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January 19-21, 2017

ACENS

Asian Conference on Engineering and Natural Sciences

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International Conference on Applied Sciences

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Welcome Message

Local Host

Kurt Ackermann

Associate Professor
English department Hokusei Gakuen University's Junior College Sapporo, Japan

Dear Conference Delegates,

As Hokkaido's first people the Ainu would say, "Irankarapte!"

Please accept a warm welcome to cool Hokkaido from me, Kurt Ackermann, and Higher Education Forum (HEF), the organizers of the 2017 Sapporo conferences.

As the transportation and financial hub of Hokkaido, Sapporo attracts a wide variety of visitors, coming for tourism or business. It has a well-established transportation infrastructure adapted to its unique winter situation, as well as a history of hosting large winter sports events, in particular the 1972 Winter Olympics. In fact, Sapporo will host the 8th Asian Winter Games soon after these conferences, from the 19th to the 26th of February 2017. This event is a prelude to the 23rd Olympic Winter Games, to be held in February 2018 in Pyeongchang in neighbouring South Korea.

Sapporo's winters, while often feeling cold to those from warmer climes, are actually quite mild by the standards of many cities that receive large amounts of snow.

The combination of plentiful snow, modern infrastructure, and (relatively!) mild temperatures makes the city and its environs a true winter playground. For visitors wishing to try their hand at some of these, there are free or reasonably-priced opportunities to try cross-country skiing (Nakajima Park), snowshoeing (Sapporo Art Park) and ice-skating. More ambitious visitors may even wish to try downhill skiing or snowboarding. In Sapporo, the possibilities for winter sports are almost limitless.

International Committees

International Committee of Nature Sciences

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ICAS-349
Study on Bird Flu Infection Process within a Poultry Farm with Effects of Spatial Diffusion

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Abstract

A nonlinear system of partial differential equations is analyzed for investigation of bird flu transmission process within a poultry farm. Numerical results show that the transmission of bird flu within a poultry farm corresponds to a traveling wave solutions. Effect of the reproduction rate that gives measure if infectious intensity is investigated. A mathematical model is described and numerical results are presented. Significance of numerical results is interpreted.

Keywords: Nonlinear system, partial differential equations, transmission process, traveling wave solutions, numerical

1. Background

Bird flu is a highly infectious and fatal disease for domestic birds. The disease is caused by virus types H5N1 carried by wild birds such as wild ducks. Most highly pathogenic strain (H5N1) has been spreading throughout Asia since 2003, before it reached Europe in 2005 and Middle East, as well as Africa in 2006. Cases of infected poultry farms were reported from several provinces of Indonesia including Bali, East Java, West Java and West Kalimantan in January 2004. Several cases of bird flu-to-human infection have also been reported. Those include cases found in 12 provinces in Indonesia. Any human-to-human infection of bird flu has not yet been reported so far. However, bird flu is now endemic to some region (Table 1) and it is inevitable for the virus to acquire the ability unless the contact between hosts and human is reduced in frequency.

Poultry farms are contact points between carriers of bird flu virus and human. The infection with highly pathogenic form transmits rapidly over a poultry farm and causes domestic birds serious symptoms that eventually lead to death. In current practice, even if infection is detected from only one bird, the entire population in the farm are culled, which have been causing immense damage to the poultry industry. Vaccination is an effective measure against bird flu because vaccinated chickens produce up to 100 thousands times less viruses when infected. While vaccinating chickens is effective, it affects export trade. Some countries even set a non-vaccination policy [1]. Now techniques to control outbreaks in a poultry farm must be developed.

Table 1: Bird flu cases in West Sumatra 2011-2015

Year	Infected	Susceptible
2011	31,508	841
2012	1,164	1,073
2013	11,038	-
2014	2,170	338
2015	3	7

Source: Department of Animal Husbandry, West Sumatra, Indonesia

In this study, infection processes of bird flu within a poultry farm is analyzed with mathematical techniques. Various mathematical models have been applied to problems that relate to bird flu infection. A mathematical model to interpret the spread Avian Influenza from the bird world to the human world with autonomous ordinary differential equations was analyzed [3], [7] and the stability analysis is carried out. The transmission dynamics and spatial spread rate by the size of the susceptible poultry birds were studied [4]. A disease transmission model with diffusive terms to investigate spatial spread of Avian Influenza among flock and human were studied [9]. A diffusive epidemic that describes the transmission of Avian Influenza among birds and humans is investigated [2]. Mathematical models for bird flu infection process within a poultry farm were also proposed in previous study [5], [6], [8], [10].

Bird flu transmission processes within a poultry farm involve three essential factors: influenza virus as source of disease, domestic birds as host, the environment as medium. The population of domestic birds in a poultry farm is maintained at the manageable capacity for efficient production with supply of new healthy birds for vacancies. Once bird flu intrudes into a poultry farm, some infected birds die at an early stage of infection, and some others live longer. Regardless of being alive or dead, infected birds are the hosts of virus, unless they are completely removed from the population. In a typical poultry farm in Indonesia, there are ten houses each of which contains 1250 chickens. Each chicken in a house is placed in 25x50 [cm] wire net cages. Groups of each of which consists of four cages placed on each side are line up in one direction which amount total length approximate 40 [m] (Figure 1).

Fig. 1: Typical of poultry farm in Indonesia (Gunung Nago Group Farm, Padang City, West Sumatra)

Mathematical model based on those factors and situation in a poultry farm that illustrated in Figure 1 were proposed in previous studies on bird flu infection processes within a poultry farm. A mathematical model was formulated in a study of the population of susceptible birds and the population of infected birds [5], and it was reformulated by taking the virus concentration into consideration [6] and spatial effects were incorporated into formulation of infection process. In recent studies, mathematical model was proposed based on the assumption that vacancies due to infection are replaced instantly, so that the total population always balances with the capacity of the farm [8]. The model was reformulated with consideration of spatial effect, and existence of traveling wave solutions in a singular limit was established [10]. Those traveling wave solutions correspond to progressive infection in a poultry farm. In this paper, analysis in the previous studies is continued. In the following sections, a mathematical model is described, and numerical techniques are illustrated. Numerical results are introduced and their significance is interpreted.

2. Mathematical Model of Bird Flu Infection Process and Stability Analysis

Let X, Y, and Z be the population of susceptible birds, the population of infected birds, and the virus concentration in the medium, respectively. The number of transformation from susceptible birds to infected birds due to infection per unit time is proportional to the virus concentration in the medium Z and the number of susceptible birds X. The decreasing rate of susceptible birds due to infection is σXZ, where σ is a positive constant. The decreasing rate in the population of susceptible birds due to infection is the increasing rate in the population of infected birds. The number of infected birds removed from the population is proportional to the number of infected birds itself. Infected birds are hosts of virus. The increasing rate of the virus concentration is proportional to the number of infected birds because virus grow inside the hosts. The decreasing rate of virus concentration is proportional to the virus concentration itself. The foregoing disquisition leads to the following system of equations [5], [6]

$$\frac{dX}{dt} = a\{c - (X + Y)\} - \omega rXZ,$$

$$\frac{dY}{dt} = \omega rXZ - mY, \quad (1)$$

$$\frac{dZ}{dt} = p(Y - rZ),$$

where a is the rate of supply of new healthy birds for vacancies, c is the capacity of the farm, m is the removal rate, p, r, and ω are positive constants. Note that $\sigma = \omega r$. When vacancies due to infection are replaced instantly, the total population always balances with the capacity of the farm. Under the situation, $X + Y = c$ and

$$\frac{dX}{dt} = -\frac{dY}{dt} = \omega rXZ + m(c - X) \quad (2)$$

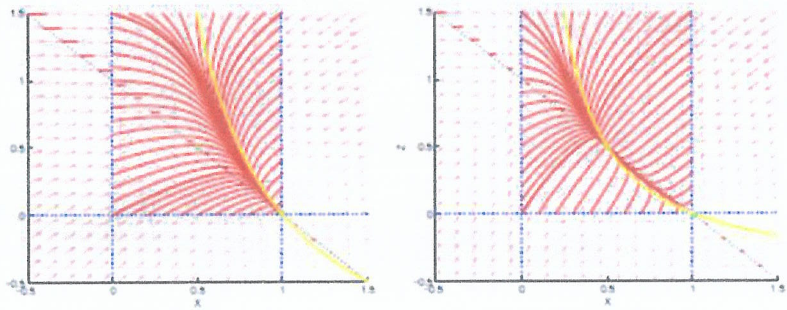
holds. Now, the system (1) becomes the following system of equations for the population of the susceptible birds X and the virus concentration Z [8]

$$\frac{dX}{dt} = m(c - X) - \omega rXZ,$$

$$\frac{dZ}{dt} = p(c - X - rZ). \quad (3)$$

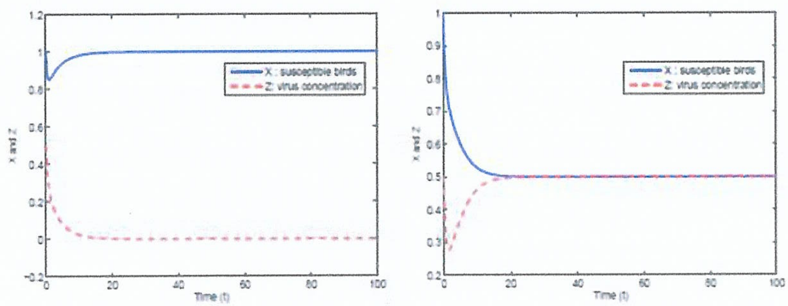
Denote by $X = X(t, X_0, Z_0)$, $Z = Z(t, X_0, Z_0)$ the solution of system (3) that satisfies initial conditions $X(0, X_0, Z_0) = X_0$, $Z(0, X_0, Z_0) = Z_0$. Let $\Gamma = \{(X, Z) | 0 \leq X \leq c, Z \geq 0\}$. The Γ is invariant under the flow generated by the system (3) in the sense that $(X(t, X_0, Z_0), Z(t, X_0, Z_0))$ belongs to Γ for $t \geq 0$ whenever (X_0, Z_0) belongs to Γ. Invariance of region Γ under the flow generated by the system (3) is illustrated in Figure 2.

Solutions of the system (3) for different values of the removal rate m were illustrated in Figure 3. There are two states that are categorized according to stability of steady state solutions, infection free state and endemic state. There are two steady state solutions of system (3). One steady state solution is $A(c, 0)$ that corresponds to the state where no birds in the population is infected. The other steady state solution is $B(m/\omega, (\omega c - m) / (\omega r))$ that corresponds to the endemic state. The steady state solution A is asymptotically stable and the steady state solution B is unstable for $\omega c - m < 0$. The steady state solution A is unstable and the steady state solution B is asymptotically stable for $\omega c - m > 0$ [8].



(a) $m = 1.5$ (b) $m = 0.5$

Figure 2. Invariant region Γ: $c = 1$, $\omega = 1$, $p = 1$ and $r = 1$. The invariant region Γ is shown for different values of m, (a) $m = 1.5$, (b) $m = 0.5$



(a) $m = 1.5$ (b) $m = 0.5$

Figure 3. Solution of the ODE system (3): $c = 1$, $\omega = 1$, $p = 1$ and $r = 1$,

(a) any solution converges to the no infection state for $c\omega - a < m$,

(b) any solution converges to the endemic state for $c\omega - a > m$.

3. Mathematical Model with Spatial Virus Diffusion

Viruses transmit from one bird to another through media such as feed, dirt and air, so that spatial effects of virus transmission should be incorporated into formulation. It is appropriate to assume that a medium is one dimensional because bird cages are lined up in one direction. Let x be the one dimensional coordinate variable. When a diffusive term is added to the right hand side of the second equation, the system (3) becomes

$$\frac{\partial X}{\partial t} = m(c - X) - \omega r X Z,$$

$$\frac{\partial Z}{\partial t} = p(c - X - rZ) + d\frac{\partial^2 Z}{\partial x^2}, \quad (4)$$

where d is the diffusion constant [10].

Traveling wave solutions of (4) are solutions expressed in terms of functions U and V as

$$X(x,t) = U(s), \quad Z(x,t) = V(s), \quad s = x - kt, \quad (5)$$

where k is propagation of wave. Substituting (5) into (4) leads to the system of the ordinary differential equations

$$U' = -\frac{1}{k}\{m(c - U) - \omega rUV\},$$

$$V' = W, \quad (6)$$

$$W' = -\frac{k}{d}W - \frac{p}{d}(c - U - rV),$$

where $V' = W$. There are two stationary points for the system (6) in the (U, V, W) phase space.One stationary point is $C(c, 0,0)$, and the other stationary point is $D\left(\frac{m}{\omega}, \frac{\omega c - m}{\omega r}, 0\right)$. A heteroclinic connection from the stationary point D to the stationary point C gives rise to a traveling wave solution of (4). Existence of such a heteroclinic orbit in a singular limit was established under the condition $\omega c - m > 0$ in a previous study [10].

In the following, model system (4) is focused on. The unknown variable X and Z of the system (3) are now functions of x and t, and they represent the population of susceptible birds and the virus concentration at location x and time t, respectively. Solutions $X(x,t)$ and $Z(x,t)$ are defined in the region in the xt plane $\{(x,t) \mid 0 \leq x \leq l,\ t \geq 0\}$. The system is associated with the homogeneous Neumann boundary conditions at both end points $x = 0$ and $x = l$,

$$\partial X/\partial x\,(0,t) = \partial Z/\partial x\,(0,t) = \partial X/\partial x\,(l,t) = \partial Z/\partial x\,(l,t) = 0, \quad (7)$$

because both susceptible birds and viruses do not diffuse across boundaries. The system is also associated with the initial conditions

$$X(x,0) = X_0(x), \quad Z(x,0) = Z_0(x), \quad (0 \le x \le l). \tag{8}$$

Note that constant solutions of the system of ODEs (3) are constant solutions of the initial boundary value problem (4), (7), (8), where $X_0(x)$ and $(Z_0 x)$ are constants.

Constant solutions of the system (4) includes the infection free equilibrium $E_0(c,0)$which represents that there are no infected birds, and endemic equilibrium $E_+(X^*, Z^*)$ where

$$X^* = \frac{m}{\omega}, \quad Z^* = \frac{\omega c - m}{\omega r}. \tag{9}$$

Let $r_0 = \frac{\omega c}{m}$. The parameter r_0 gives measure of infectious intensity. If the condition

$$r_0 > 1 \tag{10}$$

is satisfied, then the endemic equilibrium E_+ is realistic in the sense that it lies in the first quadrant. In that case, E_+ corresponds to an endemic state in which a part of the population remains infected. Those facts suggest that the state depends on the capacity of farm c, the infection rate ω, and the removal rate m.

Stability of constant solutions of nonlinear system such as system (4) has been studied by other authors [2]. Let μ be the eigenvalue of the operator $-\Delta$ with homogeneous boundary conditions on the interval $[0,l]$, that is,

$Z'' + \mu Z = 0, \quad Z'(0) = Z'(l) = 0$.

Those eigenvalues are $\mu = \left(\frac{k\pi}{l}\right)^2, \quad k = 0,1,2,\ldots$

Furthermore, let

$$J = \begin{bmatrix} 0 & 0 \\ 0 & d\Delta \end{bmatrix} + \begin{bmatrix} -m - \omega r Z^* & -\omega r X^* \\ -p & -pr \end{bmatrix}, \tag{11}$$

where $\Delta Z = \frac{\partial^2 z}{\partial x^2}$. The linearization of the system (4) is $u_t = Ju$. λ is the eigenvalue of J if and only if it is an eigenvalue of the matrix

$$\phi = \begin{bmatrix} -m - \omega r Z^* & -\omega r X^* \\ -p & -d\mu - pr \end{bmatrix}, \quad (12)$$

that has characteristic equation

$$(\lambda + (m + \omega r Z^*))(\lambda + (d\mu + pr)) - \omega p r X^* = 0. \quad (13)$$

For the infection free equilibrium E_0, the characteristic equation is

$$\lambda^2 + (d\mu + pr + m)\lambda + (md\mu + pr(m - \omega c)) = 0. \quad (14)$$

If $r_0 < 1$, then $pr(m - \omega c) > 0$, eigenvalues are all negative for any non-negative value of μ and E_0 is asymptotically stable. It means that the number of virus concentration decreases as time elapses, so that the endemic state is insignificant. On the other hand, if $r_0 > 1$, then $pr(m - wc) < 0$, there is a possibility that eigenvalue is positive for some non-negative value of μ and E_0 is unstable. For the endemic equilibrium E_+, the characteristic equation is

$$\lambda^2 + (d\mu + pr + \omega c)\lambda + (\omega c d\mu + pr(\omega c - m)) = 0. \quad (15)$$

If $r_0 > 1$, then $pr(\omega c - m) > 0$, eigenvalues are all negative for any non-negative value of μ and E_+ is asymptotically stable. It means that endemic state is significant, and that there are some infected birds in the population. Otherwise, if $r_0 < 1$, then $pr(\omega c - m) < 0$, there is a possibility that eigenvalue is positive for some non-negative value of μ and E_+ is unstable.

4. Numerical Results

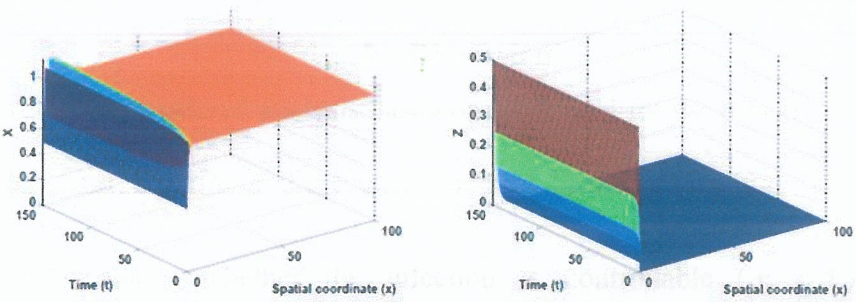
The initial boundary value problem (4), (7), (8) was solved numerically to investigate the transmission process of bird flu within a poultry farm for $l = 100$,

$$X_0 = \begin{cases} 1/2(1 - x) & 0 \le x < 1 \\ 1 & 1 \le x \le 100 \end{cases} \quad (16)$$

$$Z_0 = \begin{cases} 1/2(1-x) & 0 \le x < 1 \\ 0 & 1 \le x \le 100 \end{cases} \quad (17)$$

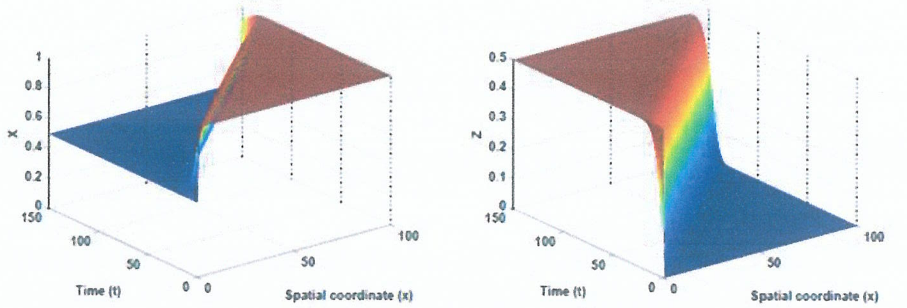
and for the values of the parameters $c = 1$, $\omega = 1$, $r = 1$ and $p = 1$. Numerical results for the susceptible birds and the virus concentration were obtained for some values of the parameter m and d.

Let $m = 1.5$ and $d = 1$, then $r_0 = 0.667 < 1$, so that, the infection free equilibrium E_0 of the system (4) is asymptotically stable, as shown in Figure 4. The figure depicts the persistence of the infection free state, in which the number of the virus concentration decrease as time elapses and population of the susceptible bird remains equal to capacity of farm. In this case, the endemic state is not significant. On the other hand, let $m = 0.5$ and $d = 1$, then $r_0 = 2 > 1$, so that, the endemic equilibrium E_+ of the system (4) is asymptotically stable, as shown in Figure 5. It shows the stability of the endemic state in which a part of the population is always infected. The figure shows the decreasing value of X and the increasing value of Z with respect time t and distance x. Traveling wave solutions appear when E_+ is asymptotically stable. The wave profile for the system (4) were illustrated in Figure 6 for $m = 1.5$ and Figure 7 for $m = 0.5$. Progressive waves of bird flu infection were profiled for different of t and d. Note that the blue line in Figure 6 and 7 are solutions of the system (4) when $t = 0$.



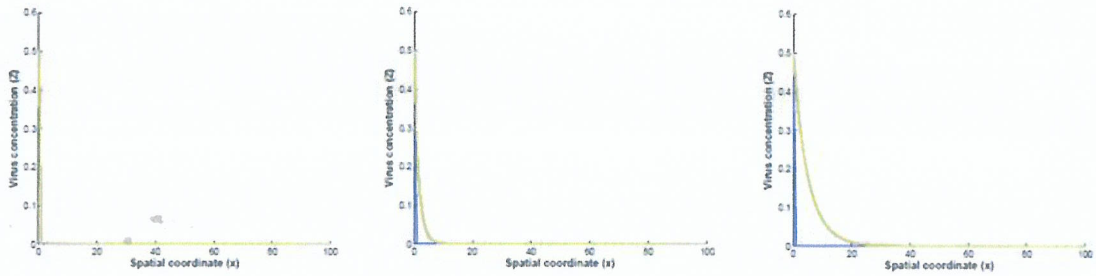
(a) X component (b) Z component

Figure 4. Solution of the PDE system (4): $m = 1.5$ and $d = 1$. The state is free of infection. A solution approaches the stationary point E_0



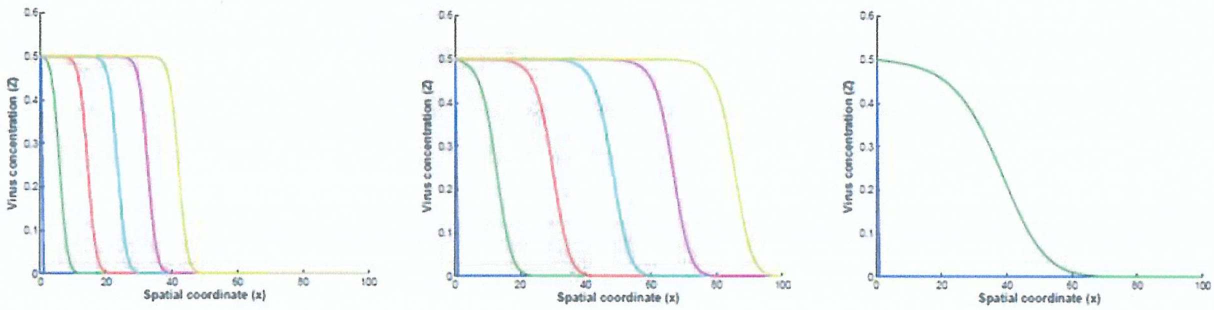
(a) X component (b) Z component

Figure 5. Solution of the PDE system (4): $m = 0.5$ and $d = 1$. The state is endemic. A solution approaches the endemic state E_+



$d = 0.1$ $d = 1$ $d = 10$

Figure 6. Profile of the virus concentration: $m = 1.5$.



$d = 0.1$ $d = 1$ $d = 10$

Figure 7. Profile of the virus concentration for $m = 0.5$.

5. Discussion

In this paper, we have considered analysis based on the model for the bird flu infection process within a poultry farm describing the transmission of bird flu infection. The parameter r_0 ($r_0 = \omega c/m$) determines whether the infection is controllable ($r_0 < 1$) or becomes uncontrollable ($r_0 > 1$). Our numerical results show that if $r_0 < 1$ then the infection free equilibrium E_0 is asymptotically stable for the system with spatial diffusion. If $r_0 > 1$ then the endemic equilibrium E_+ is asymptotically stable. The numerical results also show that the transmission of bird flu within a poultry farm is a progressive wave with a constant speed. Those waves appear when $r_0 > 1$. So, the bird flu prevails provided ω is large or m is small.

On the contrary, the traveling wave solutions do not seem to exist for $r_0 < 1$. So, the bird flu is made controllable by making ω small or m large.

In a previous study, existence of traveling wave solution in a singular limit was established [10]. Numerical results obtained in this shows that the traveling wave solutions exist for the regular problem. Moreover our results show that the wave speed is proportional to the diffusivity, that is, the smaller the diffusivity is, the slower the propagation of virus infection.

6. References

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