Is Digital Twin a Better Solution to Improve ESG Evaluation for Vaccine Logistics Supply Chain: A Game Theoretic Analysis

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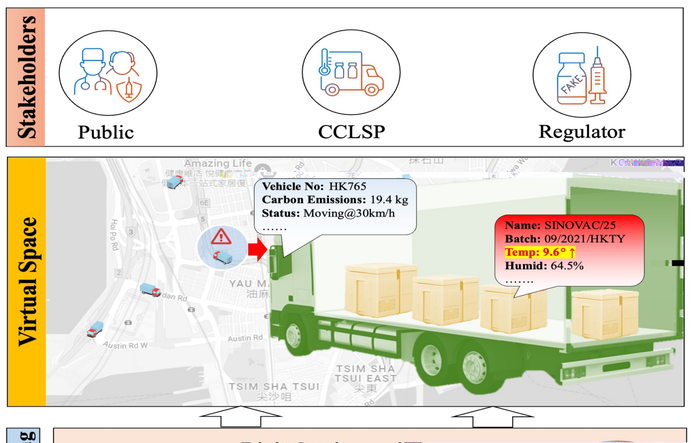
Introduction

This research systematically analyzes the influence of digital twin service (DTS) on ESG evaluation and analytically investigates the long-term behavior of sustainability concerned stakeholders in the VLSC. Firstly, an architecture of DTS enabled ESG evaluation for VLSC is proposed to describe the DTS effectiveness. After that, a tripartite evolutionary game model in a two-tiered VLSC including CCLSPs, the public, and government regulators is proposed. And the conditions for the existence of equilibrium stable points are derived to capture the feature of the government incentives and the role of the public in the DTS investment decisions of CCLSPs. The association of the factors is validated by using analytical sensitivity analysis. Lastly, managerial insights are derived which indicate that DTS can offer better solutions to improve ESG evaluation for CCLSPs in VLSC with different strategic stakeholders.

Research Questions

1. What are the functions and benefits of DTS for ESG evaluation of the VLSC from technical perspective?
2. In the tripartite evolutionary game model, is there any game equilibrium point where the CCLSPs choose to invest in DTS for improving ESG evaluation and what kind of decisions should the public and government regulators make?
3. How can this model be used to explain the changes in the strategic choice preference of the three stakeholders, and what are the main influencing factors?

DTS Enabled ESG Evaluation



The Model

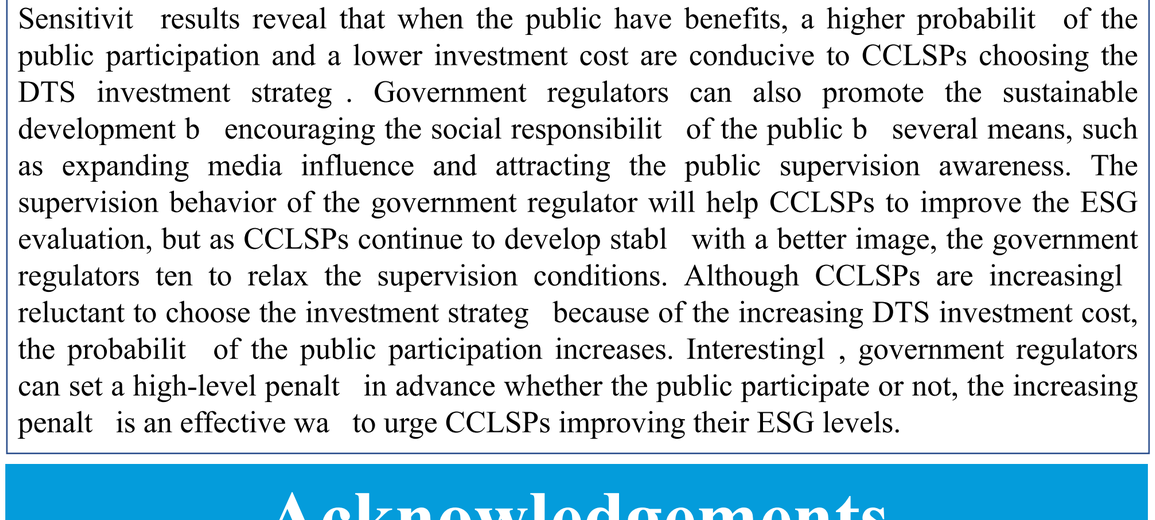
A two-tiered VLSC is considered, which composed CCLSPs who offer the logistics service, the public who are involved in the ESG evaluation process and the government regulators who supervise the vaccine logistics market. This research focuses on the design of the governance mechanism for facilitating the investment of DTS in the VLSC to improve the ESG evaluation of CCLSPs. Specifically, three main scenarios need to be discussed, the role of DTS in the ESG evaluation, the impact of government incentives on CCLSPs' investment in digital twins, and the role of public participation in the entire process.

	CCLSP payoff	Public payoff	Government regulator payoff
(I, P, S)	$R+\Delta R+S_g+J-C_{DT}$	$W_p+\Delta W_p-C_p$	$-S_g-f-J+M_g$
(I, P, NS)	$R+\Delta R-C_{DT}$	$W_p+\Delta W_p-C_p$	M_g
(I, NP, S)	$R+\Delta R+S_g+J-C_{DT}$	W_p	$-S_g-f-J+M_g$
(I, NP, NS)	$R+\Delta R-C_{DT}$	W_p	M_g
(NI, P, S)	$R-P+J-I$	$-C_p-L_p$	$-J-f+P-L_g-B$
(NI, P, NS)	$R-I$	$-C_p-L_p$	$-L_g-C_g-B$
(NI, NP, S)	$R-P+J$	$-L_p$	$-J-f+P-L_g$
(NI, NP, NS)	R	$-L_p$	$-L_g-C_g$

Model Analysis

$$\begin{cases} F(x)=\dfrac{dx}{dt}=x(x-1)(C_{DT}-\Delta R-yI-zP-zS_g) \\ F(y)=\dfrac{dy}{dt}=y(y-1)(C_p-\Delta W_p x) \\ F(z)=\dfrac{dz}{dt}=z(z-1)(J-C_g-P+f+xC_g+xP+xS_g) \end{cases}$$

$$J=\begin{bmatrix} -(2x-1)(\Delta R-C_{DT}+Iy+Pz+zS_g) & -x(x-1) & -x(x-1)(P+S_g) \\ -y(y-1)\Delta W_p & (2y-1)(C_p-x\Delta W_p) & 0 \\ z(z-1)(C_q+P+S_g) & 0 & (2z-1)(J-C_g-P+f+xC_g+Px+S_g x) \end{bmatrix}$$



Conclusions

Sensitivit results reveal that when the public have benefits, a higher probabilit of the public participation and a lower investment cost are conducive to CCLSPs choosing the DTS investment strateg . Government regulators can also promote the sustainable development b encouraging the social responsibilit of the public b several means, such as expanding media influence and attracting the public supervision awareness. The supervision behavior of the government regulator will help CCLSPs to improve the ESG evaluation, but as CCLSPs continue to develop stabl with a better image, the government regulators ten to relax the supervision conditions. Although CCLSPs are increasingl reluctant to choose the investment strateg because of the increasing DTS investment cost, the probabilit of the public participation increases. Interestingl , government regulators can set a high-level penalt in advance whether the public participate or not, the increasing penalt is an effective wa to urge CCLSPs improving their ESG levels.

Acknowledgements

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