns, which are common in health crises. Unlike traditional statistical or optimisation methods, system dynamics allows for the simulation of evolving donor responses and policy impacts across different phases of a pandemic.

To better understand the impact of the pandemic, donors are divided into three key categories: repeat, sporadic, and first-time (Thomas et al., 2015). Repeat donors are typically more consistent due to intrinsic motivation, while first-time and sporadic donors are more sensitive to fear and access issues, which can result in larger fluctuations in donation behaviour during emergencies. Ensuring a stable blood supply requires understanding the unique behaviours of different donor types this study offers that distinction by modelling the behaviours of different donor types and examining the pandemic's effects on each group.

While most existing studies have focused on short-term donation behaviour (Zou, 2006; Veseli et al., 2022), this study provides new insights into how various policy interventions can influence different donor groups during extended health emergencies by shifting the focus to long-term donor behaviour. Using a system dynamics approach, the study captures how these interventions interact with behavioural patterns over time, offering a dynamic understanding of policy effectiveness.

This study's findings will have broader implications for future health crises, particularly in terms of how donor behaviour can be maintained or even improved during pandemics. By understanding the behavioural dynamics that influence blood donation, healthcare systems can better prepare for future crises. This includes developing targeted policies that address donor fear, barriers to donation, and the need for ongoing donor engagement. In particular, the research will contribute to understanding how to sustain a healthy and willing donor population during emergencies, ensuring blood supply chains remain resilient not only in the current pandemic but also in future public health emergencies.

2. Literature review

In this section, we explore various studies related to blood supply chains, donor behaviour, and the impact of crises, such as the COVID-19 pandemic, on blood donations.

Diabat et al. (2019) proposed a bi-objective optimization model to design resilient blood supply chains during disaster scenarios. Their approach minimises delivery time and disruptions, focusing primarily on logistical challenges. While their model is helpful in disaster management, it overlooks the social factors influencing donor behaviour, which are crucial in understanding blood donation dynamics during crises. Haghjoo et al. (2020) developed a robust model for blood supply chain network design, considering facility construction costs and post-disaster risk. While this study is valuable for optimising logistical operations, it does not address the role of donors in such environments, failing to account for how donor willingness might fluctuate during or after a crisis. Hamdan and Diabat (2020) employed a stochastic optimisation model to minimise blood delivery time and costs in post-disaster supply chains. Like other logistics-focused studies, their work primarily concerns operational efficiency and does not explore the dynamics of donor behaviour, a significant factor when assessing blood donation during emergencies. Cheraghi and Hosseini-Motlagh (2020) created a stochastic programming model for managing red blood cell supply chains. This model focuses on minimising supply chain costs and ensuring blood availability, but fails to consider the evolving nature of donor behaviour, which is essential to understanding long-term blood donation patterns during crises. Seyfi-Shishavan et al. (2023) examined ways to reduce blood shortages and supply chain costs in Istanbul, proposing a multi-cycle model that accounts for disaster risks. While this approach addresses logistical concerns, it does not focus on the social and behavioural aspects of donor behaviour or the challenges faced by donors in crises.

Montazeri Takhti et al. (2016) evaluated the impact of advertising on blood donation, finding that TV advertisements had a greater impact on donation rates than other media. While their findings are insightful for short-term donor engagement strategies, they do not explore the long-term behavioural effects of crises, such as pandemics, on blood donation motivation. Hakami et al. (2022) investigated the impact of COVID-19 on blood donation services in Saudi Arabia, revealing significant disruptions resulting from quarantine measures. While their study provides insights into the immediate effects of COVID-19 on donor behaviour, it lacks a deeper exploration of the long-term effects of pandemics on blood supply chains. Kazemibabaahmadi and Kheirandish (2022) examined the effects of COVID-19 on blood transfusion centres, highlighting the introduction of new policies to protect donors. Their research primarily addresses logistical and safety measures but fails to explore how such policies influenced donor decision-making or affected their willingness to donate during and after the pandemic. Veseli et al. (2022) compared the impact of COVID-19 on repeat and first-time donors, finding that both groups became less motivated to donate. This study provides insights into donor behaviour during the pandemic, but it does not examine the underlying causes of the decline in motivation over time**.** Moghimisfandabadi et al. (2023) focused on blood product supply chain performance and suggested that increasing the number of blood donation sites would improve performance. While their findings are useful for optimising logistics and infrastructure, they do not consider the broader behavioural and social factors that influence donor participation, particularly during crises.

Siu et al. (2025) examined the barriers to blood donation during the COVID-19 pandemic among non-donors and lapsed donors in Hong Kong. Their study highlighted that pre-existing psychosocial factors, such as lack of trust and low-risk perception, significantly affected donation decisions during the pandemic. While insightful, their study relies primarily on cross-sectional data and does not capture dynamic behaviour changes over time, limiting its applicability for long-term crisis response planning. Weng et al. (2024) investigated the influence of modern media, particularly social media and online videos, on blood donation behaviour in the post-pandemic era. They found that emotionally charged narratives and visual storytelling significantly boosted donation rates, especially among younger populations. Although the study sheds light on communication strategies, it does not explore how these tools interact with behavioural patterns over time, missing a systems-level understanding of motivation dynamics. Dorner and Csordás (2025) explored the psychological determinants of blood donation willingness during the COVID-19 pandemic in Hungary. The study identified self-efficacy, altruism, and emotional barriers as key factors influencing donor behaviour. However, their analysis remains static and survey-based, without modelling how these variables evolve or respond to interventions, thus limiting insights for long-term policy effectiveness.

Table 1. Review of articles on blood supply during crises and pandemics

No	Article	Model/Approach	Main Focus	Gaps and Limitations	Analysis of Long-term Impact	Role of Crises and Epidemics
1	**Diabat et al. (2019)** – *Bi-objective Optimisation Model for Blood Supply Chains during Disasters*	Bi-objective optimization for disaster supply chain design	Focuses on minimising delivery time and disruptions	Does not account for donor behaviour in crisis scenarios	Lacks long-term focus on donor engagement	Does not address donor behaviour during prolonged crises
2	**Haghjoo et al. (2020)** – *Robust Model for Blood Supply Chain Network Design*	Robust optimization model for post-disaster blood supply	Focus on cost and facility construction	Ignores the role of donors during or after crises	Does not examine donor willingness or long-term engagement	No focus on donor behaviour or changes during crisis
3	**Hamdan and Diabat (2020)** – *Stochastic Optimisation for Post-disaster Blood Supply Chains*	Stochastic optimization for delivery time and cost reduction	Focuses on operational efficiency	Ignores social factors and donor behaviour	Does not explore behavioural aspects or long-term donor participation	Does not consider the long-term crisis impact on donors
4	**Cheraghi & Hosseini-Motlagh (2020)** – *Stochastic Programming for Red Blood Cell Supply Chains*	Stochastic programming model for supply chain management	Focuses on cost reduction and the availability of blood	Lacks consideration for evolving donor behaviour	Does not account for long-term donor participation	Does not address donor behaviour in prolonged crises
5	**Seyfi-Shishavan et al. (2023)** – *Reducing Blood Shortages and Supply Chain Costs in Istanbul*	Multi-cycle model accounting for disaster risks	Focuses on logistical and disaster risk factors	Ignores the social factors affecting donor behaviour	No exploration of long-term donor behaviour changes	Does not consider donor behaviour challenges during crises
6	**Montazeri Takhti et al. (2016)** – *Impact of Advertising on Blood Donation*	TV advertisement impact on donation rates	Focuses on the short-term effects of advertising	Does not address the long-term impact of crises	No focus on the long-term effects of pandemics on donation motivation	Focuses on short-term donor engagement

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No	Article	Model/Approach	Main Focus	Gaps and Limitations	Analysis of Long-term Impact	Role of Crises and Epidemics
				on donor behaviour		without a crisis context
7	**Hakami et al. (2022)** – *Impact of COVID-19 on Blood Donation Services in Saudi Arabia*	Analysis of COVID-19 disruptions on blood donation	Focus on disruptions caused by quarantine measures	Lacks deeper exploration of long-term pandemic effects	Does not address long-term pandemic effects on donor behavior	Examines short-term COVID-19 effects but lacks long-term analysis
8	**Kazemibabaahmadi and Kheirandish (2022)** – *Impact of COVID-19 on Blood Transfusion Centers*	Analysis of new policies for donor protection	Focus on safety measures and logistical disruptions	Lacks exploration of how policies affect donor decision-making	Does not analyze donor behavior over time	Focuses on policies but does not address donor psychology during crises
9	**Veseli et al. (2022)** – *Impact of COVID-19 on Repeat and First-Time Donors*	Comparison of donor motivation before and during COVID-19	Focus on donor motivation changes during the pandemic	Does not explore underlying causes of motivation decline	Provides insights but lacks long-term analysis	Looks at immediate crisis impact but lacks long-term behavior analysis
10	**Moghimisfandabadi et al. (2023)** – *Blood Product Supply Chain Performance and Donation Sites*	Focus on increasing blood donation sites for better performance	Optimisation of logistics and donation infrastructure	Does not consider behavioural aspects of donor participation	Does not focus on donor behavior during crises	Focus on logistics without addressing donor behavior
11	**Siu et al. (2025)** *Barriers to Blood Donation during COVID-19 in Hong Kong*	Cross-sectional survey	Investigated barriers among non-donors and lapsed donors during COVID-19	Relies on static, cross-sectional data; lacks behavioral dynamics	No dynamic or long-term behavioral analysis	Focused on psychosocial barriers during COVID-19
12	**Weng et al. (2024)** *Impact of Modern Media on Blood Donation in the Post-Pandemic Era*	Observational study	Studied the effects of social media and visual storytelling on donation behaviour	Does not model the interaction of media with behavior over time	Lacks a systems-level or longitudinal perspective	Examines media influence in the post-COVID context
13	**Dorner and Csordás (2025)** *Psychological Determinants of Blood Donation in Hungary*	Survey-based analysis	Analyzed factors like self-efficacy, altruism, and emotional barriers	Static analysis; no modelling of behavioural evolution or interventions	Limited insight into time-based policy impact	Investigate psychological factors during COVID-19

2.1. Contributions of this research

Recent years have seen a growing interest in blood supply chains, with various studies examining logistical challenges and supply chain disruptions (e.g., Seyfi-Shishavan et al., 2023; Diabat et al., 2019; Hamdan and Diabat, 2020; Haghjoo et al., 2020). However, these studies predominantly focus on optimising supply chains during crises and tend to overlook the dynamic factors influencing donor behaviour, which are crucial in understanding blood donation patterns during emergencies.

Several studies have examined variables influencing donor behaviour and strategies to increase donor engagement, such as those by Moslemi et al. (2008), Montazeri Takhti et al. (2016), and Abolghasemi et al. (2009). More recent research on the impact of COVID-19 on blood donations, including studies by Hakami et al. (2022), Spekman et al. (2021), Veseli et al. (2022), and Raghuwanshi et al. (2022), has provided valuable insights into the immediate effects of pandemics on donor behaviour. However, these studies are primarily qualitative or statistical and do not address the complex, dynamic decisions involved in blood donation during prolonged crises. Additionally, studies such as those by Veseli et al. (2022) and Hakami et al. (2022) focus on the immediate effects of pandemics but lack a systems approach to explore the long-term changes in donor behaviour.

This research aims to fill these gaps by applying a systems dynamics approach to model the long-term effects of COVID-19 on donor behaviour. By examining the interactions between factors such as donor fear and policy interventions, this study offers new insights into how blood donation behaviours evolve. Moreover, it provides recommendations for improving donor engagement during future crises, especially by focusing on the behavioural factors that influence donors' decisions.

3. Research methodology

Because the goal of the current research is to increase the number of donors during the COVID-19 pandemic, it is a practical endeavour. To determine the pattern of previous variations in the volume of donations and in repeat, sporadic, and first-time donors, the research employed data collection methods, including document studies, and utilised data from the Mashhad Blood Transfusion Centre's databases. All initial simulation data were collected monthly over a 60-month period starting in 2018 (1397 in the Iranian calendar). The historical data specifically included accumulation (stock) variables such as First-Time Donors (FD), Sporadic Donors (ED), and Repeat Donors (RD). System dynamics is used in this research due to the system's complexity, latency, and interconnectedness.

In this approach, the research problem is defined in the first step. The research problem, as mentioned earlier, is how to prevent a decrease in the number of people who donate blood under the influence of the spread of COVID-19. Then, based on the research background, the variables related to the problem and the boundary of the donor system are identified, as shown in Table 2.

Table 2. The boundary of the blood donation model in pandemic conditions

Exogenous Variables	Endogenous Variables	Subsystem
Migration to the region, Death, Migration from the region	Under 18 years old, Over 60 years old, Between 18 and 60 years old, Birth Rate,	population

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Exogenous Variables	Endogenous Variables	Subsystem
Recovey time, Infection Rate, Congestion in blood collection units, Vaccination rate	Death from epidemics, Infected, Recovered, Infecting, Susceptible, Vaccinated, fear and safety concerns	Pandemic disease
Ease of donation, The effect of the season, SMS, Advertising via virtual networks,	Time between donations, Percentage of people informed about the need for blood, Ready donors population, Re-donation from Advertising, Re-donation Appropriate treatment of staff, Potential donation population, Re-donation from Teaching, Percentage of public education in order to increase awareness and attitude, First time donors, Sporadic donors, Repeat donors	Blood donation

To define the boundary of the model and select the appropriate variables, this study relied on content analysis of previous literature and organizational documents. Additionally, six experts and specialists from the Mashhad Blood Transfusion Centre were consulted. Variables and their relationships were selected based on their relevance, impact on the donation process, and their importance in system behaviour. Subsequently, the selected variables and causal relationships were reviewed and validated by these experts to ensure their accuracy and appropriateness within the model.

3.1. The dynamic hypothesis and Causal loop diagram

The causal loop diagram shown in this study was created through several processes. Initially, a content analysis of the research background was used to identify key performance variables and factors influencing donors before designing the causal loop model. The subsequent stage involved identifying the associations between variables and the behaviour of the main performance measures, as well as completing the causal loop models through expert interviews. The causal loop diagram of the blood donation model during pandemic infections is displayed in Figure 1.

The dynamic hypothesis is that the blood centre can increase the number of blood donors by implementing various strategies, such as advertising the need for blood. As the number of potential donors increases, it leads to overcrowding at blood collection centres. Overcrowding at these centres causes fear and safety concerns among donors, leading to them postponing their blood donations. In other words, the time between two blood donations increases for repeat donors, and consequently, the number of potential donors decreases. Therefore, in policymaking, attention should be paid to the effective factors within the system, and appropriate policies should be selected and implemented.

3.2. Causal loop diagram

3.2.1. Population subsystem

Changes in the age structure of the population affect many activities and processes. The minimum acceptable age for donating blood is 18 years, and the maximum age is 60 years. Since the population has a dynamic structure, the population subsystem was considered. This subsystem has a reinforcing loop and two balancing loops.

In the first balancing loop, the population aged 18 to 60 increases due to the population under 18 after a certain period; as the population aged 18 to 60 increases, the population under 18 decreases. The second balancing loop illustrates the relationship between the population over 60 and the population aged 18 to 60.

In the reinforcing loop, as the population under 18 years increases, the population aged 18–60 increases with a delay. Consequently, as this age group increases, the birth rate rises, leading to a further increase in the population under 18 years, thus repeating the loop. In the model of blood donation in pandemic conditions, the population subsystem is highlighted in orange (Figure 1).

3.2.2. Pandemic subsystem

Since the pandemic has resulted in a significant decline in blood donations, the epidemic's subsystem and its consequences must be incorporated into the model. SIR models, which are well-known and authorized models in the study of disease outbreaks, served as the foundation for the creation of this subsystem. In the SIR model, simple assumptions are taken into consideration, such as mortality not being considered. The present study developed the SIR model and incorporated the variable of mortality due to pandemic disease, as well as the influence of vaccination, fear, and safety concerns, into the model. This subsystem has two reinforcing loops and four balancing loops, as shown in Figure 1. The population subsystem is displayed in red in Figure 1.

3.2.3. Subsystem of donors

In the blood donation system, three categories of donors are considered: first-time, sporadic, and repeat donors. Unfortunately, the rate of positive HBsAg was 40% in first-time donors and 6% in sporadic donors. HBsAg-positive samples were not observed in repeat donors (Ranjbarian, 2008). Therefore, one of the goals of the Blood Transfusion Organisation is to invest in repeat and sporadic donors and to encourage first-time donors who have healthy screening tests to become repeat donors.

As shown in Figure 1, first-time donors can be encouraged to donate again through various means, including advertising, education, and increasing awareness and positive attitudes. With the increase in the number of repeat donors, the number of sporadic donors decreases. However, under the influence of activities such as advertising and education, first-time donors often become sporadic donors, resulting in a decrease in the number of first-time donors. This cycle is balanced, but the population of first-time donors is influenced by the potential donor audience. In the figure below, the population system is shown in green.

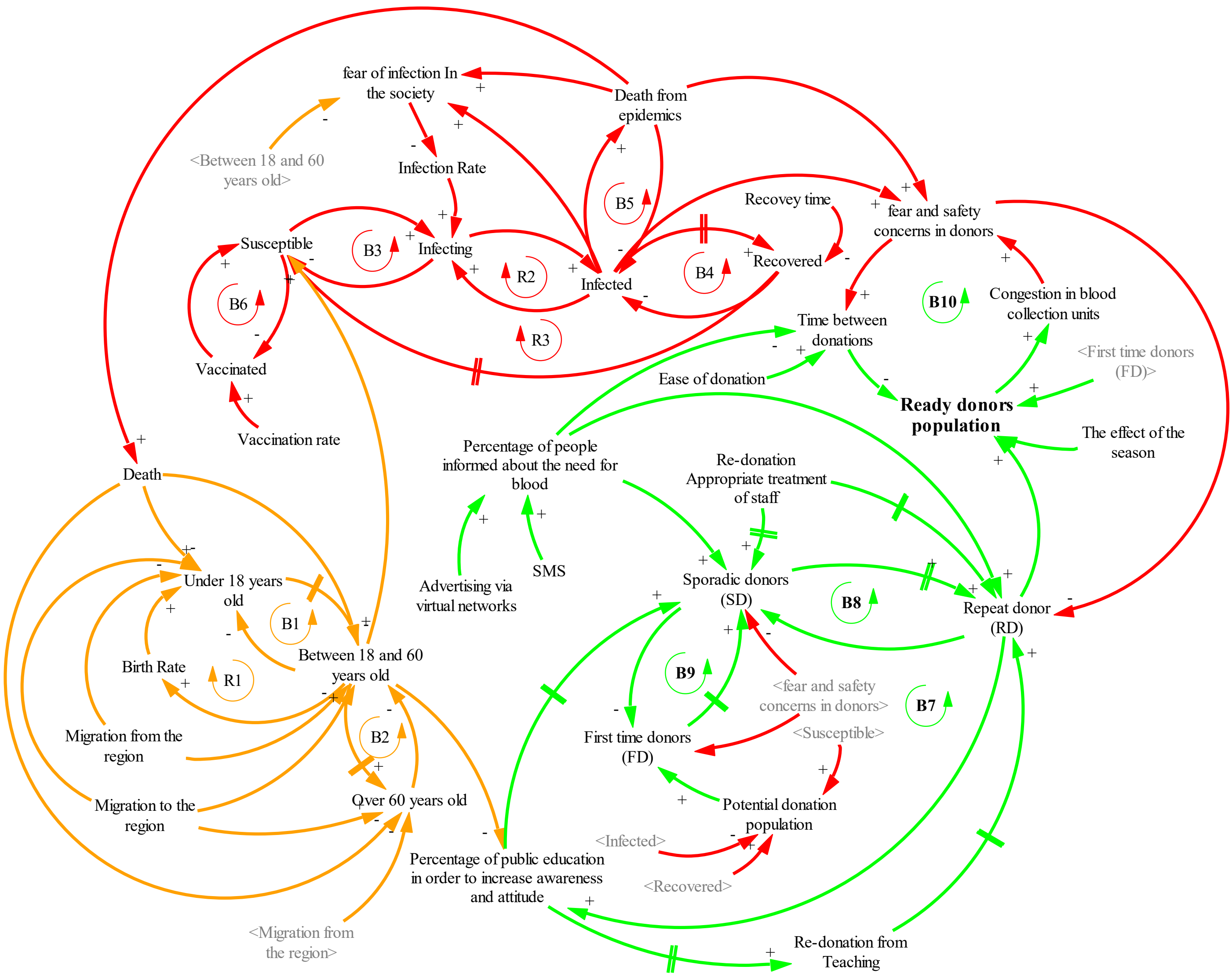

Figure 1. Causal loop diagram of blood donation model in pandemic conditions

3.3. Stock and flow diagram

As shown in Figure 2, the relationship between the population subsystem and the blood donation subsystem, as measured by the population variable, ranges from 18 to 60. The pandemic disease subsystem causes the deaths of people in the population subsystem through the mortality variable caused by pandemic disease. Additionally, the population subsystem is linked to the pandemic disease subsystem through the variable of people between 18 and 65 years old. Of course, since the target blood donation model includes people between 18 and 65 years old, only this variable is considered in the pandemic disease subsystem.

The pandemic disease subsystem affects and reduces the potential population of blood donation subsystem donors through the ratio of susceptible, sick, and recovered individuals. Donors are also concerned about overcrowding in blood collection units, and as a result, the time interval between donations increases, even for repeat donors, leading to a decrease in all three donor groups.

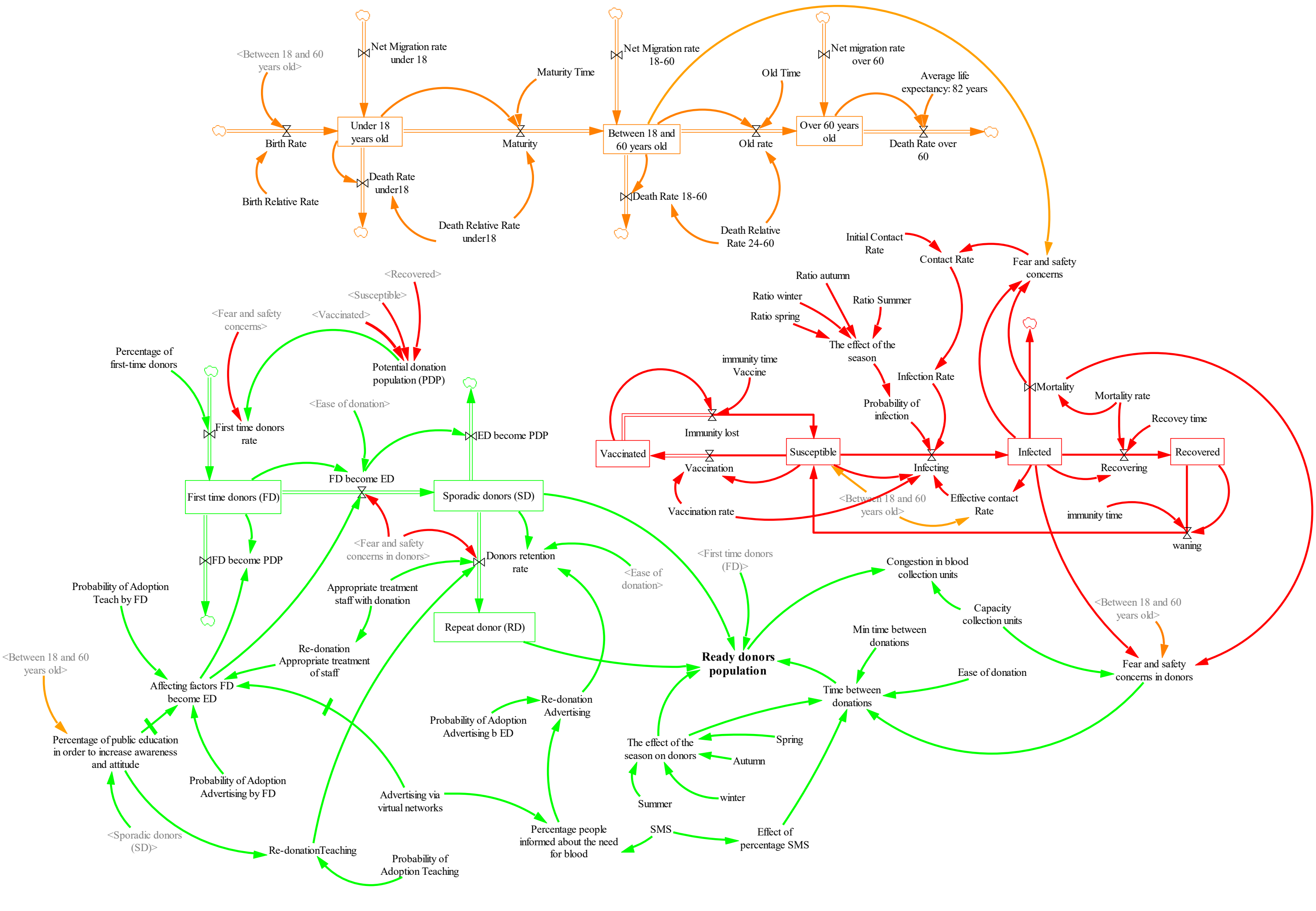

Figure 2. Stock and flow model of the blood donation model in pandemic conditions

3.4. *Formulation of the Stock and flow model*

In this step, the connections between system components are formulated, transitioning from a conceptual (qualitative) state to a quantitative state, using relevant mathematical equations. In fact, by entering equations, mental models are linked to the real world. It should be noted that all simulations in the validation test were started in 2018. Simulation courses are monthly. Table 3 presents the formulas and changes in blood donation models under epidemic conditions. The values of the accumulation variables related to the year 2018 have been simulated and extracted from the documents and statistics of the Blood Transfusion Organisation.

Table 3 .The formula of some variables of the blood donation model in pandemic conditions

No	Variable name	Variable type	Equation	Unit	Reference	Value
1	Under 18 years old	Stock	Birth Rate+Net Migration rate under 18-Death Rate under18-Maturity	people	Khorasan Razavi statistics	2254350
2	Between 18 and 60 years old	Stock	Maturity+"Net Migration rate 18-60"-"Death Rate 18-60"-Old rate	people	Khorasan Razavi statistics	3772880
3	Over 60 years old	Stock	Net migration rate over 60+Old rate-Death Rate over 60	people	Khorasan Razavi statistics	592328
4	First time donors (FD)	Stock	First time donors rate-FD become ED-FD become PDP	people	Khorasan Razavi blood transfusion organization statistics	2271
5	Sporadic donor (SD)	Stock	FD become ED-Donors retention rate-ED becomes PDP	people	Khorasan Razavi blood transfusion organization statistics	3518
6	Repeat donor (RD)	Stock	Donor retention rate	people	Khorasan Razavi blood transfusion organization statistics	6802
7	Vaccinated	Stock	Vaccination-Immunity lost	people	Jahani (2020)	0
8	Susceptible	Stock	Immunity lost+waning-Infecting-Vaccination	people	Jahani (2020)	592128
9	Infected	Stock	Infecting-Mortality-Recovering	people	Jahani (2020)	150
10	Recovered	Stock	Recovering-waning	people	Jahani (2020)	0
11	Birth Rate	Rate	Birth Relative Rate*(Between 18 and 60 years old/2)	people/ Month	Experts	
12	Maturity	Rate	((1-Death Relative Rate under18)*Under 18 years old)/Maturity Time	people/ Month	Sterman (2000)	
13	Death Rate over 60	Rate	Over 60 years old/"Average life expectancy: 82 years"	people/ Month	Sterman (2000)	
14	Old rate	Rate	((1-"Death Relative Rate 24-60")*Between 18 and 60 years old)/Old Time	people/ Month	Sterman (2000)	
15	Death Relative Rate under18	Rate	Death Relative Rate under18*Under 18 years old	people/ Month	Sterman (2000)	
16	Death Rate 18-60	Rate	("Death Relative Rate 24-60"*Between 18 and 60 years old)+Mortality	people/ Month	Sterman (2000) + Researcher	

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No	Variable name	Variable type	Equation	Unit	Reference	Value
17	Immunity lost	Rate	Vaccinated/immunity time Vaccine	people/ Month	Rehman (2023)	
18	Vaccination	Rate	DELAY1(Vaccination rate*Susceptible, 4)	people/ Month	Researcher	
19	Infecting	Rate	(1-Vaccination rate)*Susceptible* (Probability of infection*Effective contact Rate*Infection Rate)	Contact people/ /Month	Researcher + Sterman (2000)	
20	Recovering	Rate	(1-Mortality rate)*Infected/Recovey time	people/ Month	Lazovic-Lønningen (2020)	
21	waning	Rate	Recovered/immunity time	people/ Month	Rehman (2023)	
22	First time donors rate	Rate	"Percentage of first-time donors"*"Potential donation population (PDP)"	people/ Month	Experts+Researcher	
23	FD become ED	Rate	("First time donors (FD)"* Affecting factors FD become ED)*(1-(tars))+("First time donors (FD)"* Affecting factors FD become ED j)*(1+Ease of donation)	people/ Month	Experts+Researcher	
24	Donors retention rate	Rate	((" Sporadic donor (SD)"*"Re-donation Advertising")+ (" Sporadic donor (SD)"*"Re-donationTeaching")+ (" Sporadic donor (SD)"*Appropriate treatment of blood collection department staff with donation)) + (" Sporadic donor (SD)"*Ease of donation)- (" Sporadic donor (SD)"*(fear and safety concerns in donors))	people/ Month	Experts+ Researcher	
25	The effect of the season	Auxiliary	(PULSE TRAIN(0, 3, 9, 100)*Ratio spring)+ (PULSE TRAIN(3, 3, 9, 100)*Ratio Summer)+ (PULSE TRAIN(6, 3, 9, 100)*Ratio autumn)+ (PULSE TRAIN(9, 3, 9, 100)*Ratio winter)	Percent	Experts	
26	Contact Rate	Auxiliary	Initial Contact Rate *(1- fear and safety concerns)	Contact /Month	Researcher	
27	Ready donors population	Auxiliary	("Repeat donor (RD)"/Time between donations)+ (("First time donors (FD)") *(1-The effect of the season on donors))+ ((" Sporadic d donor (SD)"/2)*(1-The effect of the season on donors))	people/ Month	Experts	

4. Model validation

Validating the model is one of the most crucial phases of modelling. Essentially, validation ensures that the model is accurate and effective as a tool for policymaking. This study employs extreme conditions and behaviour reproduction tests for validation. The simulation was conducted on a monthly basis, and the results were compared visually and statistically with real data from the Blood Transfusion Centre from early 2018 (1397) to late 2022 (1401). The comparison focused on the key stock variables: First-Time Donors (FD), Sporadic Donors (ED), and Repeat Donors (RD).

4.1. Behavior-Reproduction test

With the behaviour-reproduction test, the behaviour created by the model is compared with the real behaviour of the system (reference mode); in Figure 3, the behaviour created by the model in first-time donor, sporadic donor, and repeat donor variables is compared with the reference diagram. As can be seen, the behaviour produced by the model is similar to the behaviour of the reference model.

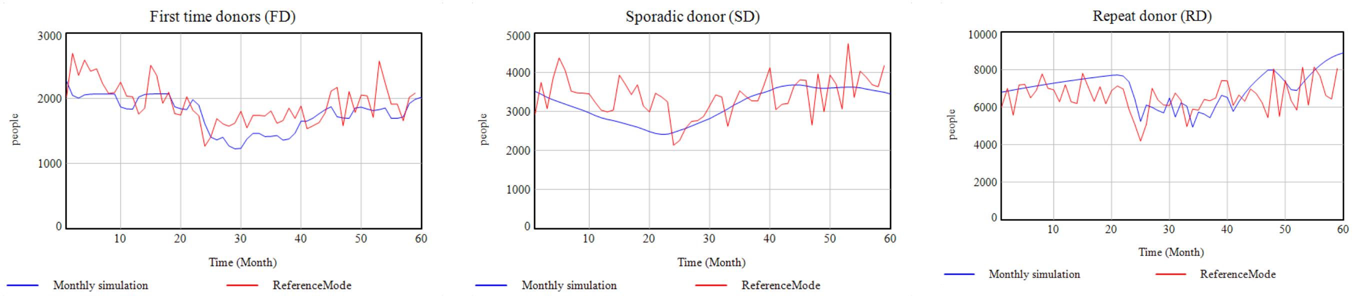

Figure 3. Comparison of the reproduction behavior of key variables with reference of mode

This comparison is based on both visual inspection and statistical analysis. Figure 3 illustrates the alignment of the simulated and real-world trends of FD, ED, and RD over the simulation period.

A comparison of the data from the simulation and the reference model for key variables has been conducted, as shown in Table 3. First, a variance comparison statistical test was used to assess the equality of variances between the two populations. The purpose of this step is to ensure that the variability in both datasets is comparable and that the observed differences are not due to significant differences in variance. The results of the variance comparison test confirmed the equality of variances at a 1% confidence level, which indicates that the two populations exhibit similar levels of variability. After verifying the equality of variances, the t-test for two populations with equal variances was performed to compare the means of the two populations. The outcomes of these tests demonstrated that, at the 1% confidence level, the variances and means of the two populations are statistically equal. This supports the validity of the behaviour reproduction process, confirming that the simulation model reliably reflects the real-world data. The detailed results of the variance comparison test, including the variance values for each population, the test statistic, and the p-value, are presented in Table 4.

Table 4. Comparison of reproduction behaviour and reference mode

Independent Samples Test										
		Levene's Test for Equality of Variances		t-test for Equality of Means						
		F	Sig.	t	df	Sig. (2-tailed)	Mean Difference	Std. Error Difference	99% Confidence Interval of the Difference	
									Lower	Upper
Repeat donor	Equal variances assumed	.413	.522	2.590	116	.011	404.62441	156.23417	-4.53380	813.78261
	Equal variances not assumed			2.590	115.545	.011	404.62441	156.23417	-4.56072	813.80953
Sporadic donor	Equal variances assumed	.572	.451	-2.473	116	.015	-204.12712	82.52680	-420.25471	12.00048
	Equal variances not assumed			-2.473	115.266	.015	-204.12712	82.52680	-420.27770	12.02347
First time donors	Equal variances assumed	.081	.777	-2.583	116	.011	-125.39305	48.53866	-252.50988	1.72377
	Equal variances not assumed			-2.583	115.946	.011	-125.39305	48.53866	-252.51086	1.72476

4.2. The extreme-conditions test

The extreme conditions test demonstrates the robustness of the model under extreme conditions. According to Dehghani Saryazdi and Owlia (2014), this means that the model should exhibit expected behaviour under all circumstances, including changes in input values or regulations.

As depicted in Figure 4, if the pandemic begins later, infections in society occur subsequently, leading to a corresponding delay and decrease in the number of potential donors.

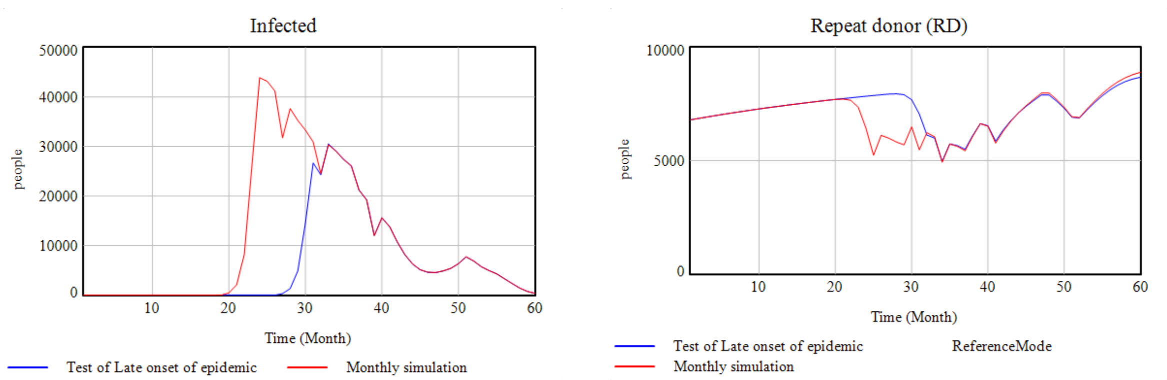

Figure 4. The extreme-conditions test of late onset of epidemic

As shown in Figure 5, when the probability of first-time donors becoming zero since 2018 is considered, this group reaches zero after two periods, causing a gradual decrease in the number of sporadic donors. Conversely, when the probability of first-time donors doubling since 2018 is considered, their donations also double, leading to an increase in the number of sporadic donors.

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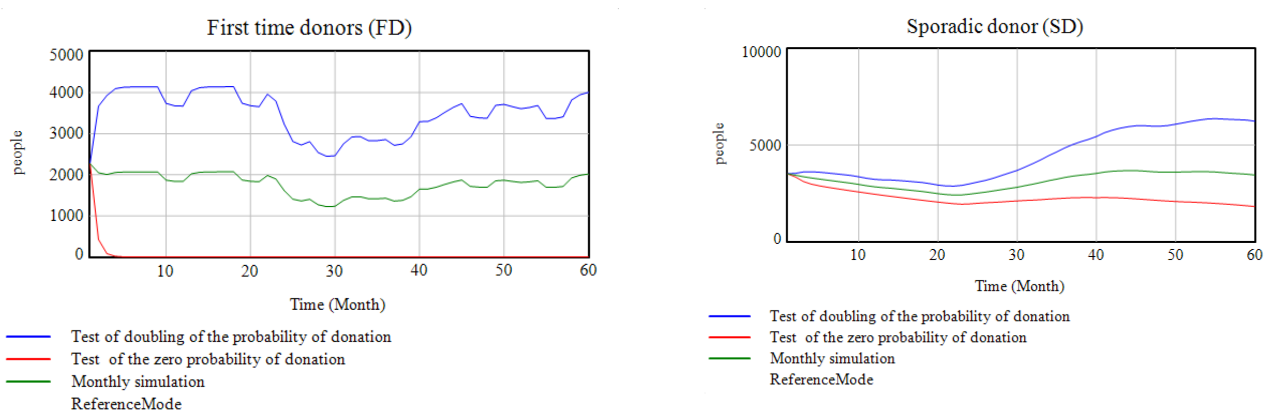


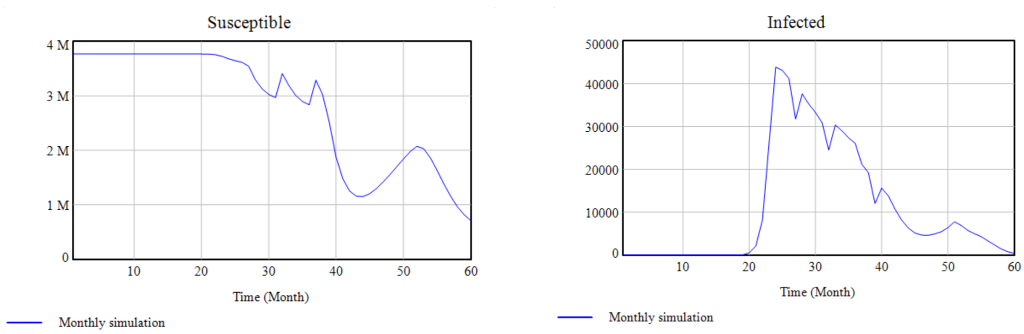
Figure 5. The extreme-conditions test of the zero and the doubling of the probability of donation

5. The results of the simulation of stock and flow model simulation

This model simulates four pandemic waves occurring during the third vaccination wave. Additionally, it posits that each new wave diminishes the immunity gained from previous vaccinations and antibodies, rendering individuals vulnerable to illness again.

As depicted in Figure 6, due to the pandemic and the associated fear and safety concerns, the numbers of first-time, sporadic, and repeat donors have all decreased. The population of potential donors, encompassing first-time, sporadic, and repeat donors, has also seen a sharp decline.

Note that the number of donors ready to donate is smaller than the sum of these three donor categories because a regular donor cannot donate blood again until 56 days after their last donation. The population of potential donors has also decreased due to the increased time interval between donations caused by fear and safety concerns during disease outbreaks, such as the coronavirus pandemic.



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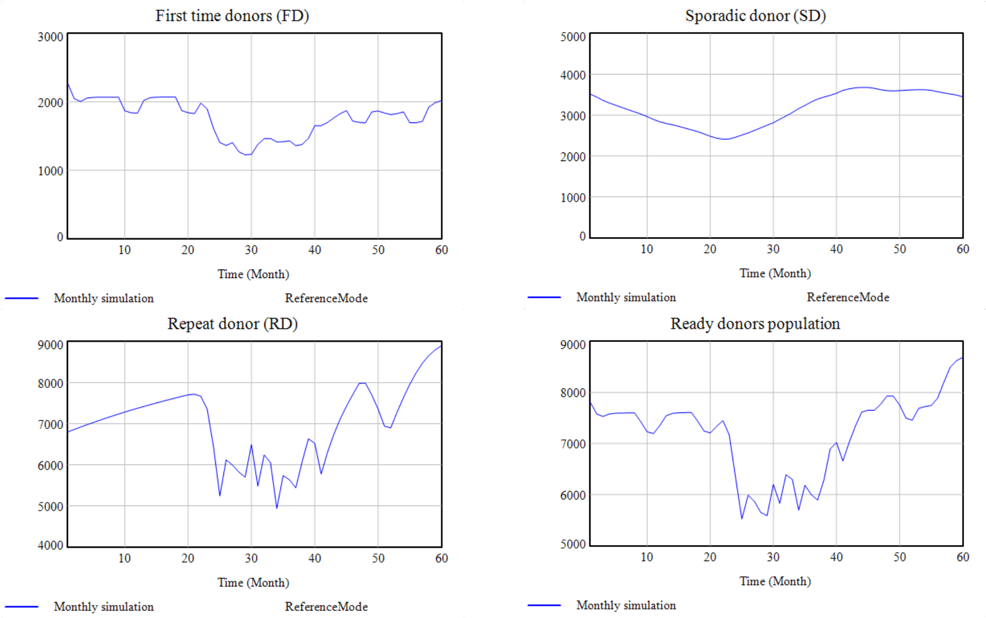


Figure 6. Monthly simulation of the blood donation model in pandemic conditions

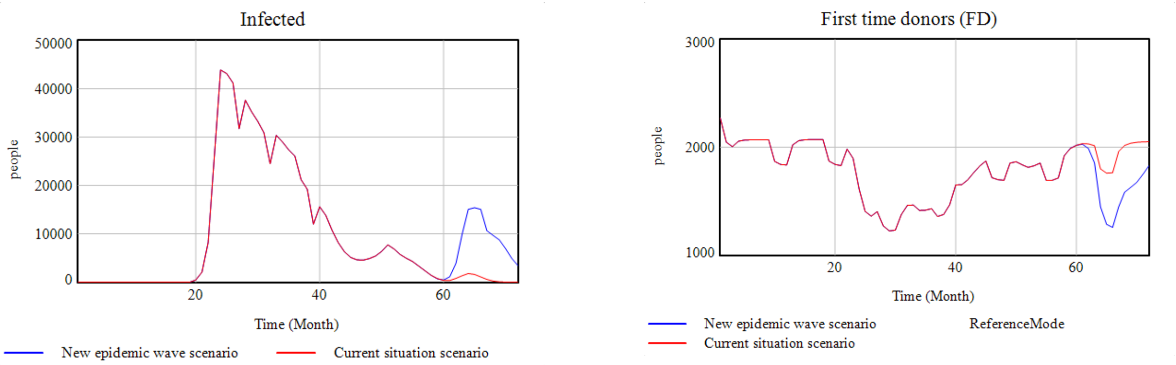
6. Scenario planning and policy design

6.1. Scenario planning

The planning and management of the blood donation system must consider potential scenarios external to the system boundary, given the unpredictability of future events. According to the scenario of a new pandemic wave, a new wave of COVID-19 infections is expected to emerge in the sixtieth month, and a vaccine will be ready seven months later. Table 5 lists the scenarios and policies.

Table 5. Scenario planning and policy design

scenario	**Policy**	
Current situation scenario (improvement of the pandemic situation)	Advertising policy	Ease of donation policy
Scenario of a new pandemic wave (new wave of the pandemic in the period of 60, and the supply of the vaccine 7 months later)	Advertising policy	Ease of donation policy



DOI: 10.22067/JSTINP.2025.91912.1142

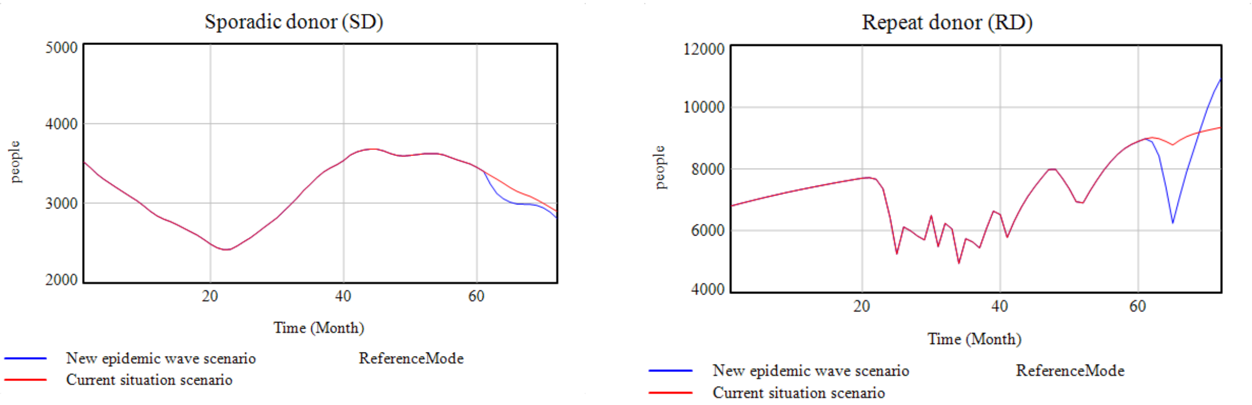


Figure 7. The scenario of the increase in the severity of the COVID-19 disease in the 60th month and the preparation of the vaccine 7 months later

As shown in Figure 7, all three donor groups experience a decline as the infected population increases progressively.

6.2. Policy design

After the designed model was confirmed, policies were developed to increase donor participation in the blood donation system. According to the articles of Reich et al. (2006) and Montazeri Takhti et al. (2016), at the time of disruption, the policy of advertising and recall increased the number of donors. According to the literature study and expert opinions, increasing the ease of donating through mobile units can reduce the impact of fear and safety concerns associated with contracting an epidemic. These policies came into effect on the 63rd and continued until the 72nd month.

In the 65th month, advertising policy has led to an increase in donors (Figure 8). The ease of donation policy is simulated in the current scenario. As shown in Figure 8, the number of donors has increased.

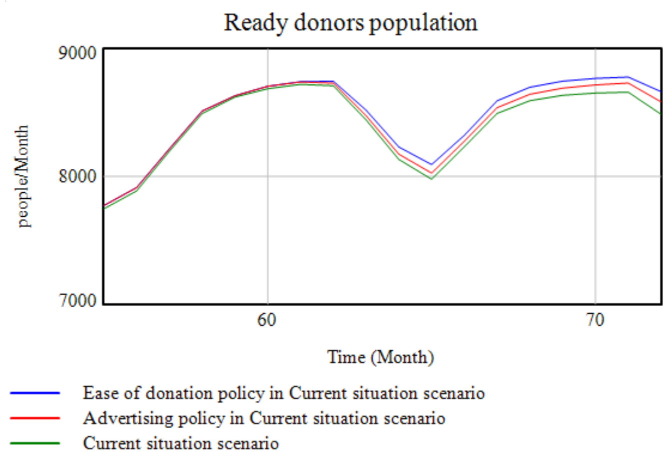


Figure 8. Policies in the current scenario

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The advertising policy is simulated in the scenario of the new pandemic wave. In the 65th month, the advertising policy initially increased donors, but after some time, it decreased again, indicating its short-term effect (Figure 9). The reason for this decline is that the increase in donors caused overcrowding in donation centres, which in turn heightened donors' fear and safety concerns. As a result, these concerns neutralised the effectiveness of the policy.

The ease of the donation policy is simulated in the scenario of the new pandemic wave. As depicted in Figure 9, the number of donors has increased without a subsequent decrease, unlike the advertising policy.

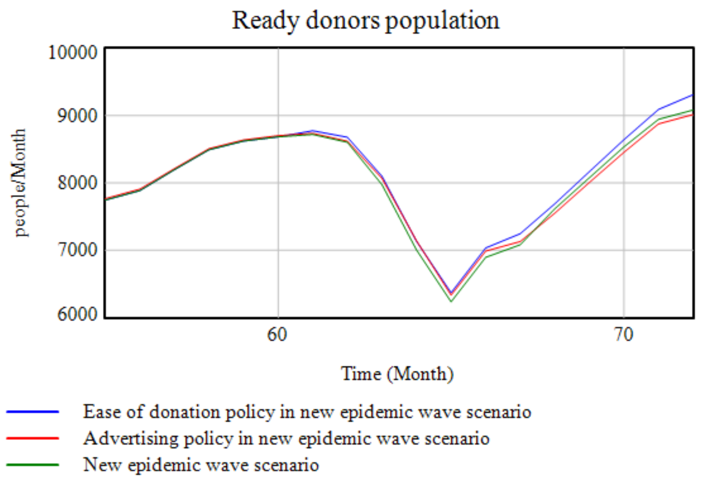

Figure 9. Policies in the new pandemic wave scenario

7. Conclusion

The COVID-19 pandemic created an unprecedented disruption in global blood donation systems, raising urgent questions about donor motivation and retention in times of crisis. One of the significant consequences of the COVID-19 pandemic has been a severe disruption in the supply of blood donations. The primary focus of this research is addressing how to prevent the decline in blood donors due to the influence of COVID-19, thereby ensuring an adequate and timely response to patient demand for blood products. Therefore, it is essential not only to prevent a decline in donations but also to understand the underlying factors that influence donor behaviour during pandemics, as well as to identify effective strategies for sustaining donor engagement in the long term.

This study highlights a critical issue: the importance of maintaining donor motivation during pandemics to prevent blood shortages at treatment centres. The pandemic has heightened fear and anxiety about the disease, reducing the willingness of individuals to donate blood. With the widespread transmission of the virus, public concern about contracting the disease has increased, leading to a decline in blood donations. As evident from the simulation results, the pandemic has extended the time intervals between donations for repeat donors due to increased fear and safety concerns. Consequently, there has been a decline across all three donor groups: first-time, sporadic, and repeat donors. This emphasizes the importance of targeting different donor types with tailored policies to address their unique barriers and motivations.

The results of implementing advertising policies and enhancing donation accessibility through increased mobile units under normal conditions demonstrate that both initiatives lead to increased donations. However, when these policies were implemented during the COVID-19 pandemic, the advertising policy initially increased donor participation. Simulation results, however, indicated a decline around month 67, driven by concerns over overcrowding and potential exposure to illness, which diminished the policy’s effectiveness. This highlights the need for adaptable policies that respond to evolving public perceptions and situational factors during prolonged crises. Therefore, it would be prudent to consider implementing policies that effectively encourage blood donation. Future research should explore how the timing and targeted messaging of advertising policies can be adjusted to address donor fatigue and fear in prolonged crises.

This study investigated the strategy of improving access through mobile units. In this policy, after coordination with donors, mobile units are activated in the homes of donors, workplaces of donors, or residences of educational institutions. Enhancing access can provide donors with more opportunities to contribute. The results indicated that this strategy mitigated the pandemic's impact on donor participation. However, further studies should investigate how mobile units could be scaled and integrated with other logistical systems to ensure sustainability during ongoing or future health crises. Therefore, including cost data in the model could lead to more accurate and reliable analyses.

In conclusion, this study provides valuable insights into the long-term behavioural impacts of the COVID-19 pandemic on blood donation over a five-year period—an aspect often overlooked in previous studies focused on short-term effects. Nevertheless, further research is needed to explore behavioural shifts beyond the pandemic and examine the broader implications for blood donation strategies in future public health emergencies. The current model has only been applied to the Mashhad region. Future research could include data from other regions of the country or even comparisons across countries. This could enhance the validity of the results and demonstrate whether these policies and findings are applicable in other geographical and cultural contexts. Incorporating more real-world data from diverse regions and blood centres could enhance the validity and generalizability of the findings.

Additionally, expanding the discussion of policy implications to include actionable and context-specific recommendations can help blood donation organisations develop more resilient and adaptive systems for crisis response and long-term donor retention.

Disclosure statement

No potential conflict of interest was reported by the author(s).

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