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Article

The Evaluation of Technology Startup Role on Indonesian SMEs Industry 4.0 Adoption using CLD-ABM Integrated Model

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Abstract: The role of the Association of Southeast Asia Nations (ASEAN) small and medium enterprises (SMEs) as the regional socioeconomic stabilizer inseparable from endogenous multi-sector collaboration. Indonesian SMEs struggled with Industry 4.0 adoption due to the lack of digital infrastructure (DI) and digital literacy (DL). This study aims to explore the role of technology startups (TS) on covering DI and DL of SMEs. The evaluation was through a multi-parties provisional simulation model of Indonesian SMEs' collaboration with government and TS. The provisional model is the integration of an Agent-based model (ABM) and causal loop diagram (CLD). The model assesses the TS collaboration impact on SMEs' Industry 4.0 adoption and SME competition with larger competitors. The simulation results imply that SMEs' collaboration with TS leads to the early adoption of Industry 4.0 that balances the business competition environment. The model also shows that exponentially rising government aid can help the SMEs to late adoption of Industry 4.0 that still unable to sustain the SMEs in business competition. Thus, the developed integrative simulation model is a state-action planning model with each state result bounded to the previous state result. The initial input parameters determine the model behavior. Thus, the model is a good resiliency planner for SMEs' Industry 4.0 adoption.

Keywords: Industry 4.0; SMEs; agent-based simulation; causal loop

1. Introduction

The small and medium enterprises (SMEs) are the economic backbone of future Association of Southeast Asia Nations (ASEAN) and Indonesia. Even more, the golden age demography bonus makes Indonesia have to provide enough employment to ensure the economic stability of the people [1]. Therefore, the SMEs that established in Indonesia (Indonesian SMEs) have a role to ensure regional stability. The economic dependency on foreign countries is not an available option for a nation to maintain its socio-economic stability. On the other hand, people's dependence on government aid will force the country to enter such a situation. Besides, the economic dependency of a country on other countries in the same region may reduce regional stability [2]. Hence, collaboration is needed to maintain regional stability.

Financial, technical, and human resource barriers hinder Indonesian SMEs Industry 4.0 adoption. Most developing countries struggle with those three major problems in Industry4.0 adoption. The specific issues of Indonesian companies on Industry 4.0 adoption are Lack of ICT infrastructure, financial constraints, management support, technical expertise, privacy concerns [3]. The Indonesian government resolves the issues by creating special regulation for industry 4.0 adoptions [4]. However, the regulation only focuses on Industry 4.0 knowledge and organizational culture empowerment. Hence, the regulation does not provide financial or technical empowerment for SMEs. Therefore, this study explores the possibility of SMEs Industry 4.0 adoption through collaboration with TS.

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The endogenous multi-sector collaboration of a nation's public and private sectors is necessary to build a robust financial structure. System modeling approaches can model such relationship dynamics. For example, the use of the Bozeman collaboration model to evaluate the economic impact of scientific research collaboration. The corresponding provisional model assesses research collaboration effectiveness among interdisciplinary scientists [5]. The expansion of the model also successfully declassifies public and private sector employees' job satisfaction [6]. However, semi-structured interview data was the basis of both models. In contrast, this study constructs a provisional model based on information feedback.

Collaboration modeling belongs to non-physical system modeling. Thus, the system complexity is high because it consists of various entities. In consequence, modeling the social system through conventional statistics requires some assumptions. There are risks of assumption exaggeration and oversimplification that lead to bias [7]. Correspondingly, the discrete event simulation (DES) approach that relies on statistical distribution is not fit to model human collaboration dynamics in medium-level abstraction. Instead, modeling the entity behavior through simple logic called the agent-based model (ABM) is more representative. It is possible to construct data-driven ABM by arranging the agent logic from historical data [8]. This study employs data-driven ABM to simulate the Indonesian SMEs and technology startups (TS) collaboration in adopting Industry 4.0.

The growth of Indonesian TS changes the economic ecosystem. TS promote technology disruption that widens access to advanced technologies. Through some cooperation with the Indonesian government, TS focus on helping SMEs sustain themselves [9]. Indonesian startup global growth ranked 5th with 2229 listed startups in 2021 [10]. The growth is due to venture capitalist funding and an active startup growth campaign involving young technology talent. The expected outcome of TS collaboration with SMEs is to maintain prosperity over the increasing population. This study models the dynamics to achieve the expected outcome.

Indonesian TS has rapidly grown while facing some major obstacles. The obstacles were digital technology infrastructure and digital literacy of the available human resources. The technology problem is a global problem since European SMEs also experienced the same digital resources problems [11]. However, funded TS has access to use giant technology company infrastructure. Most Indonesian TS use exclusive subscription plan that has lower fare by cloud service providers such as Amazon, Google, Facebook, and Microsoft [12]. Numerous training programs can overcome the digital literacy problem in the Indonesian TS ecosystem. However, outside the TS ecosystem, Indonesia's digital literacy index is 3.49 which is low [13]. Indonesia has a decacorn, 13 unicorns, and hundreds of startups in the Serie-B and Serie-A funding stage, but thousands of Indonesian TS are still in seed and pre-seed funding [14]. This study aims to analyze the contribution of the growing TS to Indonesian SMEs' adoption of Industry 4.0 technology.

The Analysis of SMEs' Industry 4.0 adoption in this study context requires the integration of system variables with the detailed entity variables. The high-level model and medium-level abstraction model connection allow the integration of both system variables. The medium-level abstract model provides a detailed model of an entity's behavior in a system. The highly abstract model provides general entity relation. The relation depicts the way an entity affects the overall system states [15]. This study applies high-level abstract modeling to understand the effect of TS and government support on Indonesian SMEs Industry 4.0 transformation. The evolution of the high-level abstract model states every time step unit can be analyzed using dynamical systems (DS). DS analyzes the changes in a system with predefined general variables [16]. Meanwhile, the construction of ABM for SMEs business competition introduces detailed factors.

The DS and ABM simulation integration enables in-depth system analysis with a general perspective. DS is a top-down modeling tool that models a system at a high abstraction level [17]. DS relies on information feedback from an entity to another entity. The most common tool to construct a DS model is the causal loop diagram (CLD) and stock & flow diagram (SFD). CLD excels at qualitative model building that only involves binary relationships represented by positive (+) and negative (-) at the arrowhead [18]. The information loop is either reinforcing (positive-positive / negative-negative) or balancing (positive-negative). Both CLD and SFD allow DS to model the complex and nonlinear behavior of a system into a simple relationship structure [19]. SFD excels at quantitative system modeling that allows the system flow estimation according to inflow and outflow quantity [20]. The SFD's ability to quantify flows makes it suitable for data-driven DS [21]. However, CLD integration with a bottom-up model such as ABM has enabled its utilization of quantitative problems. The corresponding integration scheme utilization was to explore the complexity of the construction waste management problem [15]. The flexible CLD can act as a logic gate for the bottom-up model result based on high-level interactions (ABM on top DS) or low-level interactions (DS on top ABM). This study proposes a real-time interaction model that allows the ABM model and DS concurrently to feed input and output data.

This study evaluates the digital technology disruption by the TS that targets the SMEs as their customer. This study applies and extends the provisional model by[5] and [6] by integrating ABM for a medium-level abstraction model and CLD-based DS to construct a high-level abstraction model. This study reports the first real-time ABM and CLD concurrent simulation. The first implementation of the proposed integrated model is to solve the problems described by [11]. The model represents problem [11] as the integration of SMEs' business competition behavior at the bottom abstraction layer and the Indonesian SMEs Industry 4.0 development environment at the top abstraction layer. The integrated model outputs a decision support tool to maintain a balanced manufacturing SMEs business competition environment for multi-parties users (SMEs, government, TS, investors, and funders).

2. Materials and Methods

The provisional model that relates SMEs' business competition was built by integrating DS and ABM. The DS technique used was quantitative CLD as previously implemented by [22]. The CLD employs simultaneous equation to process quantitative variables. The CLD was constructed to model SMEs-government, SMEs-TS, and TS-Government relationships. The information exchanged between the entities in the DS model which connected in real-time with the ABM model. The information processed by ABM on each simulation step was fed to the CLD to be processed.

The historical data determines the CLD simultaneous relationship and ABM model behavior. The Indonesian TS and SMEs data were collected from several open data providers. The SMEs data were collected from Indonesia open government service, and Indonesia SMEs growth projection data obtained from World Bank data [23,24]. The SMEs data were obtained from the ASEAN SMEs policy index [25], Indonesian SMEs growth data [26], and Indonesian SME’s Industry 4.0 readiness data (4IR) data [27]. The TS data were collected from databoks and some previous studies through Mendely open data. The TS data were Indonesian startup growth index, Indonesia startup classification, and Indonesia startup fundings collected from [28]. The cost components were calculated from the collected panel data. Hence, the variables were comparable due to unit homogenization as cost. The data collection was for the Industry 4.0 adoption and current SMEs operation model construction and simulation.

The ABM simulation was performed using Python programming language with the help of MESA module. MESA is an open source ABM simulation module licensed under Apache 2 [29]. The simulations consist of three scenarios applied on high-level abstraction CLD of SMEs industry 4.0 adoption. The model describes the business operations of the SMEs and the competitors to gain profits. Obtaining profits requires a set of operations that need operational costs. The simulation run was in 50 steps, with each step representing a year. The simulation agents were the SMEs, the competitors, and the profits to be gained by the SMEs’ and the competitors. The model construction assumed the competitors (the large companies) are always capable to take over the SMEs market. In opposition,

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the SMEs industry 4.0 adoption removes the first assumption. Based on the data and the underlying assumptions, the simulation parameters were defined in figure 1. The parameters were the initial population of the SMEs and the competitors, the growth rate, and the profit gained from the customers. The second scenario in figure 1(b) is related to the exponential growth of government aid which is assumed to double the growth rate. The third scenario in figure 1(c) reflects the balance competition by equally setting the "gain from customer" variables due to the SMEs Industry 4.0 adoption.

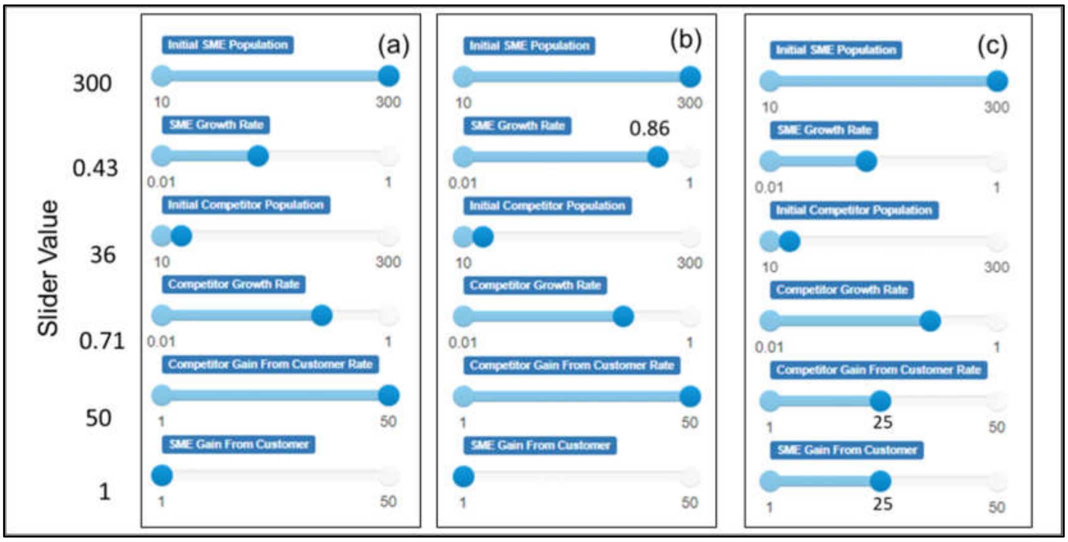

Figure 1. Simulation parameter setup: (a) current scenario, (b) doubled SMEs growth rate, and (c) SMEs with Industry 4.0 adoption**.**

The relationship model between SMEs and TS was developed based on technology infrastructure and digital literacy problems as shown in figure 2. The model components in figure 2 were determined based on available digital literacy data on [28] and the Industry 4.0 basic infrastructures reviewed by [30]. Both [28] and [30] derive the components used to evaluate the ABM simulation state and transfer to CLD through equation (12), as shown in table 2. The DI variable on equation 12 consists of the sum of equations (1) to (5) in conjunction with the DI value obtained from equation (6). The high-speed internet component is critical for production control (PC), inventory control (IC), and facility control (FC) of manufacturing operations. Each manufacturing and management operation generates data stored and processed by computing servers (cloud or dedicated). The data were comprised of production data (P), supply data (S), and management data (M). The computing servers may be required for physical control (PCtrl) of the production machine or equipment. The form of controls (PC, IC, FC, and PCtrl) can be in the form of intelligent control (AI), internet of things (IoT) control, or both that require extra computational resources. The AI may be utilized in the production line, management, or executive level as a Decision support system (DSS). The IoT control utilization is for a physical data collector in the production line controlled directly by management input or AI. All the control processes require executor software (Soft). The whole infrastructure components control was by Digital talents, SMEs employees that received a digital scholarship, or digital training. This model assumed the SMEs gained infrastructure and digital literacy through a subscription plan to the TS, and the TS gained capital from investments.

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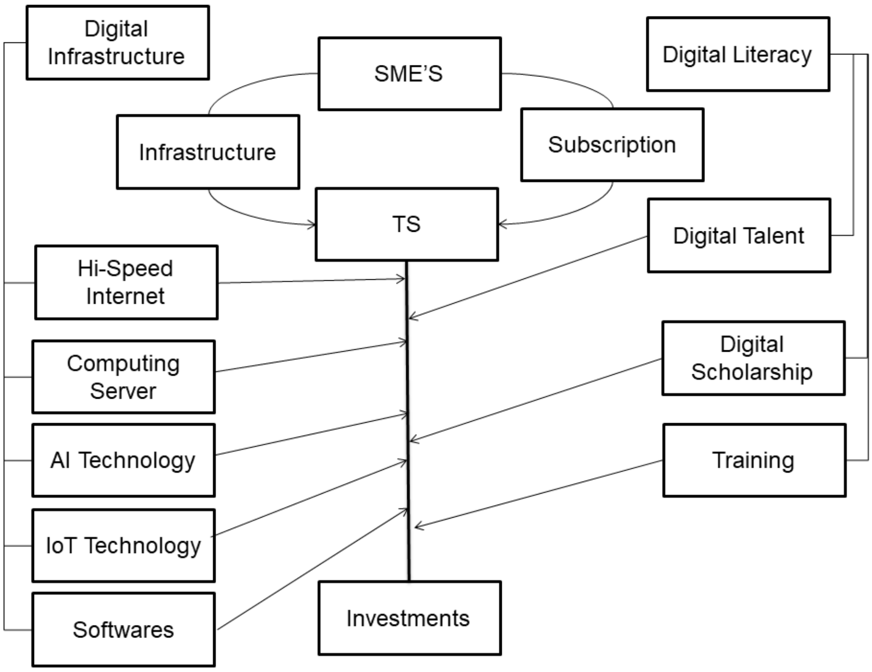

Figure 2. Model derived from major problems**.**

The detailed impact of the TS on SMEs assessment was using industry 4.0 adoption cost. The costs were operational cost (OC), digital infrastructure cost (DC), human resource cost (HC), and digital service subscription cost (SC). The subscription price assumed to have been set by TS based on its expense over profit multiplied by the initial price (I) (see equation 6 in table 1). Each TS profit consists of investment (INV) and income (INC)**, while the expense covers human resource** (HC_{TS}), operational (OC_{TS}), and infrastructure costs (IC_{TS}). Each cost relationship mathematical model was built based on digital resource utilization (see table 1). The cost utilization control was using the amount factor (A_f), usage factor (U_f), and existence factor (E_f). The A_f represents amount of a discrete or continuous resource, U_f represents the usage of a resource (continuous), and the E_f is a binary (0 or 1) variable that marks the existence of a resource.

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Table 1. Detail model of SMEs Industry 4.0 adoption cost.

Cost Component Equations		
Adoption Technology	**Adoption Cost**	
High speed internet (HSI)	$3\begin{bmatrix} A_{fPC} \\ A_{fIC} \\ A_{fFC} \end{bmatrix}\begin{bmatrix} U_{fPC} & U_{fIC} & U_{fFC} \end{bmatrix}(OC + DC + HC)$	(1)
Computing Server (CS)	$(OC + HC)\begin{bmatrix} \frac{OC+DC+HC}{OC+HC} A_{fP} & A_{fM} & A_{fS} \end{bmatrix} \times \begin{bmatrix} U_{fP} \\ U_{fM} \\ U_{fS} \end{bmatrix}$	(2)
AI Technology (AI)	$SCA_{fAI}U_{fAI}$	(3)
IoT Technology (IoT)	$CSA_{fIoT}U_{fIoT}$	(4)
Softwares (Soft)	$(HSE_{HS} + CSE_{CS} + AIE_{AI} + IoTE_{IoT})SCU_{fSoft}$	(5)
Subscription Price Setting		
SC	$\frac{OC_{TS} + HC_{TS} + IC_{TS}}{INC+INV} I$	(6)

The DS simulation was employed to observe system behavior on the high-level abstraction side. The DS simulation compared the initial condition (SMEs Industry 4.0 adoption without TS collaboration) and TS collaboration with SMEs. The DS simulation was performed using Vensim® PLE software. The high-level abstraction model constructed using CLD focused on a SMEs Industry 4.0 adoption capability and measured by SMEs competitiveness. The CLD variables and the simultaneous equation are listed in table 2. The variables were concurrently updated with the ABM. All simultaneous variables unit listed in table 2 were currency. The government aid was a predefined variable obtained from [26]. The digital inf cost was the total infrastructure cost while the digital HR cost was the total human resource related cost obtained from table 1.

Table 2. Causal loop Simultaneous Equations of SMEs Industry 4.0 adoption cost.

Variable	Simultaneous Equation	
Initial SMEs System		
Government Aid	$SIMULTANEOUS(First\ Aid * (Government\ Aid * 0.01), First\ Aid)$	(7)
SMEs Investment	$SIMULTANEOUS(SME's\ Investment\ SME's\ Competitiveness, Initial\ Investment)$	(8)
SMEs Capital	$SIMULTANEOUS(Government\ Aid\ + SME's\ Investment - "SME's\ Industry\ 4.0\ Adoption", Government\ Aid\ + SME's\ Investment)$	(9)
Digital Literacy	$SIMULTANEOUS(IF\ THEN\ ELSE(SME's\ Capital \geq Minimum\ Digital\ HR\ Cost, Digital\ HR\ Cost, 0), 0)$	(10)
Digital Infrastructure	$SIMULTANEOUS(IF\ THEN\ ELSE(SME's\ Capital \geq Minimum\ Infrastructure\ Cost, Digital\ Inf\ Cost, 0), 0)$	(11)
SMEs Industry 4.0 Adoption	$SIMULTANEOUS(Digital\ Infrastructure\ + Digital\ Literacy, 0)$	(12)
SMEs Competitiveness	$SIMULTANEOUS(DELAY1I("SME's\ Industry\ 4.0\ Adoption" + 1, Final\ Simulation\ Year, "SME's\ Industry\ 4.0\ Adoption"), 0)$	(13)
SMEs with Tech. Startups System		
Technology Startup	$SIMULTANEOUS(Venture\ Capital\ + Angel\ Investors\ + (0.2 * SME's\ Capital) - Digital\ Infrastructure\ - Digital\ Literacy, Venture\ Capital + Angel\ Investors)$	(14)
Venture Capital	$SIMULTANEOUS(Initial\ Capital\ + Initial\ Capital * Growth, Initial\ Capital)$	(15)
Angel Investors	$SIMULTANEOUS(Inital\ Investment\ + Initial\ Investment * Growth, Initial\ Investment)$	(16)

The DS simulation was driven by the medium-level abstraction ABM simulation result. The variables values in equation 7 to equation 16 were based on the output of the ABM simulation result on each time step. The MESA ABM simulation and Vensim® DS simulation was running simultaneously through a Python script intermediary. The concurrent real-time connection between ABM and CLD was achievable through multi-threading. The Vensim® model (.mdl file) and dataset (.vdhl) was read by Python through PySD module. The Pandas module modifies the dataset for the simulation. The variable analysis was using Vensim® slider basic I/O.

3. Results

3.1. Medium level abstraction analysis

The ABM simulations of SMEs competition with three different scenarios projects the future state of each agent. The initial and termination states of the simulation showed in figure 3. The grid represents the market for SMEs and competitors to perform their business operations. The green-colored grid indicates the availability of profits that are available to be gained by the occupant agents. The orange-colored shop icon portrays the SMEs and the tall building icon portrays the competitors. Figures 3(a) and 3(b) depict the first simulation scenario's initial and termination state representing the model maintaining its current simulation state. Figures 3(c) and 3(d) represent the initial and termination state of the doubling growth rate scenario by exponentially increasing the government aid to the SMEs each year. However, both scenarios failed to maintain a balance competition. The inexistence of SMEs at the termination state indicates the corresponding failure (see figure 3(b) & 3(d)). Meanwhile, the balanced competitive model indicated in Figures 3(e) and 3(f) shows the ability of SMEs to compete with larger competitors as they adopt Industry 4.0 early with a collaborative strategy.

Figure 3. Simulation states: (a) 1st scenario initial, (b) 1st scenario termination, (c) 2nd scenario initial, (d) 2nd scenario termination, (e) 3rd scenario initial, and (f) 3rd scenario termination.

The dynamics of the business competition by the SMEs and the competitor agents were to obtain maximum profit and cover their operational costs from time to time. These conditions are represented by the agents' behavior that plotted timely as the simulation started. Figure 4 presents each plot of each simulation scenario. Figure 4(a) represents the first scenario that indicates the competitors are superior to the SMEs. The competitors fully absorb the profits on each simulation step. Meanwhile, the SMEs were early eliminated from the competition in the 6th year. This event strengthens the competitors as the competitors absorb the reinitiated profits at each simulation step. However, the competitors were self-competing which declined the competitor population after the 18th year.

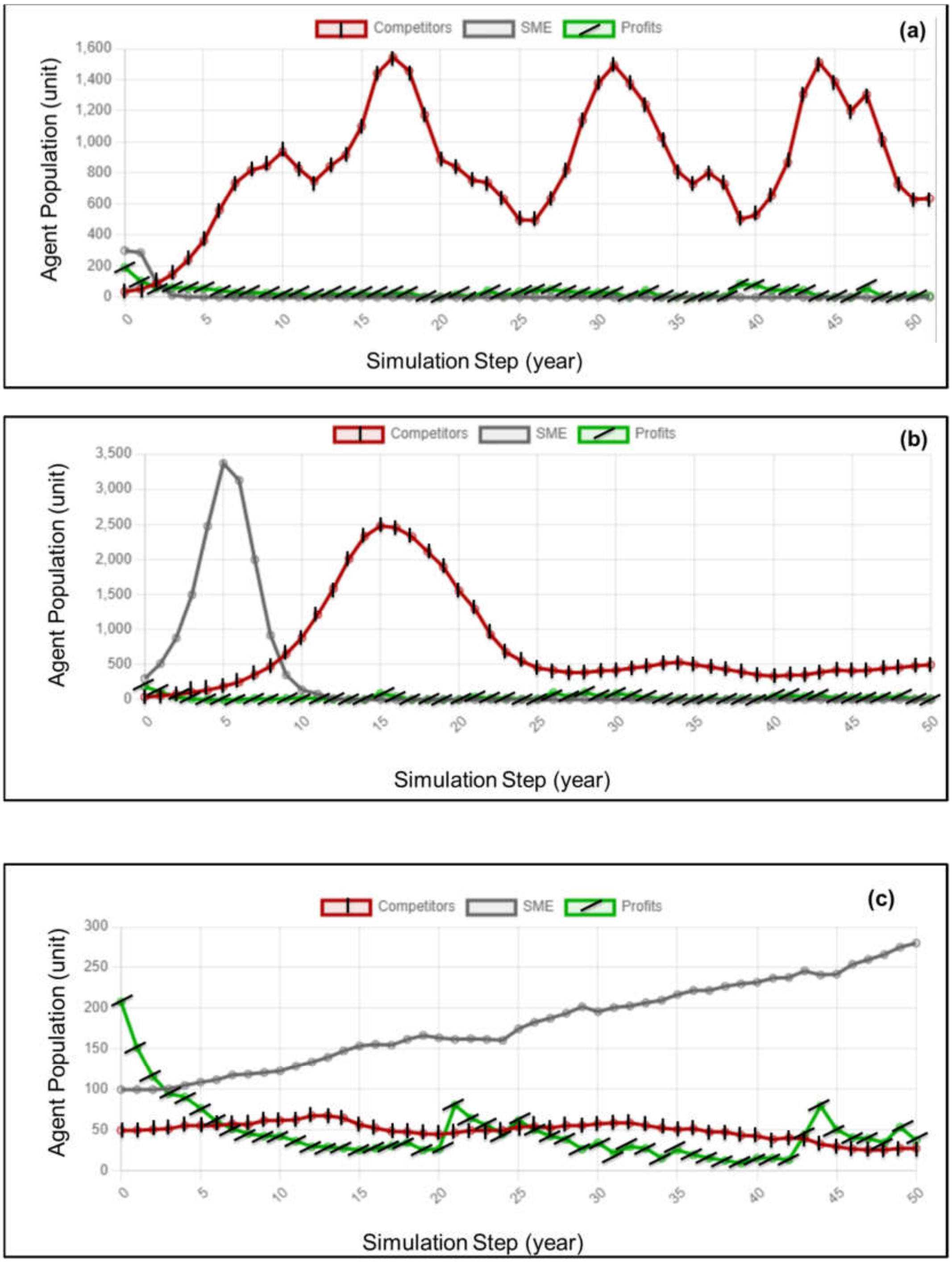

Figure 4. Competition Simulation Plot: (a) Superior competitors, (b) SMEs growth rate doubling, and (c) Balanced competition.

Third-party involvement has changed the competitive dynamics. The SMEs with doubled growth rate in figure 4(b) has rapidly increased along with the exponentially rising government aid in the first five years. However, due to the model obeying the first assumption, competitors were able to overtake SMEs profits. This definition of assumption was due to the competitors being more technologically sophisticated and having better financial management. In year 9, the SMEs population fell, followed by the exponential growth of the competitors. As the SMEs vanished in year 14, the competitors began to self-competing. As a result, the competitors' population becomes narrower. The narrowed competitors compete in the balance competition from year 26 to the termination year. The dynamics of the balanced model in figure 4(c) show small growth for SMEs and competitors. The SMEs are in favor of their higher initial population compared to the competitors. Also, the TS helps SMEs' technology advancement to compete with the competitors equally.

3.2. High level abstraction analysis

The high-level abstraction of CLD simulates the ability of SMEs to adopt Industry 4.0. The simultaneous equations (see table 2) of the initial SMEs model flow have generated the model in figure 5. Current Indonesian SMEs capitals depend on government aid with IDR 1.6 million / SMEs valuation and external investment [31]. In this model, the external investments were not from loans or returnable favors. Therefore, both variables reinforced the SMEs capital. The SMEs has to adopt Industry 4.0 to increase their competitiveness. However, the lack of digital infrastructure and digital literacy restricts them from Industry 4.0 adoption.

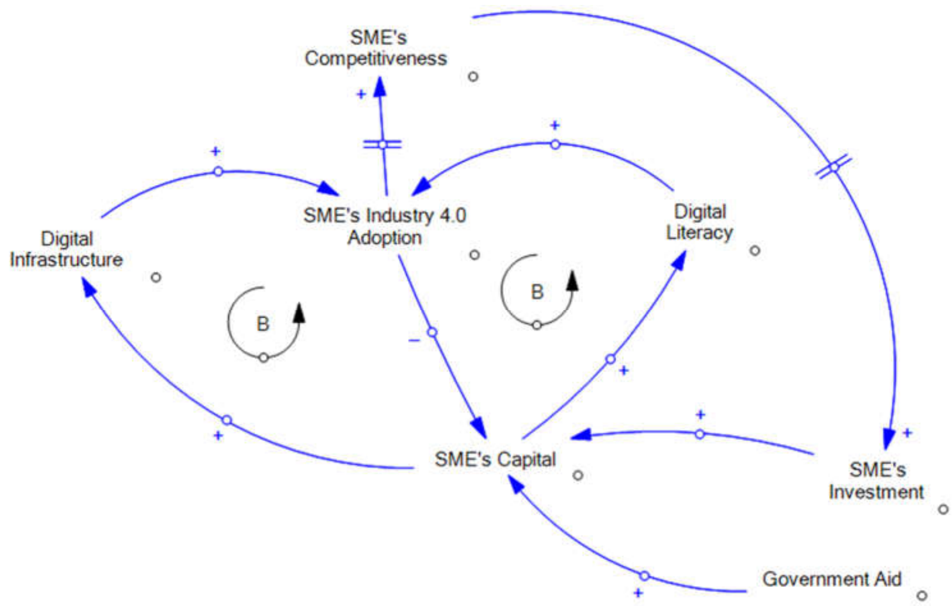

Figure 5. Causal loop of SMEs Industry 4.0 adoption without collaboration.

Industry 4.0 adoption requires cost and investments in digital infrastructure and digital literacy. Based on simultaneous equation (10) and equation (11) in table 2, the industry 4.0 adoption by the SMEs requires the SMEs to allocate the profit surplus. The required allocation was a 50% surplus. Both digital infrastructure and digital literacy create a balanced causal loop between SMEs capital and Industry 4.0 adoption capability. The delayed impact of Industry 4.0 adoption is the capital reinforcement as the future period investment increases due to reduced operational cost.

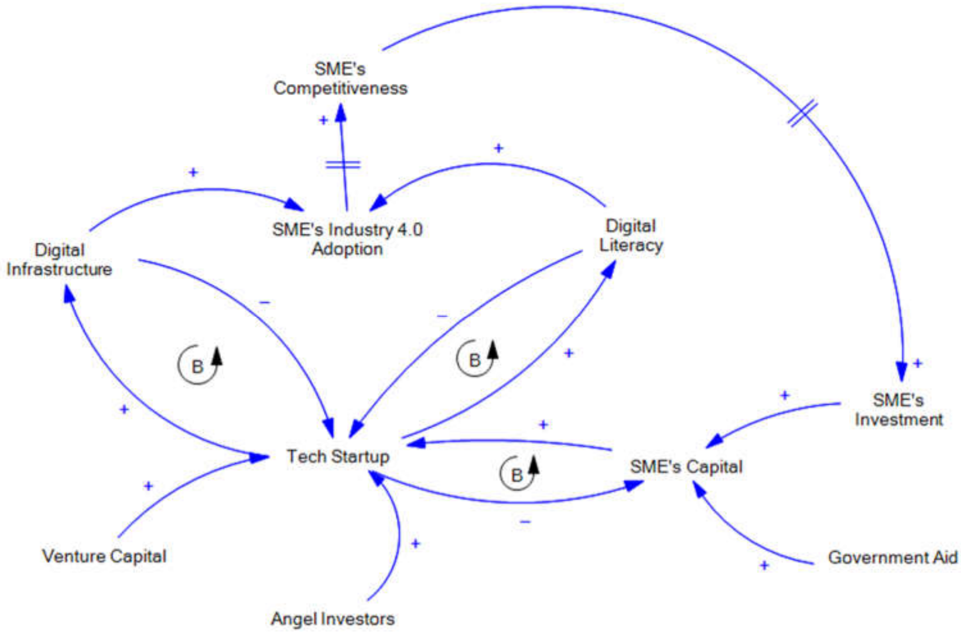

Figure 6. Causal loop of TS collaboration on SMEs Industry 4.0 adoption.

The TS collaboration has covered all SMEs Industry 4.0 technological needs. The TS is assumed to offer subscription-based digital infrastructures for the SMEs. This condition balances the SMEs capital as the SMEs only need to spend subscription costs. Also, venture capital and angel investors capitalize on TS. The capitalization enables them to own digital infrastructure and hire digitally literate employees. Hence, the collaboration with TS has enabled the early adoption of Industry 4.0 by SMEs. Thus, this condition equates the SMEs with the larger companies.

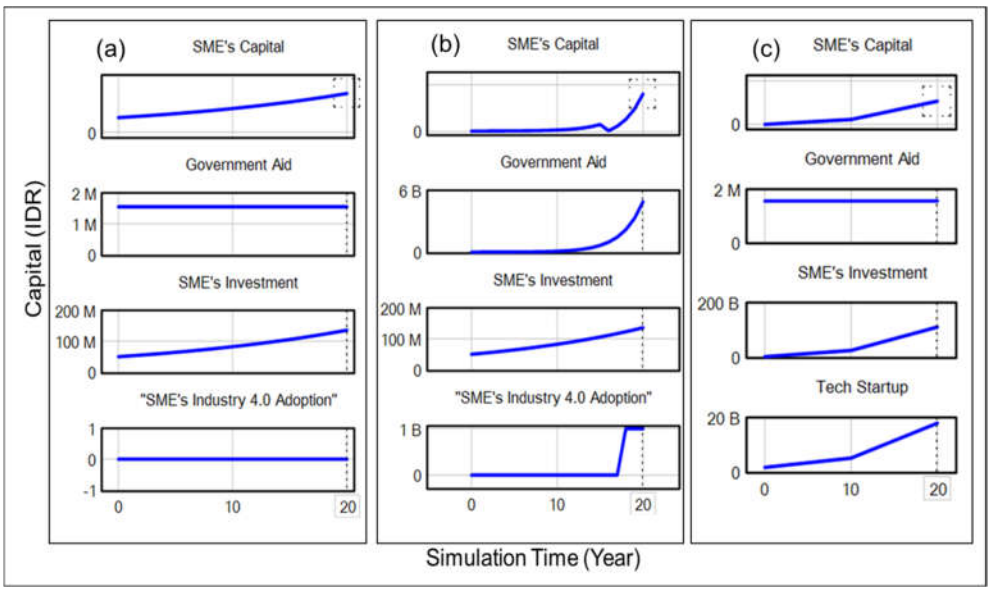

Figure 7. Causal loop simulation of SMEs Industry 4.0 adoption results: (a) steady system, (b) government aid exponential growth, (c) TS collaboration.

The quantitative results of the causal loop simulation indicate that TS collaboration is the best way to maintain SMEs competitiveness. The quantitative results in figure 7 are the outputs of all simultaneous equations in table 2 using ABM simulation parameters and outputs as the input of the equations. As a result, the link can be made from figure 7(a) to figure 4(a), figure 7(b) to figure 4(b), and figure 7(c) to figure 4(c). The SMEs' inability to adopt Industry 4.0 is visible in figure 7(a) despite the linearly increasing capital

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each year. Figure 7(b) shows by growing the government aid exponentially each year, SMEs can adopt Industry 4.0 in the 18th year. The early industry 4.0 adoptions by SMEs and TS collaboration increases the SMEs investment rapidly by ten folds compared to the previous scenario, as seen in figure 7(c). Thus, TS collaboration is critical to enabling the early adoption of Industry 4.0 for SMEs.

4. Discussion

The combination of side-by-side medium and high-level abstraction model simulation of SMEs Industry 4.0 adoption provides some insights to view the future of the chosen strategies. The initial step of the simulations initiates the model dynamics as reflected by each simulation step initiate future simulation step. The ABM and the highly abstract CLD models utilization in this simulation employ encapsulated mannered simultaneous relation. Encapsulated simultaneous relation assumes the neglection of the external factors once the system state has evolved [32]. Hence, the initial parameters settings are the only cause of the whole model dynamics.

The simultaneous model enables detailed focus observation on a few parameters of SMEs Industry 4.0 adoption. The focus enhances the model capability to provide correct behavior on each step. The physical system behavior validates the correctness of the model behavior. The behavior of Indonesian SMEs' business competition with the large competitors' validation is by comparing the SMEs' capability with large companies. The SMEs' lack of infrastructure, capital, and strategies in business enforce SMEs to gain smaller profits from the large competitors [33]. The behavior setting is a part of the first assumption of the ABM simulation. Therefore, the competitors are always capable of overtaking SMEs markets leads to SMEs bankruptcy. Hence, the ABM simulation model with provided assumptions correctly reflects the actual business competition environment.

The real-time concurrent ABM integration with CLD reveals the relationship dynamics of high level and medium level abstraction variables. The model behavior is a direct response of ABM, CLD, or both model parametrical changes. The usual integration scheme of ABM and CLD is by specify one model as the receiver and other model as data transmitter [18]. Therefore, the behavior of the receiver model is steered by the transmitter model. The developed integrated model specifies both ABM and CLD to act as transmitter and receiver. Hence, both models affect each other as the simulation runs.

The ABM integration with the CLD helps the SME industry 4.0 adoption possibility assessment. The simulation scenarios in the medium-level abstraction ABM simulation define the causal loop simultaneous relationship. In the first scenario, the linear increment capital was not enough to help SMEs to adopt Industry 4.0 in 20 years. The exponentially increment government aid is also not enough to support the Industry 4.0 adoption at the right time. The results fit with the current Indonesian SMEs' competition environment. The previous study shows government support and competitor pressure does not affect SME business operations [34]. These reflect the successful model integration as the ABM parameter tuning leads to change in CLD simultaneous behavior. Therefore, this integrated model is useful as a decision support tool for policy makers.

The long and short-term robust system design is possible upon a strong initial parameter definition. The well-planned initial move in a competitive business environment affects the overall future decision [35]. Therefore, the current combined simulation model is fit for robust system planning. A robust system is a system that is unaffected or insignificantly affected by noises due to parametrical changes [36]. Although all models obey the Occam razor principle, this integrated model also possesses incorrectness due to assumptions [37]. However, the future state of SME industry 4.0 adoptions planning is achievable by utilizing this integrated model. Therefore, the decision support role of the model is through current state-action planning.

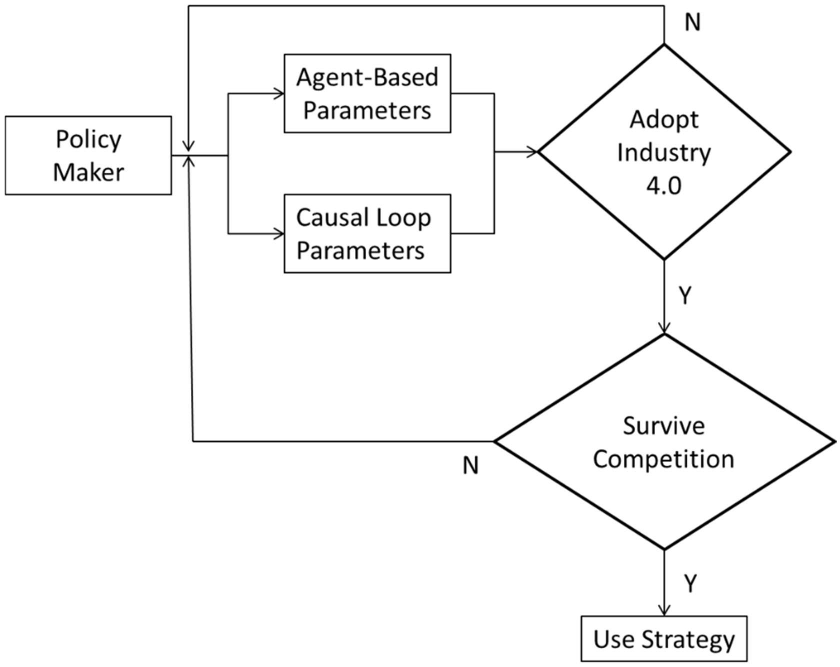

Figure 8. State-action decision support of integrated model**.**

The state-action planning of the integrated ABM and causal loop model offers dual side future state prediction. State-action planning is the use of a system modeling to predict the state of a system through parameter tuning [38]. As shown in figure 8, the policy maker decides the initial parameter of the model based on current situation. The policy maker can tune the parameters in the SMEs ABM and CLD simultaneously to assess both industry 4.0 adoption and competition survival of the SME. The strategy should be chosen if the Industry 4.0 adoption and surviving competition were possible.

The implementation of the state-action planning has shown stable and logically true prediction. A simulation model is defined as logically true if it can respond parameter tuning as the real system respond to it [39]. The results shows the SMEs are unable to compete with larger competitors due to capital limitation. Those limitations, restricts their technological progression which results in late adoption of the latest technology. Consequently, the larger competitors were superior to the SMEs. Hence, the result of the simulation is a valid representation of the physical system.

The collaborative strategy with TS removes SMEs current limitations. Indonesian SMEs problems are marketing, technology, capital access and human resources quality [40]. The first assumption of the competition simulation based on these problems. The industry 4.0 adoption removes the competition barriers due to the technology and human resource support by the TS. This barrier removal was due to today's marketing is packed with technology component [41]. Consequently, the advances in technology improve the marketing capability of an SME. As most business process automated and assisted by technology, the quantity of human resource needed by SME will be declined. As a result, the adoption of Industry 4.0 resolve whole SME problem. Early adoption of Industry 4.0 is possible through TS collaboration. Thus, the interplay between government policy, TS solutions for SMEs, and SME efforts to collaborate with TS are important factor to realizing this simulation study results.

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Table 3. The DS & ABM integration technique comparisson.

Study	Case	Integration	Behavior Steering
This study	Industry 4.0 Adoption	DS concurrent ABM	
[18]	Waste Management	DS on top ABM	✓
[42]	Industrial Process	ABM on top DS	✓

This study contributes to the development of real-time concurrent DS integration with ABM. This study reports the first concurrent DS and ABM simulation that understanding each other state. The DS model process the ABM output while the ABM process the DS output. Therefore, the developed integrated model is the combination of the top-down integration by [18] and bottom-up integration by [42]. Also, the concurrency of the model is maintained in real-time. Furthermore, the developed concurrent integrated model is also removes the behavior steering by one model since both models steer each other.

Along with the benefits of the constructed integrated model imposes some limitations. The current integrated model relied on the initial parameters of the ABM and CLD. Some detailed parameters of SMEs' business competition were random and uncontrollable. Therefore, the effectiveness of the model still relies on simulation replication. The reliance on random variables can be improved in the future by understanding the fundamental mechanism of SMEs' business operations. The developed integrated model application in different research areas is also considered. Future test of the model in a different system other than Industry 4.0 transformation is required to assess the flexibility of the constructed integrated model.

5. Conclusions

This study confirms that Indonesian TS has a significant role as SMEs' Industry 4.0 transformation helper. This study provides an inter-abstraction provisional model by integrating ABM and CLD. The model utilization is to explore the future solution for Indonesian SMEs to adopt Industry 4.0 by including the external variables of TS growth and government aid. The ABM models the SMEs' business competition with the CLD models the relationship of the external variables. The simulation model reveals the collaboration and competitive dynamics of Indonesian SMEs. The simulation results suggest TS collaboration provides capital immune for the SME. Rising government aid may accelerate the Industry 4.0 adoption but does not alter SME competitiveness due to late adoption. The SME collaboration with TS is the best strategy to sustain Indonesia SMEs in the business competition. TS covers the SME limitations by providing digital technology access through a subscription at a lower cost and without initial investment. However, current developed integrative model relies heavily on random parameters generated by ABM. Hence, understanding fundamental SMEs operation is important to build more effective model. The generalization of the proposed concurrent real-time model to solve another problem is also considered.

Supplementary Materials: Figure S1: title; Table S1: title; Video S1: title.

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Data Availability Statement: In this section, please provide details regarding where data supporting reported results can be found, including links to publicly archived datasets analyzed or generated during the study. Please refer to suggested Data Availability Statements in section "MDPI Research Data Policies" at https://www.mdpi.com/ethics. If the study did not report any data, you might add "Not applicable" here.

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