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# VALIDITY OF MARKET ECONOMIC ANALYSIS UTILIZING MAXWELL'S ELECTROMAGNETIC EQUATIONS

Kenji Shirai[1], Yoshinori Amano[2], Takayuki Uda[1] and Atsuya Ando[1]

[1]Faculty of Business and Informatics
Niigata University of International and Information Studies
3-1-1, Mizukino, Nishi-ku, Niigata 950-2292, Japan
dr.kenji5761@gmail.com; { uda; atsuya }@nuis.ac.jp

[2]1563-7, Kaideimamachi, Hikone, Shiga 522-0056, Japan
y_amano@kyohnan-elecs.co.jp

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Abstract. *In this paper, Schrödinger's wave equation represents individual organizations (companies and other commercial organizations) as a market or local field as a wave field. The paper also discusses the relevance of the Ampere-Maxwell electromagnetic equation in the electromagnetic field to the market economy. The focus will be on the interactions that occur between individual economic agents and market actors in the economic field. The profit rate in financial statements, which describe the behavior of individual economic agents, i.e., profit-seeking organizations, always fluctuates stochastically. In other words, it is the result of interaction with the market. By interaction, we mean that the rate of profit is determined by the relationship between supply and demand. In other words, the rate of profit is always stochastic because the mass point of capital (an object that has mass but no size and whose position can be specified by a single point) on the financial statements moves stochastically in time and space. Thus, capital is always changing stochastically. Specifically, economic quality points excited by supply and demand information as economic information are considered to correspond to electric fields, demand to magnetic fields, and price flows and demand flows to electric currents.*
**Keywords:** Schrödinger's wave equation, Ampere-Maxwell electromagnetic equation, Economic field, Demand, Supply

1. **Introduction.** The authors, who have long been involved in the manufacturing operations of control devices for general industrial machinery, began to promote such research with the following motivation. Previous studies have reported that, from all angles, synchronous processes are superior to asynchronous processes in terms of rate of return. As a major contribution, they have proposed measures to improve the efficiency of production systems backed by mathematical models of deterministic systems, which are advection-type diffusion equations, and stochastic systems, which are lognormal-type stochastic differential equations [1, 2, 3, 4]. Some reports based on analytical mechanics, Riemannian space theory, and general relativity showing the superiority of the synchronous production process [5, 6, 7, 8, 9, 10]. The process that concretely realizes a synchronous production system is called a production flow system. The production flow system is presented with real data in all of our proposed papers. Spin glasses are a group of materials that exhibit a behavior different from that of ordinary magnets due to inhomogeneous interactions caused by impurities in the alloy. In this case, spin is considered to represent the natural behavior of particles [11, 12, 13]. Therefore, using the spin glass theory of complex

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systems as described above, we have considered critical states due to phase transitions when considering economic factor particles with irregular interactions assuming spins and impurities [14].

In this paper, the behavior of the entire system is considered to be bounded by Schrödinger's wave equation in physics. The behavior of the entire system is considered to be bounded by Schrödinger's wave equation in physics. In the quantum field, matter has strong duality (particle nature + wave nature), and the equation of motion focusing only on the particle nature of matter cannot strictly describe the motion of electrons. Therefore, the Schrödinger equation is necessary. Under this restriction, specifically with regard to economic quality points excited by information on supply and demand as economic information, supply is considered to correspond to an electric field, demand to a magnetic field, and the flow of prices and demand to an electric current. The focus is on the interactions that occur between individual economic agents and market actors in the economic field. The rate of profit in financial statements, which describe the behavior of individual economic agents, i.e., profit-seeking organizational entities, always fluctuates stochastically. In other words, it is the result of interactions with the market. By interaction, we mean that the rate of profit is determined by the relationship between supply and demand. In other words, the rate of profit is always stochastically changing because the quality point of capital on the financial statements moves stochastically in time and space. Therefore, capital is always changing stochastically. In electromagnetism, the Ampere-Maxwell electromagnetic equations exist for electromagnetic fields on the assumption that the electric and magnetic fields are orthogonal. We propose that this electromagnetic equation is valid for market economy application under the assumption that equity and liabilities in financial statements are always orthogonal.

Here is a summary of each chapter.

- In Chapter 2, we present the superiority of the synchronous production process over the asynchronous production process in a production system called production flow system, based on the know-how we have cultivated over the years. The mean and variance of the production process are the key items for evaluating the production flow process. See Appendix A.
- In Chapter 3, in quantum mechanics, matter has duality (particle nature and wave nature). The Schrödinger equation, which rigorously describes the motion of electrons, is essential. In the behavior of the entire organization of a company, individual entities are considered as numerous particles of action under one mass. These particles are activated particles and have energy individually. However, the behavior of each particle has fluctuations $\sigma_i^2$, $i = 1, 2, \ldots, N$, and these overall behavior entities are established. We propose that this can be thought of as if it were analogous to the behavior of an electron acting stochastically around a nucleus with a certain mass.
- Chapter 4 proposes that spin in physics is a property that corresponds to the "rotation" of elementary particles, and that in an economic field, for example, it corresponds to the fluctuation of a company's debt, which can increase or decrease. It refers to "rotation" in economic fields. The Lorentz force is a force created by an electric current and a magnetic field. This Lorentz force is based on the assumption that capital and debt in an economic field are always orthogonal. Therefore, this paper assumes that capital and debt are always orthogonal. The Lorentz force analyzes how the action in the electromagnetic field corresponds to the action in the economic field. Next, the Ampere-Maxwell electromagnetic equations are derived by utilizing the Euler-Lagrange equations that describe the motion of physical systems in classical mechanics. We will present which of these electromagnetic equations

correspond to balance sheet items in a business entity. Finally, we present how the dynamics model corresponds to BS (Balance Sheet)/CS (Cash Flow Statement)/PL (Profit and Loss statement).

- Chapter 5 describes the laws of electromagnetism. The equivalence of electric field, magnetic field, electric current, and capacitor is proposed in terms of electromagnetism and economic field, respectively. While the electric and magnetic fields are always orthogonal, the economic field illustrates that equity and debt are always orthogonal based on a large two-year balance sheet.
- Chapter 6 showed that the electric and magnetic fields in Ampere-Maxwell's electromagnetic equations are equivalent to demand and supply in the economic field. In the next issue, we will report on the stochastic analysis of demand and supply in the economic field.

2. **Production Firm of a Small or Medium Enterprise and Production System.** The company in this study is the "supplier" in Figure 1 and "factory" here. Companies assume that $N$ (number of) suppliers exist; however, this study focuses on one company since no data is published for the rest of the company $(N-1)$. Then a production process which is called a production flow process is shown in Figure 2. The production process, which produces small quantities of a wide variety of products, goes through several stages of the production process. In Figure 2, the processes consist of six stages. Every S1-S6 step of the production process produces materials.

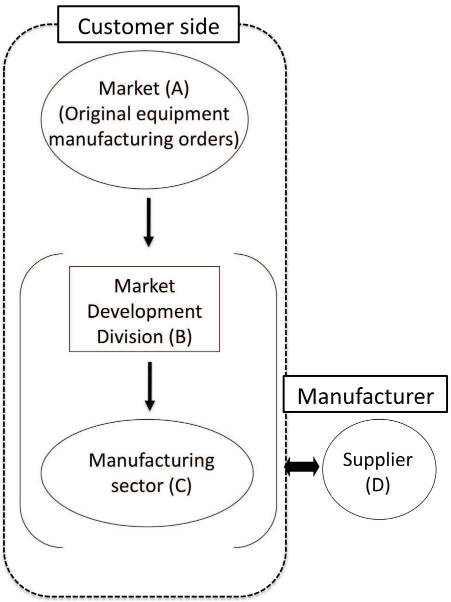



Figure 1. Business structure of company of research target

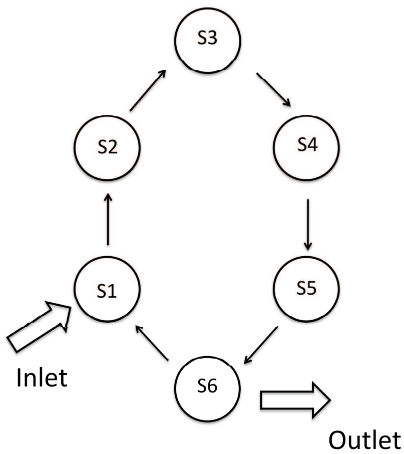



Figure 2. Production flow process

S1 to S6 perform work stages 1 to 6 on the production line in Figure 2. They are S1-S6 in Tables 4, 6 and 8 in Appendix A. K1-K9 in the tables are nine workers. Figure 2 represents a production process called a production flow system, which is a production method used in the production of control equipment. The production flow system, which in this case has six stages, is commercialized by the production of material in steps S1-S6 of the production process.

The direction of the deflection is the direction of the production flow. With this system, production materials are supplied from the inlet and the final product will be shipped from the outlet.

**Assumption 2.1.** *The production structure is non-linear.*

**Assumption 2.2.** *The production structure is a closed structure; that is, the production is driven by a cyclic system (production flow system).*

- Reasonability of Assumption 2.1. Assumption 2.1 indicates that the determination of the production structure is considered a major factor, which includes the generation value of production or the rate of return generation structure in a stochastic production process (hereafter called the production field). Because such a structure is at least dependent on demand, it is considered to have a non-linear structure. Since the value of such a commodity is dependent on the rate of return, its production structure is non-linear. As a result, Assumption 2.1 reflects the realistic production structure and is somewhat valid.
- Reasonability of Assumption 2.2. Assumption 2.2 is completed in each step and flows from the next step until stage S6 is completed. Assumption 2.2 is reasonable because production starts from S1. For more detailed analysis, please refer to our Appendix A.

## 3. Overview of the Schrödinger's Wave Equation.

In the quantum field, matter has strong duality (particle nature + wave nature), and the equations of motion that focus only on the particle nature of matter cannot describe the motion of electrons rigorously. Therefore, the Schrödinger equation is necessary. Therefore, we will give an outline of the Schrödinger equation.

### 3.1. Wave function.

Schrödinger's wave equation is the fundamental equation of quantum mechanics, the revolutionary new mechanics that now governs the microscopic field. This can be compared to Newton's equation of motion, which is the fundamental equation of classical mechanics (Newtonian mechanics) governing the macroscopic field. In the microscopic field, particles are both particles and waves. This section describes the physical aspects of matter. Matter has a large number of active particles under the mass of the overall acting entity. These particles are active particles and have energy individually. However, there are fluctuations $\sigma_i$, $i = 1, 2, \ldots$ in the behavior of each particle, and the entity of the overall behavior is established as an aggregate of these. This is analogous to the behavior of electrons acting stochastically around an atomic nucleus of a certain mass. In other words, the behavior of the individual behavioral entities is bounded by the mass of the whole entity. Thus, the behavior of the entire system is constrained by the following equation.

In other words, there are many action particles under the mass of the whole action entity. These particles are activated particles and individually energy. This can be thought of as if it were analogous to the behavior of an electron acting stochastically around an atomic nucleus with a certain mass. In other words, the mass of the individual action entities is bounded by the mass of the whole entity.

The time evolution of the variable $x(t)$, which represents the position of a particle in quantum mechanics, is assumed to evolve over time by the following Ito-type stochastic differential equation. Forward time evolution in the forward direction,

$$dx(t) = b(x(t), t)dt + dw(t) \tag{1}$$

$$< dw(t) >= 0, \ \ < dw(t)dw(t) >= \frac{\hbar}{m}dt \tag{2}$$

For backward time backward development

$$dx(t) = b_*(x(t), t)dt + dw(t) \tag{3}$$

$$< dw_*(t) >= 0, \ \ < dw_*(t)dw_*(t) >= \frac{\hbar}{m}dt \tag{4}$$

where $w(t)$ is the Wiener process.

Equation (2) and Equation (4) give the statistical properties of the noise term representing the quantum fluctuation. These equations are the forward time evolution of the distribution function $P(x,t)$ for the probability variable $x(t)$.

$$\frac{\partial P(x,t)}{\partial t} = \left(-b(x,t) + \frac{\hbar}{2m}\frac{\partial^2}{\partial x^2}\right)P(x,t) \tag{5}$$

and, time regression development

$$-\frac{\partial P(x,t)}{\partial t} = \left(-b_*(x,t) + \frac{\hbar}{2m}\frac{\partial^2}{\partial x^2}\right)P(x,t) \tag{6}$$

These two equations can be rewritten. These equations, together with the Nelson-Newton equation described below, are the basic equations of quantization. From these results, the following Schrödinger equation can be derived. For details, please refer to [15, 16].

$$i\hbar\frac{\partial \psi}{\partial t} = \left(-\frac{\hbar^2}{2m}\frac{\partial^2}{\partial x^2} + V\right)\psi \tag{7}$$

where $b(x,t)$, $b_*(x,t)$ and $P(x,t)$ are expressed as

$$b(x,t) = \frac{\hbar}{m}(Im + Re)\frac{\partial}{\partial x}\ln\psi(x,t) \tag{8}$$

$$b_*(x,t) = \frac{\hbar}{m}(Im + Re)\frac{\partial}{\partial x}\ln\psi(x,t) \tag{9}$$

$$P(x,t) = |\psi(x,t)|^2 \tag{10}$$

**Assumption 3.1.** *Assume that $\sigma$ at $\hbar = m\sigma^2$ is the following equation.*

$$\sigma^2 = \sum_{n=1}^{N}\frac{1}{N}\sigma_n^2 \tag{11}$$

From the above assumption, it is assumed that each level has a variance $\sigma_n^2$, and $\sigma^2$ as Planck's constant is expressed by its average value. In other words, let $n$ be the number of levels in the individual population around the mass $m$ of the action aggregate. In this view, there are certain energy levels around the acting entity, which are bounded by the size of the acting entity, and the individual entities in each level are determined by stochastic laws. Again, the Schrödinger Equation (7) is presented in Equation (12) below. Hence, the behavior of the entire system is bounded by the following equation

$$i\hbar\frac{\partial \psi}{\partial t} = -\frac{\hbar^2}{2m}\nabla^2\psi + V\psi, \ {}^\forall\hbar = m\sigma^2, \ \sigma^2 = \frac{1}{N}\sum_i \sigma_i^2 \tag{12}$$

From dynamic equilibrium theory [17], $\psi(y,t)$ denotes consumption behavior. $y$ is an input-output vector with uncertainty. Also, $y(t)$ is bounded by

$$dy(t) = \mu(y,t) + \sigma(y,t)dZ(t) \tag{13}$$

where $Z(t)$ is the Wiener process.

In Equation (12), $\psi(x,t)$ is defined as $y \equiv x$. From this, Equation (12) is

$$i\hbar\frac{\partial \psi}{\partial t} = -\frac{\hbar^2}{2m}\nabla^2\psi + V(x)\psi, \ {}^\forall\hbar = m\sigma^2 \tag{14}$$

However, $V(x)$ is the potential. Also, $m$ is the total amount of capital existing in the market. At this time, let $E_g$ be the energy, from the quantum mechanical condition [18].

**Definition 3.1.**

- *$E_g = \hbar\nu$, where $\nu$ is the frequency and represents the active state of the particle.*
- *$p$ is the momentum. $p = \hbar k$, where $k$ is the wavenumber and represents the active state per unit time.*
- *$\Delta p \cdot \Delta x \geq \frac{\hbar}{2}$ is a deviation of disposable income and momentum of action is indeterminate.*
- *Market velocity $\omega = \frac{k}{2\pi}$, $\lambda$ is wavelength.*

That is, $\omega$ is throughput, the variable of productive forces for profit generation.

The above discussion represents the market or individual organizations (companies and other commercial organizations) as a local field as a wave field. In other words, by describing consumption variables or ordinary profit variables in an organizational field as stochastic variables in a field, for example, by stochastic differential equations, we can define, for example, marginal consumption functions and ordinary profit rate functions. Furthermore, the parameter $\hbar$ (which is Planck's constant for physical systems) that describes the above wave equation is bounded by its variance with respect to the random variable. The wave equation considers the approach to the economic field. The turning power of capital on the acquisition of earnings is derived from the number of turns of capital by the economic electromagnetic field (wave field). In other words, it converges to net income.

3.2. **Energy level and entropy.** In Figure 3, $t \in [0, T]$, $k = 2\pi/\lambda$, $\omega = k/(2\pi) = 1/\lambda$.

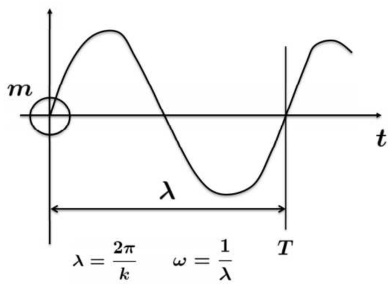



FIGURE 3. Wave function

The energy of the market, i.e., the active force, is bounded by the rotational force of capital, and its momentum is bounded by the unit time per constrained by the number of rotations, where $\hbar = m\sigma^2$ and $\sigma^2$ is the variance of the random variable representing uncertainty.

If we now define $V(x) = 0$, the solution to the original equation becomes

$$\psi(x,t) = \int_{-\infty}^{\infty} q(x) e^{ixt} e^{-i\frac{E_g(x)}{\hbar}} dx \tag{15}$$

When the general solution is expressed in this way, $\psi(x)$ becomes

$$\psi(x,t) = \int_{-\infty}^{\infty} q(x) e^{ixt} dx \tag{16}$$

However, $q(x)$ is given by a normal distribution such that

$$q(x) = e^{-\frac{a^2 x^2}{2}} = e^{-\frac{1}{2}\left(\frac{x}{1/a}\right)^2} \tag{17}$$

Therefore, $\psi(\xi)$ is represented by the following standard normal distribution.

$$\psi(\xi) = \frac{1}{\sqrt{2\pi}} e^{-\frac{1}{2}\xi^2}, \ {}^{\forall}\xi = \frac{x}{2\pi} \tag{18}$$

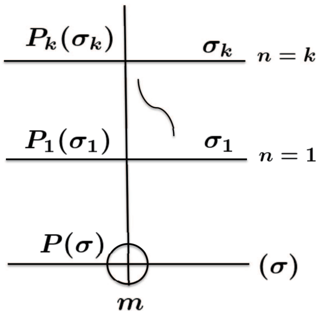



FIGURE 4. Individual entities at individual levels

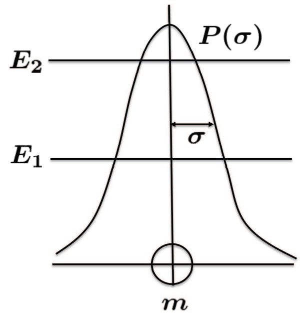



FIGURE 5. Cost $P(\sigma)$ for energy level $E_n$ for $m$

Figure 4 shows the state of $P_n(\sigma)$ with respect to $m$ due to the energy level $E_n$. In other words, the cost $P(\sigma)$ has fluctuations due to $\sigma$. Figure 5 shows the $P(\sigma)$ state of $m$ due to energy level $E_n$ with fluctuations. In other words,

$$P_g\left(\sigma^2\right) \approx E_g = \frac{\hbar\pi^2}{2mL^2}n^2, \ \forall\hbar = m\sigma^2 \cong m\sum_{n=1}^{N}\frac{1}{N}\sigma_n^2$$
$$P_g(\sigma^2) = \frac{\pi^2\sigma^2}{2L^2}n^2 \approx \sigma^2 \tag{19}$$

Now, entropy in Shannon's information theory is a mathematical measure of the uncertainty or predictability of information. Thus, Shannon's entropy $S$ is defined as follows.

**Definition 3.2.** *Shannon's entropy $S$.*

$$S = -\int P(x;\mu,\sigma)\ln P(x;\mu,\sigma)dx \tag{20}$$

where the probability that $P(x;\mu,\sigma)$ is greater than some real number $\theta$ is expressed as

$$P(>\theta) = \int_{-\infty}^{\infty}\frac{1}{\sqrt{2\pi}\sigma}\exp\left(-\frac{1}{2}\cdot\left(\frac{x-\mu}{\sigma}\right)\right) \tag{21}$$

Here, $z = ((x-\mu)/\sigma)$ and the following equation is obtained.

$$P(>\theta) = \int_{-\infty}^{\infty}\psi(x;\mu,\sigma)dt = \int_{-\infty}^{\infty}\frac{1}{\sqrt{2\pi}\sigma}\exp\left(-\frac{1}{2}\cdot z^2\right) = \Phi\left(\frac{\theta-\mu}{\sigma}\right) \tag{22}$$

Thus, the volume of the production phase space $W(E_g)$ is

$$W(E_g) = \sqrt{\frac{m}{2}}\cdot\frac{2L^2}{\pi\hbar}\cdot E_g^{\frac{1}{2}} \tag{23}$$

At this point, differentiate Equation (23) to obtain entropy.

$$\frac{W(E_g)}{dE_g} = \sqrt{\frac{m}{2}}\left(\frac{L^2}{\pi\hbar}\right)\frac{1}{\sqrt{E_g}} \tag{24}$$

Then, to find the entropy $S_\Omega$, the change in volume $\Omega(E_g, S_\Omega, 1)$ becomes

$$\Omega(E_g, S_\Omega, 1) = \sqrt{\frac{m}{2}}\left(\frac{L^2}{\pi\hbar}\right)\frac{\Delta E_g}{\sqrt{E_g}} \tag{25}$$

Therefore, from Boltzmann's formula, entropy $S_\Omega$ becomes [19]

$$S_\Omega = k_B \ln\Omega(E_g, m_\Omega, 1) \tag{26}$$

where $k_B$ is Boltzmann's constant and $m_\Omega$ is the area.

Here, the following quantum conditions are the basis for the above considerations.

$$E_g = \hbar\omega,\ \omega = 2\pi\nu \left(\nu = \frac{1}{T}\right),\ p = \frac{\hbar}{T} \tag{27}$$

The volume of the aforementioned production space is obtained from the following equation.

$$W(E_g) = \int_{H(p,q)<E_g} dW(E_g),\ \ ^{\forall}\Delta W = \Delta p \cdot \Delta x \tag{28}$$

where, it is bounded under the Hamiltonian $\mathcal{H}$.

$$\mathcal{H} = \frac{p^2}{2m} + \frac{1}{2}m\omega x^2,\ \ ^{\forall}\omega = \frac{E_g}{\hbar},\ p = \frac{\hbar}{\lambda} \tag{29}$$

The above represents the volume of the production space based on the data from testrun1 to testrun3 (see Appendix A). Therefore, if thickness is ignored, the area is $n$. However, $n \in \{n_1, n_2, \ldots, n_{\max}\}$.

$$W(E_g) \approx n \times L = n \times L \Rightarrow n = \frac{\sqrt{2mL^2}}{2\pi\hbar} \cdot L = \sqrt{\frac{m}{2}} \cdot \frac{L}{\pi\hbar} \cdot E_g^{\frac{1}{2}} \Rightarrow E_g = \frac{h^2\pi^2 n^2}{2mL^2} \tag{30}$$

The measurement of the lead time $T$ is the source of the $\mathcal{H}$ measurement and the source of the energy $E_g$ measurement. Also, quantum entropy, as mentioned above, is

$$S_\Omega \propto \{m, E_g\};\ \ S_\Omega(x) = k_B \ln\left[\frac{\sqrt{m}}{\pi\hbar}x\right] \tag{31}$$

Furthermore, the quantum throughput function $h(x)$ is

$$h(x) \propto \{m, E_g\} \tag{32}$$

Thus, in a quantum statistical manifold, the probability density function of $\psi(x)$ is

$$\psi(\xi) = \frac{1}{\sqrt{2\pi}\sigma} \exp\left(-\frac{\xi - \mu}{\sigma}\right)^2 \tag{33}$$

Equation (33) is equivalent to the probability density function of energy.

In Figure 6, $P_{ij}$ has total $N$ pieces, $\sigma^2 = \frac{1}{N}\sum_{i,j=1}^{N} \sigma_{ij}^2$. However, $i \neq j$.

Further,

$$E_g^2 = p^2 + m^2 \tag{34}$$

If these hold, the following Schrödinger wave equation holds in steady state.

$$E_g \cdot \psi = -\frac{\hbar^2}{2m}\nabla \cdot \psi + V \cdot \psi,\ \ ^{\forall}\hbar = m\sigma^2 \tag{35}$$

That is, it is a constraint equation for $x$ in the wave equation derived from the ordinary profit function. For example, for a closed field, it can be defined as

$$V(x)|_{x=0} = \infty,\ \ V(x)|_{x=L} = \infty \tag{36}$$

In this case, $\psi(x)$ is given by the following equation [19]. For the calculation of the formula, see Appendix B for the derivation of $\psi(x)$.

$$\psi(x) = \sqrt{\frac{2}{L}} \sin\frac{n\pi}{L}x,\ \ x = 1, 2, \ldots$$

$$E_g = \frac{\hbar\pi^2 n^2}{2mL^2},\ \ \psi_n(0) = \psi_n(L) = 0 \tag{37}$$

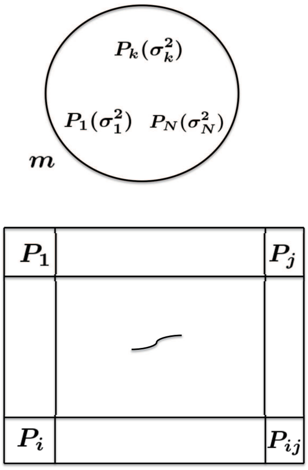



FIGURE 6. Economic fields as many-particle systems

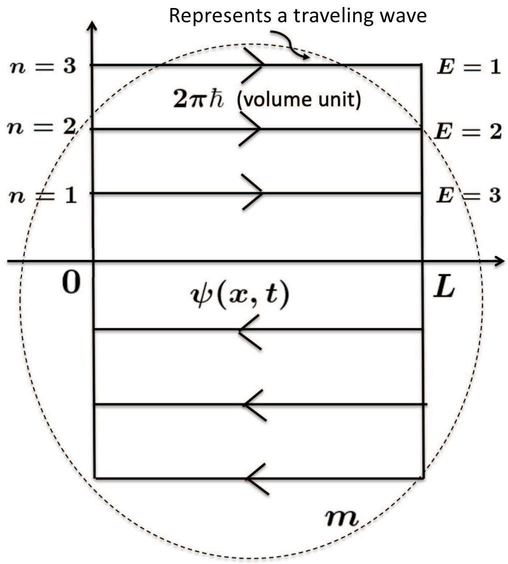



FIGURE 7. Traveling waves in the energy level

In Figure 7, the wave motion is measured from $\psi(x,t)$. In a quantum system, what is measured as a probability element is basically a probability distribution for the motion of a quantum.

Here, the probability using the probability density function $\psi(x,t)$ is

$$P(x;\mu,\sigma) = \int_{-\infty}^{\infty} \psi(x;\mu,\sigma), \ \ ^{\forall}\psi(x,\mu,\sigma) = \frac{1}{\sqrt{2\pi}\sigma} \exp\left(-\frac{1}{2}\cdot\left(\frac{x-\mu}{\sigma}\right)\right) \tag{38}$$

3.3. **Statistical analysis of testrun data.** The mean $\mu_s$ and variance $\sigma_s^2$ of testrun1 (T1), testrun2 (T2), and testrun3 (T3), respectively, are as follows from Appendix A. The set lead time for T1 is $\sum_{i=1}^{9} = 145$ (min), and for T2 and T3 $\sum_{i=1}^{9} = 20 \times 9 = 180$ (min). The mean $\mu_s$ and variance $\sigma_s^2$ of each process are in Table 1. The mean and variance values of the asynchronous process T1 are greatly improved by the mean and variance values of the synchronous processes T2 and T3 as shown in Table 1.

TABLE 1. Testrun testdata

| | T1 | T2 | T3 |
|---|---|---|---|
| $\mu_s$ | 0.73 | 0.92 | 0.92 |
| $\sigma_s^2$ | 0.29 | 0.06 | 0.03 |

4. **Lorentz Force.** First define charge $e$, gravity, and charge spin.

**Definition 4.1.** *Definition of the charge $e$.*

*The excited state (state of value) of a mass point (an object that has mass but no size and whose position can be specified only by a single point). In an economic field, it refers to the state of having value or price, such as goods or services.*

**Definition 4.2.** *Definition of gravity*

*The potential is unique to the pledge. It is the retention of value of the pledge $m$.*

**Definition 4.3.** *Spin of charge*

*Quantum mechanics is a theory for describing physical phenomena on microscopic scales and is reported to understand the behavior of electric charges from a quantum perspective* [15]. *In other words, the behavior of charged particles (e.g., electrons) has been shown to be both wave-like and particle-like. The spin state of the charge causes magnetization (magnetic moment) and behaves as a single permanent magnet. Spin in physics is the property corresponding to the "rotation" of elementary particles, which in an economic field corresponds to fluctuations, for example, an increase or decrease in a company's debt. For more information on "rotation" in economic fields, see Section 4.1.*

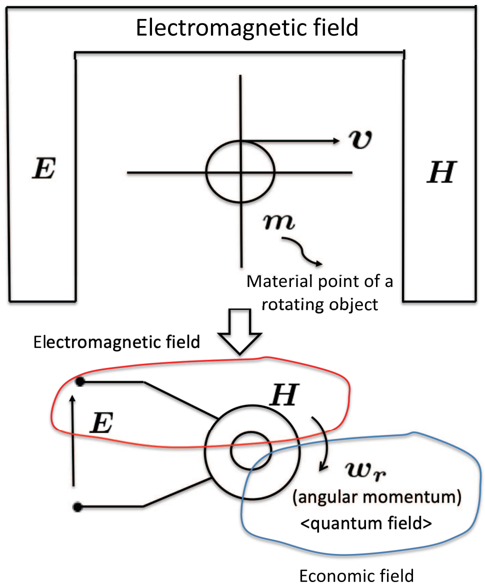



FIGURE 8. Electromagnetic and economic fields

The Lorentz force is a force created by a current and a magnetic field, $t \in \mathcal{R}^+$, $x \in \mathcal{R}^n$ (in Euclidean space) in space-time $(t, x)$ for Figure 8. A mass point is flowing in an electromagnetic field with velocity $\boldsymbol{v}$. In this state, Lorentz force is excited. The Lorentz force is defined as follows.

**Definition 4.4.** *Lorentz force* $\boldsymbol{F}$

$$\boldsymbol{F} = e(\boldsymbol{E} + \boldsymbol{v} \times \boldsymbol{B}) \tag{39}$$

The electric and magnetic fields of plane-wave light are orthogonal. The proof is omitted. The basic relational equation is one of the Maxwell equations.

$$\mathrm{rot}\boldsymbol{E} = -\frac{\partial \boldsymbol{B}}{\partial t} \Rightarrow \boldsymbol{k} \times \boldsymbol{E} = w\boldsymbol{B} \tag{40}$$

where $\boldsymbol{k}$ is the wave light vector, and $w$ is the coefficient.

For $e$ under the Lorentz force, since the electromagnetic field $\{\boldsymbol{E}, \boldsymbol{B}\}$ is the propagation field of $C$, which is the spatial simultaneity of monetary values, $e$ can be defined as the rate of monetary exchange in the revenue field, for example, the rate of value of the product, which can be regarded as the current profit, or the turnover motion of sales. This can be regarded as the turnover motion of recurring profit or sales.

In Equation (40), the fact that the magnetic field is made by the outer product of the electric field and the wavenumber vector means that the electric and magnetic fields are orthogonal in plane waves. That is, $< \boldsymbol{E} \cdot \boldsymbol{H} >= 0$. The state of Lorenz force $\boldsymbol{F} = 0$

is viewed as the state in which prices in the economic field are determined. That is, $\boldsymbol{E} = -\boldsymbol{v} \times \boldsymbol{B}$. In other words, Equation (41) corresponds to the induced electromotive force in electromagnetism [20, 21, 22].

$$\boldsymbol{S} = -\frac{d\phi}{dt} \tag{41}$$

where $\phi \propto \boldsymbol{D}$, $\boldsymbol{S}$ is supply, and $\boldsymbol{D}$ is demand.

Figure 9 shows that the electric and magnetic fields are orthogonal. The electric field corresponds to capital in the economic field and the magnetic field corresponds to debt in the economic field. Furthermore, the $\boldsymbol{S}$ region in the plane wave corresponds to profit, and the $\boldsymbol{L}$ region represents debt as a recovery of capital. The inner product is zero as an economic quality point on the balance sheet.

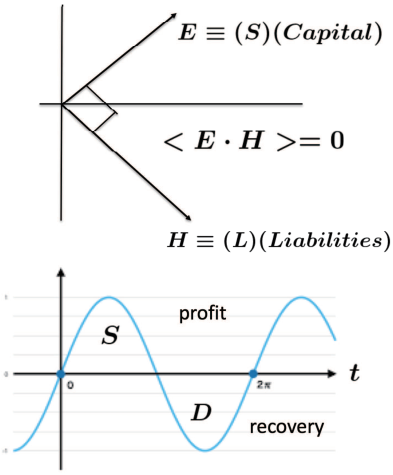



FIGURE 9. $< \boldsymbol{E} \cdot \boldsymbol{H} > = 0$

There are several forms of Lorentz force. In Figure 10, when a charge is at rest in an electrostatic field, the electric force $\boldsymbol{F}_e = q\boldsymbol{E}$. For a moving charge, $\boldsymbol{F}_m = q\boldsymbol{v} \times \boldsymbol{B}$ acts as a magnetic force [20, 21, 22]. Figure 11 shows that a charged point moving at a certain speed ($\boldsymbol{v}$) in a magnetic field $\boldsymbol{B}$ is subject to Lorentz force due to a current $\boldsymbol{I}$ flowing in a conductor. From the point of view of the charged mass point, the force is received from the electromagnetic field $\boldsymbol{E} + \boldsymbol{v} \times \boldsymbol{B}$, where neither electric nor magnetic fields can be distinguished.

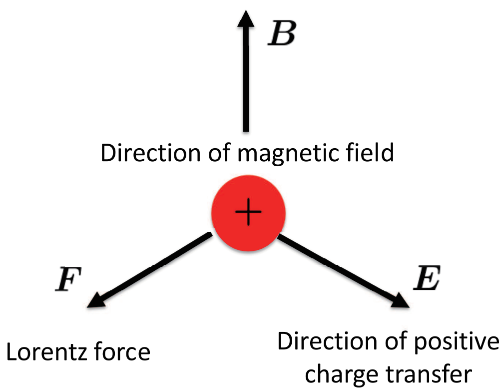



FIGURE 10. Lorentz power working for charging particles

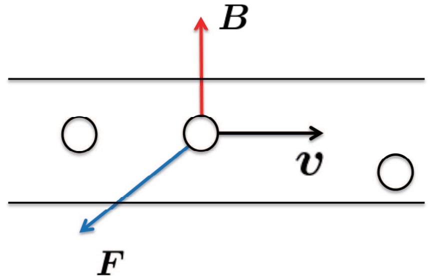



FIGURE 11. Lorentz power that works for the charge point

The Lorentz force $\boldsymbol{F}$ is as follows. If the charges are stationary, $\boldsymbol{F} = q\boldsymbol{E}$, and this is called an electrostatic field. A stationary charge is subject to the Coulomb force, and a moving charge is subject to the Lorentz force.

In Figure 11, the conductor is pulled by the Lorentz force in the direction of the blue arrow [20, 21, 22]. The following relationship exists between this Lorentz force, electric current and magnetic field.

$$\boldsymbol{F} = \boldsymbol{I} \times \boldsymbol{B} \tag{42}$$

The direction of current flow in a conductor is defined as the direction in which a charged particle with positive charge $q$ flows with velocity $\boldsymbol{v}$.

$$\boldsymbol{I} = q\boldsymbol{v} \Leftarrow \boldsymbol{F} = q\boldsymbol{v} \times \boldsymbol{B} \tag{43}$$

In general, the force acting on a particle with charge $q$ moving at velocity $\boldsymbol{v}$ in an electric field $\boldsymbol{E}$ and magnetic field $\boldsymbol{B}$ is the Lorentz force.

$$\boldsymbol{F} = q(\boldsymbol{E} + \boldsymbol{v} \times \boldsymbol{B}) \tag{44}$$

If the charges are stationary, then $\boldsymbol{F} = q\boldsymbol{E}$, which is called an electrostatic field. The Coulomb force acts on a stationary charge, and the Lorentz force acts on a moving charge.

The Lorentz force in the economic field is pulled by the strength of demand, causing the supply force to fluctuate. At the same time, the price of a commodity in the market fluctuates. We believe that this corresponds to Lorenz force.

Capital turnover $\approx (PL)/(BS) \approx$ (sales)/(invested capital). Here, the market assumptions are as follows

- There are numerous sellers and buyers.
- Entry and exit from the market is free.
- Services traded in the market are homogeneous.
- Both sellers and buyers share information about their services.

Above all, there are many suppliers and demanders, who have no power to influence prices, and competition is free. As a result, the law of one price exists. Information is symmetrical. These are the principles of a perfectly competitive market. In Figure 12, the densities of ① and ② are the following, respectively.

$$① = \boldsymbol{E}(x)\left\{-\nabla \cdot -\frac{1}{C}\frac{\partial \boldsymbol{A}(x)}{\partial t}\right\},\ \ ② = \boldsymbol{H}(x)\left\{\nabla \times \boldsymbol{A}(x)\right\} \tag{45}$$

$$\boldsymbol{E} \approx \frac{\partial \boldsymbol{H}(x)}{\partial t} \tag{46}$$

Let $\boldsymbol{E}(x)$ and $\boldsymbol{H}(x)$ be the following equations.

$$\boldsymbol{E}(x) \cong \sin(\omega t),\ \ \boldsymbol{H}(x) \cong w\cos(\omega t) \tag{47}$$

Fourier transforming Equation (47) yields the following equation.

$$w\cos(\omega t) \equiv \sum_k w_k \cos(\omega_k t_k) \equiv \boldsymbol{A}(x) \tag{48}$$

Assets and liabilities move continuously in phase distance space on the basis of the spatial simultaneity of monetary values. Assets and liabilities move as waves in space-time with respect to each other. In particular, when they move sinusoidally, their mathematical structures are complementary to each other as differential or integral structures [23]. Thus, we can say the following.

- Assets generate scalar potential fields and liabilities generate vector potential fields.
- In the field where assets and liabilities are generated, they have a Lagrangian due to their density with each other.

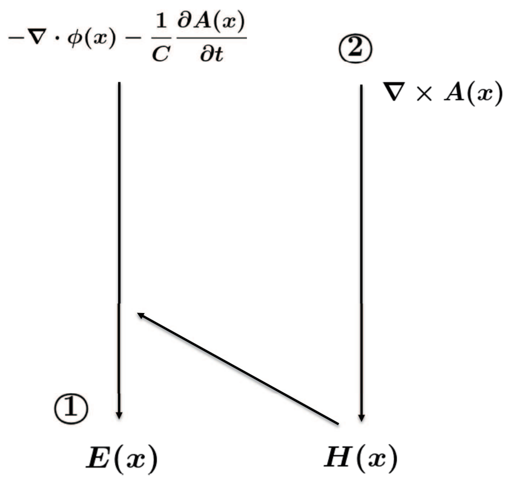



FIGURE 12. Relationship between electric and magnetic field

- Applying the Eulerian-Lagrangian equation to the above Lagrangian yields the electromagnetic equation as an equation of space-time continuity generated from assets and liabilities.

Assets and liabilities achieved on the balance sheet are subject to the following conditions.

**Lemma 4.1.** *Assets invest capital. Liabilities are capital financing.*

*Assets and liabilities are positive real numbers, and they exist as zero balances on the balance sheet at any observation point or at the time of settlement of accounts in the economic field. In other words, assets are denoted by* $\dot{\boldsymbol{E}}(x)$ *and liabilities are denoted by* $\dot{\boldsymbol{H}}(x)$*, the inner product of the two is expressed by the following equation.*

$$< \dot{\boldsymbol{E}}(x) \cdot \dot{\boldsymbol{H}}(x) >= |\boldsymbol{E}| \cdot |\boldsymbol{H}| \cos\theta \tag{49}$$

*Thus, when* $\theta = \pi/2$*, Equation (49) is zero, representing a zero balance.*

In Figure 13, the following equation holds.

$$\begin{aligned} e_L = -L\frac{d\boldsymbol{i}}{dt} \Rightarrow \boldsymbol{E} = L\frac{d\boldsymbol{i}}{dt} \cong \frac{d\boldsymbol{H}}{dt} \\ {}^{\forall}\boldsymbol{i} = \frac{1}{C}\int \boldsymbol{E}dt, \ \ \boldsymbol{H} = \oint \boldsymbol{A}(x,t)dx \end{aligned} \tag{50}$$

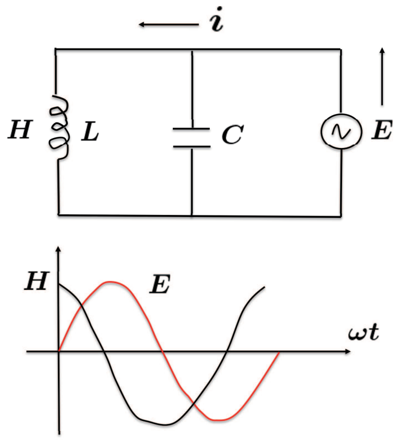



FIGURE 13. Electromagnetic field circuit

**Definition 4.5.** *Assets: $k = Xe^{j\omega t}$, $k$ is earning power, liabilities: $d\int X \cdot e^{j\omega t}dt$ where assets $\approx \frac{d}{dt}$(liabilities) $\Leftarrow$ (differential structure), liabilities are integral structure.*

The Euler-Lagrangian equation then finds the interaction between the electromagnetic field and the particles. This yields the motion of a particle moving in an electromagnetic field and the response of the particle to changes in the electromagnetic field. First, for $\boldsymbol{E}_i(x)$

$$\frac{\partial \mathcal{L}(x)}{\partial \boldsymbol{E}_i(x)} - \partial_t \frac{\partial \mathcal{L}(x)}{\partial \partial_t \boldsymbol{E}_i} - \partial_j \frac{\partial \mathcal{L}(x)}{\partial \partial_j \boldsymbol{E}_j(x)} = -\frac{1}{4\pi}\boldsymbol{E}_i(x) - \frac{1}{4\pi}\left(\nabla \cdot \phi(x) + \frac{1}{c}\partial_t \boldsymbol{A}(x,t)\right) = 0 \quad (51)$$

From Equation (51), we obtain

$$\boldsymbol{E}_i(x) = -\nabla \cdot \phi_i(x) - \frac{1}{c}\partial_t \boldsymbol{A}(x,t) \quad (52)$$

Furthermore, we obtain the following equation for $\psi(x)$.

$$\frac{\partial \mathcal{L}(x)}{\partial \phi_i(x)} - \partial_t \frac{\partial \mathcal{L}(x)}{\partial \partial_t \phi_i(x)} - \partial_j \frac{\partial \mathcal{L}(x)}{\partial \partial_j \phi_j(x)} = -\frac{1}{4\pi}\left(\nabla \cdot \boldsymbol{E}(x)\right) = 0 \Rightarrow \nabla \cdot \boldsymbol{E}(x) = 0 \quad (53)$$

The Lagrangian $\mathcal{L}$ of the electromagnetic field is the density, and from the previous discussion

$$\begin{aligned}\mathcal{L} = &-\frac{1}{8\pi}\left\{\boldsymbol{E}^2(x) - \boldsymbol{H}^2(x)\right\} \\ &-\frac{1}{4\pi}\boldsymbol{E}(x)\left\{\nabla \cdot \phi(x) + \frac{1}{c}\partial_t \boldsymbol{A}(x,t)\right\} - \frac{1}{4\pi}\boldsymbol{H}(x) \cdot \boldsymbol{A}(x,t)\end{aligned} \quad (54)$$

The Eulerian-Lagrange derivative becomes

$$\frac{\partial \mathcal{L}(x)}{\partial u_i(x)} - \partial_t \frac{\partial \mathcal{L}(x)}{\partial \partial_t u_i(x)} - \partial_j \frac{\partial \mathcal{L}(x)}{\partial \partial_j u_j(x)} = 0 \quad (55)$$

From this, we obtain the following equation for $\boldsymbol{H}(x)$.

$$\begin{aligned}&\frac{\partial \mathcal{L}(x)}{\partial \boldsymbol{H}_i(x)} - \partial_t \frac{\partial \mathcal{L}(x)}{\partial \partial_t \boldsymbol{H}_i(x)} - \partial_j \frac{\partial \mathcal{L}(x)}{\partial_j \boldsymbol{H}_j(x)} \\ &= -\frac{1}{4\pi}\boldsymbol{H}_i(x) - \frac{1}{4\pi}(\nabla \times \boldsymbol{A}(x,t)) = 0 \Rightarrow \boldsymbol{H}(x) = \nabla \times \boldsymbol{A}(x,t)\end{aligned} \quad (56)$$

Finally, we obtain the following equation for $\boldsymbol{A}_i(x,t)$.

$$\begin{aligned}&\frac{\partial \mathcal{L}(x)}{\partial \boldsymbol{A}_i(x,t)} - \partial_t \frac{\partial \mathcal{L}(x)}{\partial \partial_t \boldsymbol{A}_i(x,t)} - \partial_j \frac{\partial \mathcal{L}(x)}{\partial \partial_j \boldsymbol{A}_j(x,t)} \\ &= -\frac{1}{4\pi}\left(\frac{1}{c}\partial_t \boldsymbol{E}(x)\right) - \frac{1}{4\pi}\left(\nabla \times \boldsymbol{H}(x)\right) = 0 \Rightarrow \nabla \times \boldsymbol{H}_i(x) - \frac{1}{c}\partial_t \boldsymbol{E}(x) = 0\end{aligned} \quad (57)$$

From the above, the following equation is obtained.

$$\boldsymbol{H}(x) = \nabla \times \boldsymbol{A}(x,t) \quad (58)$$

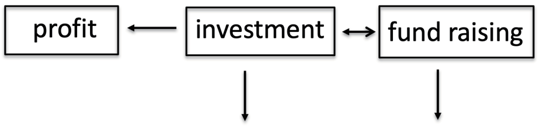
$$\boldsymbol{E}_i(x) = -\nabla \cdot \phi_i(x) - \frac{1}{c}\partial_t \boldsymbol{A}(x,t) \quad (59)$$

$$\nabla \times \boldsymbol{H}(x) - \frac{1}{c}\partial_t \boldsymbol{E}(x) = 0 \quad (60)$$

$$\nabla \cdot \boldsymbol{E}(x) = 0 (= 4\pi\rho(x)) \quad (61)$$

where $\rho(x)$ is net income.

Figure 14 shows the balance sheet of the company from the electromagnetics point of view. The assets section is where the investments are made. The divergence of assets converges to ordinary income. The liabilities section is the place of financing. The ① is liquidity, ② is flow, $-(1/c)(\partial/\partial t)\boldsymbol{A}(x,t)$ in the assets section acts on the liabilities section, and $-(1/c)(\partial/\partial t)\boldsymbol{E}(x)$ is the interaction with the asset portion. The ③ is an addendum. Figure 14 is the definition of zero balances for assets and liabilities. Liabilities are proportional to the rotation of the vector potential generated from equity. In general, a firm invests its invested capital (investment in the profit field) as the sum of its own current assets and the capital raised from its liabilities, and recovers its ordinary profit (net income) through the turnover of its capital.




| | Total Assets | Total Liabilities |
|---|---|---|
| ① | $\nabla \cdot \boldsymbol{E}(x) = 0$ or $\nabla \cdot \boldsymbol{E}(x) = 4\pi\rho(x)$ | $\boldsymbol{H}(x) = \nabla \times \boldsymbol{A}(x,t)$ |
| ② | $\boldsymbol{E}(x) = -\nabla \cdot \phi(x) - \frac{1}{c}\partial_t \boldsymbol{A}(x,t)$ | $\nabla \times \boldsymbol{H}(x) - \frac{1}{c}\partial_t \boldsymbol{E}(x) = 0$ or $= \frac{4\pi}{c}\boldsymbol{J}(x)$ |
| ③ | $\delta\phi(x) = 0$ | net assets |

FIGURE 14. Balance sheet from an electromagnetic perspective

4.1. **Dynamical model.** From an engineering point of view, it defines the turnover of capital in a business entity; see Figure 15.

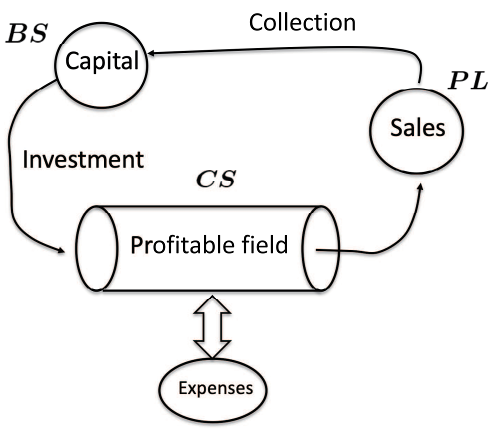



FIGURE 15. Cycle of capital deposit to payback

**Definition 4.6.** *The turnover of capital refers to the process from the investment of capital in a business entity to the recording of sales through activities at the profit center and the collection of profit if there is profit. This sequence of events is defined as "capital turnover".*

Gross capital turnover is the degree of effective utilization (efficiency) of total capital. The strategy to increase turnover requires an increase in sales and a decrease in total assets. This requires a reduction in excess inventory. In addition, proper management of trade receivables is necessary. Alternatively, the collection rate of trade receivables should be increased. For your information, turnover = $PL$ (sales)/$BS$ (accounts receivable).

In Figure 16, invested capital generates capital turnover relative to sales; $BS$ preserves spatial simultaneity with respect to the monetary value of the organization with capital. In addition, liabilities finance assets; $CS$ and $PL$ generate capital linkages.

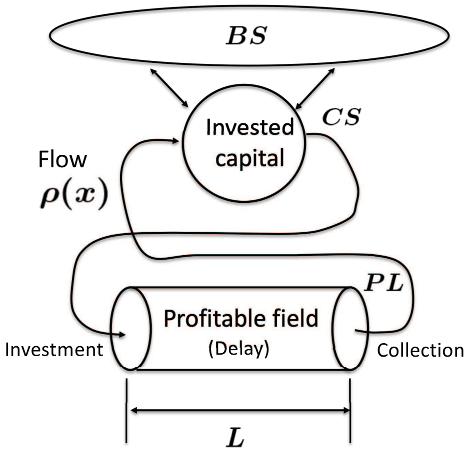



FIGURE 16. $BS/CS/PL$ interrelationships

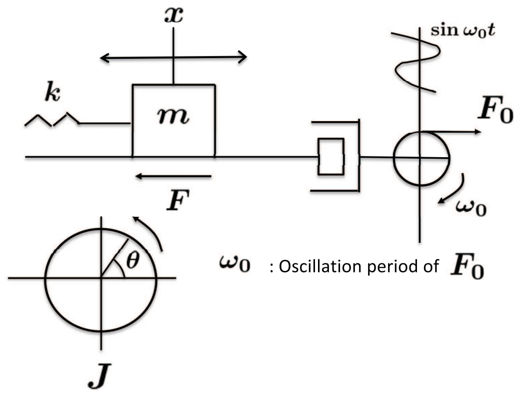



FIGURE 17. Dynamical model

A dynamical system model is used to analyze Lorentz forces in electromagnetism in detail [24].

In Figure 18, current assets increase or decrease due to investment flows. We now propose that the dynamical system model corresponds to $BS/PL/CS$ as follows.

$$m\frac{d^2x}{dt^2} + a\frac{dx}{dt} + kx \equiv F_0 \tag{62}$$

where $m\frac{d^2x}{dt^2}$ corresponds to ① and $kx$ corresponds to ② and represents the increase or decrease in assets, and $a\frac{dx}{dt}$ corresponds to ③ in Figure 18 and represents financing and profit contributions. $kx$ is the term with the nonlinearity of investment return. $x(t)$ denotes research, development and capital investment flows. In other words, $m\frac{d^2x}{dt^2}$ is total assets, $a\frac{dx}{dt}$ represents total liabilities. At this time, on $BS$, [total assets] + [total liabilities] = 0. Here, on $CS$ (cash flow statement), the flow of funds is expressed in positive and negative magnitudes within $CS$. In other words, they are reduced to current assets, fixed assets and similar liabilities. Each element within the $BS$ (balance sheet) is represented by a positive real number. They are allocated so as to have a zero balance. Within $PL$ (income statement), ordinary income and operating income on sales are calculated and reduced to elements of net assets.

Thus, the equilibrium equation (62) is a conditional equation in a vector field. Here, the following definitions are used.

**Definition 4.7.**

$$kx = k_1\left(x - \beta x^3\right) + k_2 x \tag{63}$$

*where* $k_1\left(x - \beta x^3\right)$ *depends on investment flows, and* $k_2 x$ *depends on financial flows.*

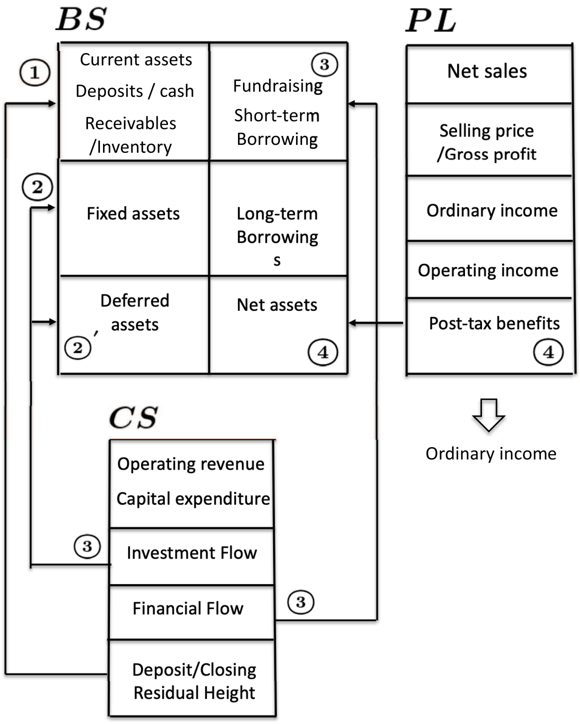



FIGURE 18. $BS/PL/CS$ relationship

Therefore, the following equation holds on the balance sheet

$$\left(m\frac{d^2x}{dt^2}+k_1\left(x-\beta x^3\right)\right)+\left(a\frac{dx}{dt}+k_2x+F_0\right)=0 \tag{64}$$

In other words, it is an equilibrium equation, where the first term $(\cdot)$ on the left side of Equation (64) is deposits or cash. The second term $(\cdot)$ on the left side is current liabilities, fixed liabilities, net assets, etc.

The probability field for ordinary income is defined by

$$i\hbar\frac{\partial\psi(x,t)}{\partial t}=-\frac{\hbar}{2m}\nabla_x^2+V(x)\psi(x,t) \tag{65}$$

$$dx(t)=\mu(x,t)dt+\sigma dW(t),\ \forall\frac{dR(t)}{R(t)} \tag{66}$$

where $R(t)$ is ordinary profit, $x(t)$ is bounded by the stochastic process of ordinary profit margin. $|\psi(x,t)|^2$ denotes the transition probability of recurring profit margin.

Put $\frac{dR(t)}{R(t)}=dx(t)$ as the probability field. However, $R(t)$ is the lead-time function. The behavior of $x(t)$ can be expressed by a normal-type stochastic differential equation.

$$dx(t)=\mu(x,t)dt+\sigma dW(t) \tag{67}$$

From this,

$$i\hbar\frac{\partial\psi(x,t)}{\partial t}=-\frac{\hbar^2}{2m}\nabla_x^2\psi(x,t)+V(x)\psi(x,t) \tag{68}$$

$$|\psi(x,t)|^2=\rho(x,t) \tag{69}$$

## 5. On the Laws of Electromagnetism.

5.1. **About electric field, magnetic field, electric current, electric potential, and capacitor.** A field is an interaction moving through space. There are two types of fields: one is a scalar field, in which each point in space has a defined magnitude (number), such as pressure, and temperature. The other is a vector field, in which a vector quantity exists at a point in space, such as an electric field, magnetic field, and electromagnetic wave. The intensity of the field corresponds to the fluid velocity. In other words, the intensity and direction of the electric field also correspond to this. The fluid must go somewhere without disappearing. In other words, since the divergence is zero, it is defined by Equation (70) [20, 21, 22]. The electromagnetic field symbols used below are functions related to time and space, and are omitted for convenience.

$$\nabla \cdot \boldsymbol{E} = 0,\ \nabla \cdot \boldsymbol{H} = 0 \tag{70}$$

where $\boldsymbol{E}$ is the electric field and $\boldsymbol{H}$ is the magnetic field.

The laws of electromagnetism can be summarized as follows [20, 21, 22].

$$\boldsymbol{H} = \nabla \times \boldsymbol{A} \tag{71}$$

$$\boldsymbol{E} = -\nabla\phi - \frac{1}{c}\frac{\partial \boldsymbol{A}}{\partial x} \tag{72}$$

$$\nabla \times \boldsymbol{H} - \frac{1}{c}\frac{\partial \boldsymbol{E}}{\partial x} = \frac{4\pi}{c}\rho \tag{73}$$

$$\nabla \cdot \boldsymbol{E} = 4\pi\rho \tag{74}$$

$$\delta\phi = 0 \tag{75}$$

where $\boldsymbol{E}$: electric field [V/m] = [N/C], $\boldsymbol{B}$: magnetic flux density [T] = [Wb/m$^2$], $\boldsymbol{D}$: electric flux density [C/m$^2$], $\boldsymbol{A}$: vector potential [V·s·m$^{-1}$], $\boldsymbol{H}$: magnetic field [A/m], $\phi$: magnetic flux density [Wb], $c$: optical velocity [m·s$^{-1}$], $\boldsymbol{J}$: current density [A/m$^2$], $\rho$: charge density [C/m$^3$].

However, $\boldsymbol{D}$ is the demand field and $\boldsymbol{S}$ is the supply field. This is equivalent to the following equation when expressed in differential form.

$$\mathrm{div}\boldsymbol{D} = \kappa\rho,\ {}^{\forall}\boldsymbol{D} = \epsilon\boldsymbol{E} \tag{76}$$

$$\mathrm{rot}\boldsymbol{H} - \frac{1}{c}\frac{\partial \boldsymbol{D}}{\partial t} = 0 \tag{77}$$

$$\mathrm{div}\boldsymbol{B}(t) = 0,\ \boldsymbol{B} = \mu\boldsymbol{H} \tag{78}$$

$$\mathrm{rot}\boldsymbol{E}(t) + \frac{1}{c}\frac{\partial \boldsymbol{B}}{\partial t} = 0 \tag{79}$$

where $\boldsymbol{D} = \mu\boldsymbol{H}$ and $\boldsymbol{S} = \epsilon\boldsymbol{E}$.

For Equation (76), a market cost, e.g., borrowing from a bank, generates an interest rate. This interest rate is called the cost. This interest rate fluctuates stochastically due to market trends. For Equation (77), the spin of market debt, e.g., a firm's debt, fluctuates between increasing and decreasing. This variation corresponds to the spin in physics. This spin is equal to the rate of change in external flows (the "flow" of economic activity, i.e., the aggregate of production, income, expenditures, etc. over a given period) and market costs. For Equation (78), market debt does not disappear; for Equation (79), the spin of the cost of capital and the rate of change of market debt are conserved. In the above differential form of the electromagnetic equation, $\boldsymbol{E}$ and $\boldsymbol{H}$ can be replaced by market prices and market supply, respectively, without contradiction.

$$\boldsymbol{H} = \nabla \times \boldsymbol{A} \tag{80}$$

$$\boldsymbol{S} = -\nabla\phi - \frac{1}{c}\frac{\partial \boldsymbol{A}}{\partial r} \tag{81}$$

$$\nabla \times \boldsymbol{D} - \frac{1}{c}\frac{\partial \boldsymbol{S}}{\partial r} = \frac{4\pi}{c}\boldsymbol{J} \tag{82}$$

$$\nabla \boldsymbol{S} = \rho \tag{83}$$

$$\delta\phi = 0 \tag{84}$$

where $\boldsymbol{D}$ is the demand field and $\boldsymbol{S}$ is the supply field. This is equivalent to the following equation.

$$\mathrm{div}\boldsymbol{S} = \rho \tag{85}$$

$$\mathrm{div}\boldsymbol{D} = 0 \tag{86}$$

$$\mathrm{rot}\boldsymbol{S} + \frac{1}{c}\frac{\partial \boldsymbol{D}}{\partial x} = 0 \tag{87}$$

$$\mathrm{rot}\boldsymbol{D} - \frac{1}{c}\frac{\partial \boldsymbol{S}}{\partial x} = \frac{1}{c}\boldsymbol{J} \tag{88}$$

where $\boldsymbol{J}$ is the capital flow due to demand changes, and $\rho$ is the capital density.

Equations (80)-(84) are equations similar to the electromagnetic equations in the economic field. In these equations, the coefficient $4\pi$ is a numerical value for calculation because the isosurface is considered, which is problematic in an economic field. As described above, the market model is considered as an electromagnetic field. Equations (85)-(88) are the differential form of Equations (80)-(84). For Figure 17, replace Equation (72) with the following equation.

$$\boldsymbol{S} + \boldsymbol{e}_A = \boldsymbol{\phi} \tag{89}$$

$$\boldsymbol{e}_A \approx \frac{\partial \boldsymbol{A}}{\partial r} \approx \frac{\partial \boldsymbol{I}(t)}{\partial t} \tag{90}$$

$$\boldsymbol{S} + \frac{1}{c}\frac{\partial \boldsymbol{A}}{\partial x} = -\nabla\boldsymbol{\phi} \tag{91}$$

$$\boldsymbol{J} = \boldsymbol{I} - \boldsymbol{I}_S \tag{92}$$

$$\boldsymbol{I} \approx \boldsymbol{A} \equiv \boldsymbol{D} \tag{93}$$

$$\boldsymbol{I}_S = \frac{\partial q}{\partial t} \approx \frac{\partial \boldsymbol{S}}{\partial x} \tag{94}$$

In Figure 17, $\boldsymbol{J}$ is derived as follows.

$$\boldsymbol{J} = \boldsymbol{I} - \boldsymbol{I}_S = \boldsymbol{D} - \frac{1}{c}\frac{\partial \boldsymbol{A}}{\partial x} \tag{95}$$

$$\int_S \nabla \times \boldsymbol{E} \cdot dS = \oint_C \boldsymbol{E} \cdot dS = 0 \tag{96}$$

5.2. **Mapping from electromagnetic field to economic field.** According to Dr. Miura, the view is that equity and debt are orthogonal [25, 26, 27]. Therefore, we propose an application of electromagnetism to the economic field by assuming the orthogonality of electric and magnetic fields that we propose with reference to this paper. The following table shows how matters that play an important role in the electromagnetic field correspond to what role they play in the economic sector.

Table 2. Electromagnetic field and economic field

| Electromagnetic field | Economic field |
|---|---|
| Electric field ($\boldsymbol{E}$) | Supply or market cost |
| Magnetic field ($\boldsymbol{H}$) | Demand or market debt |
| Current ($\boldsymbol{J}$) | Price $\boldsymbol{P}$ flow or demand flow |
| Lorentz force ($\boldsymbol{F}$) | Price fluctuation force |

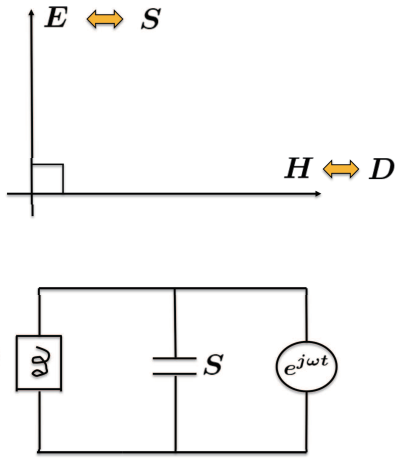



FIGURE 19. $\boldsymbol{E}$ and $\boldsymbol{H}$ orthogonal and their equivalent circuits

In the orthogonal axes of Figure 19, $\boldsymbol{E}$ is the supply in the market and $\boldsymbol{H}$ is the consumption in the market. As mentioned above, $\boldsymbol{E}$ and $\boldsymbol{H}$ are assumed to be orthogonal. The equilibrium points $\boldsymbol{E}$ and $\boldsymbol{H}$ are always orthogonal at this point, no matter which point the equilibrium point moves to. The same electric circuit in Figure 19 represents the orthogonal state of $\boldsymbol{E}$ and $\boldsymbol{H}$ as an equivalent electric circuit. The coil $L$ in the economic field means consumption, which is equivalent to supplying it with a capacitor $C$. This consumption is equivalent to the consumption of free energy by the dissipative term.

In Figure 19, $\{\boldsymbol{E}, \boldsymbol{H}\}$ is the electromagnetic field for the supply and demand of goods in the market. There exists here a virtual excited particle $\rho$ excited by the above. The virtual electromagnetic field $\{\boldsymbol{E}, \boldsymbol{H}\}$ in the market induces $\boldsymbol{E}$ (market costs) and $\boldsymbol{H}$ (market liabilities) from economic individuals (quality points) with capital density $\rho$. This $\{\boldsymbol{E}, \boldsymbol{H}\}$ is called the electromagnetic field due to economic behaviour.

$$\boldsymbol{D}(t) = \boldsymbol{D}e^{j\omega t}, \ \ \boldsymbol{S}(t) = \int_0^t \boldsymbol{D}(t)dt = \int_0^t \boldsymbol{D}e^{j\omega t}dt = \frac{1}{j\omega}\boldsymbol{D}e^{j\omega t} \tag{97}$$

Figure 20 shows that the economic field is equivalent to the electromagnetic field as a physical field. The specifics are discussed below. In the Schrödinger field described in the previous section, individual economic and market agents interact. Since economic fields are equivalent to electromagnetic fields, the electromagnetic equations that hold in electromagnetic fields also hold in economic fields. In the economic field, the equivalent of the electromagnetic equation corresponds to economic demand and supply.

Figure 21 represents the balance sheet as a reasonable method of financial notation in a capitalist economy. This is a table that can be obtained in both macro and micro economies.

- Faraday's law: time variations in the magnetic field produce an electric field.
- Anperer-Maxwell's law: relationship between magnetic field and current density (displacement current).
- Gauss's law: divergence of electric fields and charge density.

These must be established in the economic field.

- Capital value (capital density): supply $\Longleftrightarrow$ Electric field $\boldsymbol{E}(x,t)$
- Demand $\Longleftrightarrow$ Magnetic field $H(x,t) \Longrightarrow \boldsymbol{A}(x,t)$
- Market price (excited by demand) $\Longleftrightarrow$ Current $\boldsymbol{i}(x,t)$ or demand flow
- Electric potential (electric) $\Longleftrightarrow$ Excited from the electric field $\phi(x,t)$ (scalar potential)

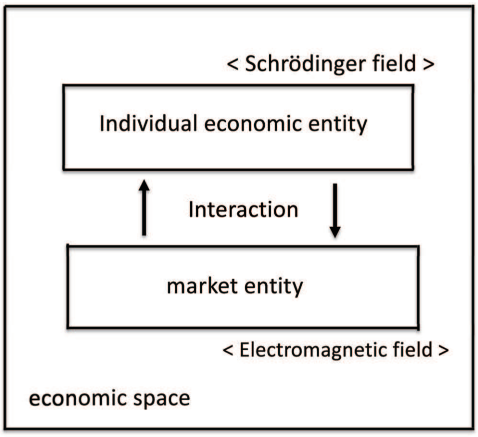



Figure 20. Individual subjects in individual standard

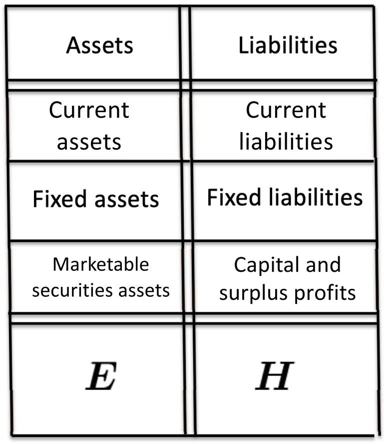



Figure 21. Balance sheet

Table 3. Assets and liabilities

| Assets | Capital |
|---|---|
| $aa$ | $cc$ |
| $bb$ | $dd$ |

In Table 3, $aa$ is current assets and $bb$ is fixed assets. $cc$ is current liabilities + fixed liabilities. $dd$ is capital stock + retained earnings.

$$(aa + bb) - (cc + dd) = 0 \tag{98}$$

5.3. **Numerical examples.** One year balance sheet is the normalized data for $\boldsymbol{E}$ and $\boldsymbol{H}$ described in Figure 22. $\boldsymbol{E}$ and $\boldsymbol{H}$ locations extracted from the normal distribution map are linearly approximated in Figure 23. In Figure 23, we use two balance sheets for each single year in Figure 22. Calculating each value from $\boldsymbol{E}_1$ through $\boldsymbol{E}_3$ and from $\boldsymbol{H}_1$ through $\boldsymbol{H}_3$ according to the calculation method described in Figure 23, the angle of intersection with the vertical axis is approximately $\pi/4$ as shown in Figure 23. Therefore,

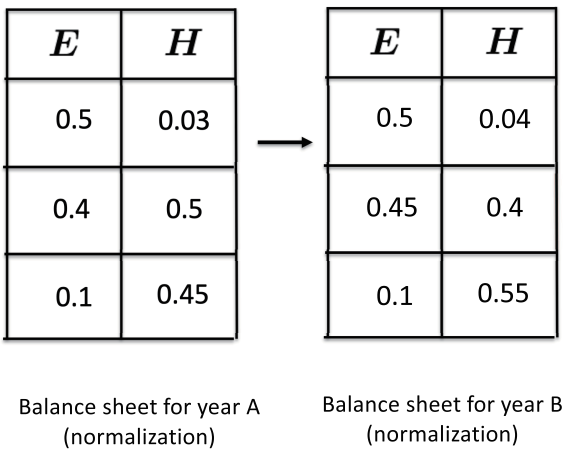



Figure 22. One year balance sheet (normalization)

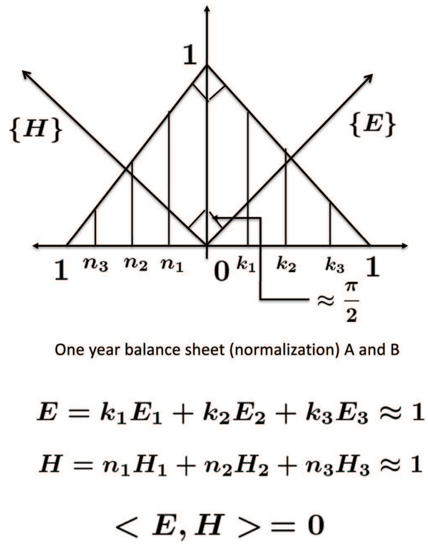



Figure 23. $< \boldsymbol{E}, \boldsymbol{H} >= 0$

the intersection angle of $\boldsymbol{E}$ and $\boldsymbol{H}$ is $\pi/2$ in Figure 23. That is, $< \boldsymbol{E}, \boldsymbol{H} > = 0$. It can be seen that the relationship between capital and debt in the economic field maintains Fleming's left-hand rule in electromagnetism.

6. **Conclusion.** In this paper, with respect to economic quality points excited by information about supply and demand as economic information, supply is considered to correspond to an electric field, demand to a magnetic field, and price flows and demand flows to electric currents. From this, it was shown that the flow of products generated by demand and supply is specified by Schrödinger's wave equation. He also proposed that the $BS/CS/PL$ interrelationship in the economic field satisfies Ampere-Maxwell's electromagnetic equation.

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**Appendix** A. **Analysis of Actual Data in the Production Flow System.** Based on the control equipment, the product can be manufactured in one cycle. The production throughput required to maintain 6 pieces of equipment/day is as follows:

$$\frac{(60 \times 8 - 28)}{3} \times \frac{1}{6} \simeq 25 \text{ (min)} \tag{99}$$

where the throughput of the previous process is set as 20 (min). In Equation (99), "28" represents the throughput of the previous process plus the idle time for synchronization. "8" is the number of processes and the total number of all processes is "8" plus the previous process. "60" is given by 20 (min) × 3 (cycles).

One process throughput (20 min) in full synchronization is

$$T_s = 3 \times 120 + 40 = 400 \text{ (min)} \tag{100}$$

Therefore, a throughput reduction of about 10% can be achieved. However, the time between processes involves some asynchronous idle time.

As a result, the above testrun is as follows.

- (testrun1): Each throughput in every process (S1-S6) is asynchronous, and its process throughput is asynchronous. Table 4 represents the production time (min) in each process. Table 5 represents the variance in each process performed by workers. Table 4 represents the target time, and the theoretical throughput is given by $3 \times 199 + 2 \times 15 = 627$ (min).

  In addition, the total working time in stage S3 is 199 (min), which causes a bottleneck. Figure 24 is a graph illustrating the measurement data in Table 4, and it represents the total working time for each worker (K1-K9). The graph in Figure 25 represents the variance data for each working time in Table 4.
- (testrun2): Set to synchronously process the throughput.

  The target time in Table 6 is 500 (min), and the theoretical throughput (not including the synchronized idle time) is 400 (min). Table 7 represents the variance data of each working process (S1-S6) for each worker (K1-K9).

TABLE 4. Total production time at each stage for each worker

| | WS | S1 | S2 | S3 | S4 | S5 | S6 |
|---|---|---|---|---|---|---|---|
| K1 | 15 | 20 | 20 | 20 | 20 | 20 | 20 |
| K2 | 20 | 20 | 20 | 20 | 20 | 20 | 20 |
| K3 | 10 | 20 | 20 | 20 | 20 | 20 | 20 |
| K4 | 20 | 17 | 15 | 19 | 18 | 16 | 18 |
| K5 | 15 | 15 | 20 | 20 | 20 | 15 | 15 |
| K6 | 15 | 15 | 15 | 15 | 15 | 15 | 15 |
| K7 | 15 | 20 | 20 | 20 | 20 | 20 | 20 |
| K8 | 20 | 20 | 20 | 20 | 20 | 20 | 20 |
| K9 | 15 | 14 | 14 | 15 | 14 | 14 | 14 |
| Total | 145 | 161 | 164 | 169 | 167 | 160 | 162 |

TABLE 5. Volatility of Table 4

| | S1 | S2 | S3 | S4 | S5 | S6 |
|---|---|---|---|---|---|---|
| K1 | 1.67 | 1.67 | 3.33 | 1.67 | 1.67 | 1.67 |
| K2 | 2.33 | 2 | 2.33 | 2 | 1.33 | 1.67 |
| K3 | 1.67 | 3.67 | 3.33 | 2.33 | 2.33 | 3.67 |
| K4 | 0.67 | 0 | 1.33 | 1 | 0.33 | 1 |
| K5 | 0 | 1.67 | 1 | 0.33 | 0 | 0 |
| K6 | 0 | 0 | 0 | 0 | 0 | 0 |
| K7 | 1.67 | 1.67 | 5 | 1.67 | 2 | 1.67 |
| K8 | 4.67 | 6 | 5 | 4.67 | 5.67 | 6 |
| K9 | 0.33 | 0.33 | 0 | 0.33 | 0.33 | 0.33 |

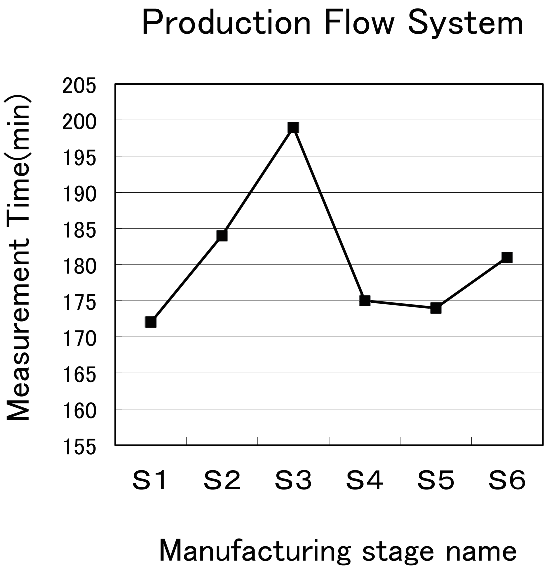


FIGURE 24. Total work time for each stage (S1-S6) in Table 4

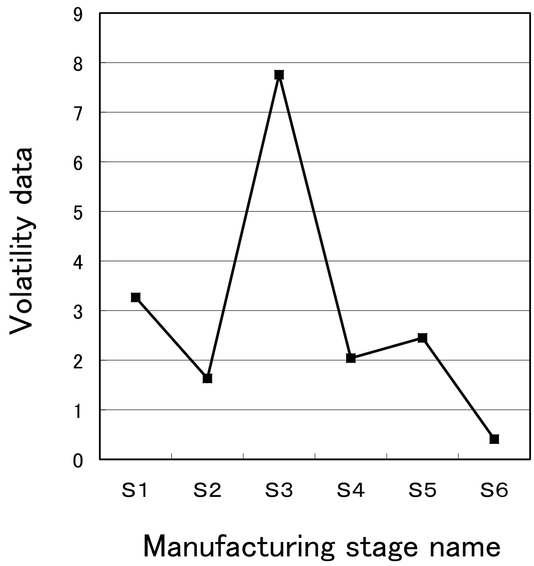


FIGURE 25. Volatility data for each stage (S1-S6) in Table 4

TABLE 6. Total production time at each stage for each worker

| | WS | S1 | S2 | S3 | S4 | S5 | S6 |
|---|---|---|---|---|---|---|---|
| K1 | 20 | 20 | 20 | 20 | 20 | 20 | 20 |
| K2 | 20 | 20 | 20 | 20 | 20 | 22 | 20 |
| K3 | 20 | 20 | 20 | 20 | 20 | 20 | 20 |
| K4 | 20 | 20 | 20 | 20 | 20 | 20 | 20 |
| K5 | 20 | 20 | 20 | 20 | 20 | 20 | 20 |
| K6 | 20 | 20 | 20 | 20 | 20 | 20 | 20 |
| K7 | 20 | 20 | 20 | 20 | 20 | 20 | 20 |
| K8 | 20 | 20 | 20 | 20 | 20 | 20 | 20 |
| K9 | 20 | 20 | 20 | 20 | 20 | 20 | 20 |
| Total | 180 | 180 | 180 | 180 | 180 | 182 | 180 |

TABLE 7. Volatility of Table 6

| | S1 | S2 | S3 | S4 | S5 | S6 |
|---|---|---|---|---|---|---|
| K1 | 0 | 1.33 | 0 | 0 | 0 | 0 |
| K2 | 0 | 0 | 0 | 0 | 0.67 | 0 |
| K3 | 0 | 0 | 0 | 0 | 0 | 0 |
| K4 | 1.67 | 1.67 | 0 | 0 | 0 | 0 |
| K5 | 0 | 0 | 0 | 0 | 0 | 0 |
| K6 | 0 | 0 | 0 | 0 | 0 | 0 |
| K7 | 0 | 0 | 0 | 0 | 0 | 0 |
| K8 | 2.33 | 2.33 | 0.67 | 1 | 0 | 0 |
| K9 | 0 | 0 | 0 | 0 | 0 | 0 |

Table 8. Total production time at each stage for each worker

| | WS | S1 | S2 | S3 | S4 | S5 | S6 |
|---|---|---|---|---|---|---|---|
| K1 | 20 | 18 | 19 | 18 | 20 | 20 | 20 |
| K2 | 20 | 18 | 18 | 18 | 20 | 20 | 20 |
| K3 | 20 | 20 | 20 | 20 | 20 | 20 | 20 |
| K4 | 20 | 13 | 11 | 11 | 20 | 20 | 20 |
| K5 | 20 | 16 | 16 | 17 | 20 | 20 | 20 |
| K6 | 20 | 18 | 18 | 18 | 20 | 20 | 20 |
| K7 | 20 | 14 | 14 | 13 | 20 | 20 | 20 |
| K8 | 20 | 20 | 20 | 20 | 20 | 20 | 20 |
| K9 | 20 | 20 | 20 | 20 | 20 | 20 | 20 |
| Total | 180 | 157 | 156 | 155 | 180 | 180 | 180 |

Table 9. Variance of Table 8

| | S1 | S2 | S3 | S4 | S5 | S6 |
|---|---|---|---|---|---|---|
| K1 | 0.67 | 0.33 | 0.67 | 0 | 0 | 0 |
| K2 | 0.67 | 0.67 | 0.67 | 0 | 0 | 0 |
| K3 | 0.33 | 0.33 | 0.33 | 0 | 0 | 0 |
| K4 | 2.33 | 3 | 3 | 0 | 0 | 0 |
| K5 | 1.33 | 1.33 | 1 | 0 | 0 | 0 |
| K6 | 0.67 | 0.67 | 0.67 | 0 | 0 | 0 |
| K7 | 2 | 2 | 2.33 | 0 | 0 | 0 |
| K8 | 0.67 | 0.67 | 0 | 0 | 0 | 0 |
| K9 | 1.67 | 1.67 | 1.67 | 0 | 0 | 0 |

- (testrun3): The process throughput is performed synchronously with the reclassification of the process. The theoretical throughput (not including the synchronized idle time) is 400 (min) in Table 8.

Table 9 represents the variance data of Table 8. "WS" in the measurement tables represents the standard working time. This is an empirical value obtained from long-term experiments.

**Appendix** B. **Derivation of $\psi(x)$.** For simplicity, we consider it in terms of a one-dimensional wave equation.

$$-\frac{\hbar h^2}{2m}\frac{d^2}{dx^2}\psi = \boldsymbol{E}\psi$$

A trigonometric function appears in this solution, and is $-1$ times the original function after two differentiations. Therefore, Let $\psi = A\sin bx$. $A$ and $b$ are undetermined coefficients. Schrödinger's boundary and normalization conditions are as follows. For $x = 0$ and $x = L$,

$$\psi = A\sin(b\times 0) = 0,\;\; \psi = A\sin(b\times L) = A\sin bL$$

To satisfy $A\sin bL = 0$,

$$bL = n\pi,\;\; (n = 1, 2, 3, \ldots) \Rightarrow b = \frac{n\pi}{L}\;\; (n = 1, 2, \ldots)$$

The normalization condition then states that the probability that a particle exists in the region from $x = 0$ to $x = L$ is 1.

$$\int_0^L \left|A\sin\frac{n\pi}{L}x\right|^2 dx = |A|^2\int_0^L \sin^2\frac{n\pi}{L}xdx = |A|^2\left[\frac{1}{2}x - \frac{1}{2}\left(\frac{2n\pi}{L}\right)^{-1}\sin\frac{2n\pi}{L}x\right]_0^L = |A|^2\frac{L}{2}$$

The result of the above equation must be 1 (normalization condition)

$$|A|^2\frac{L}{2} = 1,\;\; A = \sqrt{\frac{2}{L}}$$

Therefore, the wave function to be sought is

$$\psi = \sqrt{\frac{2}{L}}\sin\frac{2n\pi}{L}$$

**Appendix** C. **Proof that Electric and Magnetic Fields are Waves.** We prove that electric and magnetic fields are waves based on the following equation.

$$\nabla \times \boldsymbol{E} = -\frac{1}{c}\frac{\partial \boldsymbol{H}}{\partial t} \Rightarrow \nabla \times \nabla \times \boldsymbol{E} = -\frac{1}{c}\frac{\partial \nabla \times \boldsymbol{H}}{\partial t} \tag{101}$$

The left-hand side of Equation (101) can be expanded as follows.

$$\nabla \times \nabla \times \boldsymbol{E} = \nabla(\nabla \cdot \boldsymbol{E}) - \nabla^2 \boldsymbol{E} = -\nabla^2 \boldsymbol{E} \ (\because \nabla \cdot \boldsymbol{E} = 0) \tag{102}$$

The right-hand side of Equation (101) can be expanded as follows.

$$-\frac{1}{c}\frac{\partial \nabla \times \boldsymbol{H}}{\partial t} = -\frac{1}{c}\frac{\partial}{\partial t}\left[\frac{\partial \boldsymbol{E}}{\partial t}\right] = -\frac{1}{c^2}\frac{\partial^2 \boldsymbol{E}}{\partial t^2} \tag{103}$$

From Equations (102) and (103), we obtain as follows.

$$\frac{\partial^2 \boldsymbol{E}}{\partial t^2} = c^2 \nabla^2 \boldsymbol{E} \tag{104}$$

As with the analysis of the electric field, the analysis of the magnetic field is as follows.

$$\nabla \times \boldsymbol{H} = \frac{1}{c}\frac{\partial \boldsymbol{E}}{\partial t} \Rightarrow \frac{\partial^2 \boldsymbol{H}}{\partial t^2} = c^2 \nabla^2 \boldsymbol{H} \tag{105}$$

This means that $\boldsymbol{E}$ and $\boldsymbol{H}$ are waves of $c$ [end of proof].

## Author Biography

**Kenji Shirai** received the B.Sc. degree in Electrical Engineering from Ritsumeikan University, Japan, 1973; the M.Sc. degree in Electrical Engineering from Ritsumeikan University, Japan, 1975; the Ph.D. degree in Electrical Engineering from Ritsumeikan University, Japan, 2000.

Dr. Shirai is engaged in research on optimal control of distributed parameter systems, modeling of industrial systems applying mathematical finance, and optimal control.

**Yoshinori Amano** received the B.Sc. degree in Electrical Engineering from Ritsumeikan University, Japan, 1971; the M.Sc. degree in Electrical Engineering from Ritsumeikan University, Japan, 1973; the Ph.D. degree in Electrical Engineering from Ritsumeikan University, Japan, 1977.

Dr. Amano is engaged in research on optimal control of distributed parameter systems, modeling of information systems applying mathematical finance, and optimal control.

**Takayuki Uda** received a doctoral degree (Information Science) from the Graduate School of Information Sciences, Tohoku University, Japan, in 2009; a master's degree (Informatics) from the University of Library and Information Science (now Information and Media Studies, University of Tsukuba).

Dr. Uda is currently a full-time Professor at the Department of Information Systems, Faculty of Business and Informatics, Niigata University of International and Information Studies. His research fields are data science and natural language processing. His research results contribute to the education and research of students.

**Atsuya Ando** received the Dr. Eng. degree in System Information Engineering from Tsukuba University, in 2013. In 1990, he joined the Nippon Telegraph and Telephone Corporation (NTT) Wireless Systems Laboratories, Yokosuka, Japan. He was engaged in research and development of personal and base station antennas for wireless mobile communication systems. From 2000 to 2003, he was with the ATR Adaptive Communications Research Laboratories, Kyoto, Japan, engaging in research and development on adaptive array antennas for wireless ad-hoc network systems. In 2019, he moved to Niigata University of International and Information Studies, and he is currently a Professor in the Department of Information Systems, Faculty of Business and Informatics. His research interests include mobile and base station antennas using metamaterials for wireless communication systems.