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Original research article

Developing Epidemic Simulator of Rabies in Dogs based on SEIR, Inclination Map and Initial Dog Population

Chawapat Youngjitikornkun[1], Jirawat Jiwattanakul[1], Worapan Kusakunniran[1,*], Anuwat Wiratsudakul[2], Weerapong Thanapongtharm[3], Kansuda Leelahapongsathon[4]

[1]*Faculty of Information and Communication Technology, Mahidol University, Nakhon Pathom 73170, Thailand*

[2]*Faculty of Veterinary Science, Mahidol University, Nakhon Pathom 73170, Thailand*

[3]*Department of Livestock Development, Bangkok 10400, Thailand*

[4]*Department of Veterinary Public Health, Faculty of Veterinary Medicine, Kasetsart University, Nakhon Pathom 73140, Thailand*

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ABSTRACT

Rabies is endemic in some regions of Thailand, where dogs are the most common reservoir of the virus. One of regular ways to control the disease is to perform a mass vaccination. However, such operations cannot be fully effective due to the need of a large area of operation protocol, where an infected dog is difficult to be tracked. Therefore, this paper is to propose a rabies epidemic simulation system, estimating an epidemic area. Rabies transmissions are modeled, following the SEIR model. Dog behavior and epidemic area are calculated using a normal distribution technique, with a probabilistic model calculated from environmental factors. Epidemic areas from 6 outbreaks in Ta-Chang, Khlong-Ree, Kuan-Lung, Tung-Tam-Sao and 2 outbreaks in Tung-Wang, are evaluated in three aspects including shapes, sizes and infected case coverage percentage. The evaluations show that the result from Klong-Ree area is the only one that expands into the unreachable area. The second outbreak epidemic results of Klong-Ree and Tung-Wang give a larger radius of 3.25 km and 3.18 km respectively, when compared to the standard vaccination radius of 3 km. Lastly, the first outbreak result of Tung-Wang is the only one that cannot cover other rabies report cases. In summary, the developed simulation has around a 1.29% chance to generate the epidemic in the unreachable area. The average epidemic radius is about 2.52 km or 84% of the standard guideline. The average accuracy of the simulation which is measured from coverage percentage is approximately 83%.

Keywords: Coverage area forecasting; Epidemic simulation; Probabilistic model; Rabies simulation

***Corresponding author:** worapan.kun@mahidol.edu
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1. Introduction

Rabies is a viral infection that is almost always fatal and can be spread among mammals. The disease has remained the cause of death and is still endemic throughout some regions of Thailand [1]. Around 20 cases of rabies-infected human and 300 confirmed cases on infected animal have been reported annually, with the domestic dogs as the most common reservoir of the virus [2, 3]. To counter the spread of the disease, the Department of Livestock Development (DLD) has proposed several campaigns to control rabies transmission, such as raising awareness about the risk of rabies, proper treatment after exposure, and preventive measures among the public [4], providing training programs for volunteers to observe possible rabies cases in their area, and promoting vaccination and sterilization of stray dogs. Although mass vaccination is by far the most effective method to control the spread of the disease [5], the ongoing program is not effective enough due to several reasons, including inadequate collaboration between organizations, lack of financial planning, failure of immunization, and difficult geographical terrain.

Once the rabies outbreak occurs, vaccination protocol is handled by the regulatory authorities. The place where the case was reported will be considered as the epicenter, and the area of 2.5-3 km. radius around the epicenter will be demarcated as a containment zone [6]. To minimize spreading of the virus, susceptible dogs sighted in the area will receive appropriate medication and vaccine administration provided by veterinarians. However, it is difficult to discover every dog in the outbreak zone, as some of them tend to hide in hard-to-reach areas, such as uninhabited forests, sinkholes, and mountain slopes. It also takes time to prepare vaccines and adequate equipment for vaccination process, which may increase the risk of further spread of rabies to other non-infected dogs in the area.

Several epidemiology models have been developed to estimate the spread of rabies, which play an important role in controlling disease outbreaks.Some models observed other animals, such as a bat [7], fox [8], raccoon [9] and cat. Some models represent the outbreak on the country-scale map, such as in Africa [10], China [11], Europe, but it poses difficulties in simulating small-scale epidemic situation. Some of them, however, provide only mathematical results, which lack the ability to represent epidemic area on actual geographic map, and to predict density of dog populations. The solution is to create an epidemic simulation that can estimate the behavior of infected dogs and display the actual area of outbreak. It also helps veterinarians identify the size of containment area and estimate population of dogs, reducing workload and time needed for vaccination process.

To created an rabies epidemic simulation, map simulation of dog's behavior using population density of probabilistic model [12, 13] is used as the base system of the simulation. The base system was revised in many aspects to include the rabid dog into the system. Using normal distribution method, it will keep track of possible trails of the infected dogs and their habitats and combine with the probability from environment factor to creating the walking behavior and epidemic area. In addition, SEIR model also is used to model the transmission dynamic of rabies, which often is used in modeling rabies transmission between dog-to-dog and dog-to-human [11, 14, 15] . The data can provide a better picture of the outbreak by visualizing the calculated epidemic area on a virtual map. Furthermore, some essential data, such as number of infected cases, or rate of reproduction, can be incorporated into the calculation process. The results of the simulation also can be exported into human-readable format for further use in vaccination planning.

2. Virtual World-Base and Dog Behavior System Overview

In this research project, the rabies epidemic simulation system is developed based on the world base and dog behavior system [12, 16]. The detailed explanation could be found in our previous conference paper [16]. These base systems generate the home range and walking paths of each group of healthy dogs. The simulation procedures are performed as follows. First, the simulation generates a virtual map developed using the Mapbox SDK module. It is separated into defined grids of squares, in which the height data of each grid in the map area is retrieved to calculate an elevation for the model of the dog movement behavior.

Second, the system will ask users to enter the inputs of density/quantity of dogs in each grid location of the interested areas in the map, and world obsolete sphere setting or behavior activity rates. Then, such groups of dog populations will be automatically placed on the generated map terrain based on pre-set parameters. The system will reproduce the home range of each group of dogs, by determining its home size via the normal distribution and predicting the walking habits via the kernel density estimation method [17, 18].

The process is converged when there is no consecutive change from its previous result in the generated normal distribution and kernel density estimation. In the final step, an expansion of the home range is calculated using the group centroid of the population density, to estimate the walking paths and patterns. Then, the calculated walking paths are combined with the afford range and the activity rate to determine a distance from the center of the dog group to the current dog destination. Finally, the heuristic pathfinding is initiated using those behavior settings, in order to construct a walking path directly to the predefined roaming area, as can be seen in Fig. 1.

In details of each system component, the map terrain is computed as a texture for both data retrieval and representation, using the Mapbox SDK. The general settings covering the geographic allocation, visualization surges, and coordinate data, are provided by the Mapbox SDK, for constructing the base virtual world map. The X and Z coordinate-allocations are stored within each generated terrain and could be recaptured as the latitude and longitude arrangements. In addition, the Y coordinate-allocation is separately adjusted from the real world reference using the scale of textures to the world’s ground height. An object placement function is implemented to accept an information of dogs’ group destinations from users. They represent the current dog groups added into the map.

In the level of map visualization, the basic color representation is applied to visualize behavior models, where a raw connection to the original placement is its location and perceptible elevation. Once the object placement and world’s parameter settings are completed, the normal distribution is applied to expand the influence of the source quantities together with the transition of population capacity, where the home size is computed from the

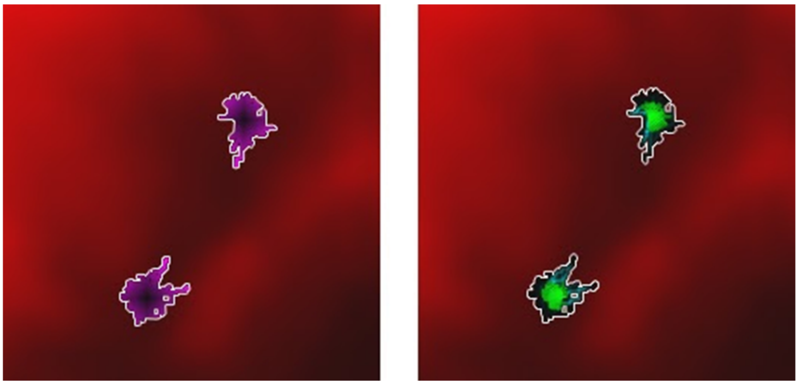

Fig. 1. The result from afford ranges (range from most to least afford as black to light purple), and the combination of dog behavior and afford ranges in each group.

amount of population stated by the input.

Then, all outputs of the world-base and dog behaviors are normalized to the scale of 0 and 1, for both needs of visualization and development's scope (as shown in Fig. 2). They would be further used as the probability density establishment. Therefore, grid rendering square size, population size per block, and number of process convergence are presented for data adjustment.

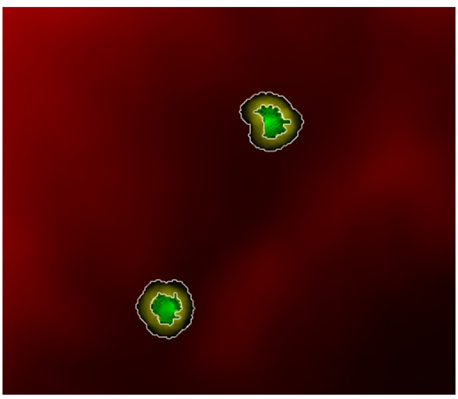

Fig. 2. The result from Normal Distribution and the extended range of home size.

A ratio of home size per population is given to accumulate the expandable size of the home, which acts as a predicted size of the dog's walking patterns. By using the kernel density estimation with 8 orientations, the forecast creates a replication of radius along with essential clustering analysis from collections of normalized distances. Moreover, walking habits from any indistinguishable point could simulate movements to each edge of extended radius, which affects the density of the population based on the moving frequency. Therefore, the mentioned probability and scaling are used to control afford ranges that could strengthen and weaken the odds between nearer and farther areas respectively.

3. Base System, Adjustment and Implemented of Epidemic Scenario

3.1 Base system inheritance

The world base system displays the walking path and home range of each group of dogs calculated from their behavior model. However, it can only simulate normal healthy dog behavior. To create an epidemic scenario, an infected dog, with different behavior model, has to be added into the system. Nevertheless, the spatial data of the map and pre-calculated healthy dog's home range data from base system are necessary to simulate the whole scenario. Heights of the area are also used for calculating the incline, which affects walking behavior and home range of infected dogs. Meanwhile, the data of healthy dogs will be stationed at susceptible state in SEIR model.

In the developed epidemic simulation, the behavior/movement of infected dogs are estimated using 3 key factors including: 1) initial dog population, 2) inclination map, and 3) SEIR model. The distribution based on an incline-factor of the inclination map is applied to track the possible trails of initial infected dogs, as discussed in section 3.6. The simulated area, in each run of the simulation, is split into equal grids with approximate numbers of initial dog population. The spread of rabies also relies on the initial dog populations. The higher population could lead to the higher chance of the spreading. The detailed explanation is given in sections 3.4 and 3.8. In addition, to make the simulator realistic, the SEIR model is also taken into a consideration of the temporal space. The rabies could be spread out only if bitten dogs are in exposed (E) or infected (I) state. The detailed method is proposed in section 3.2.

3.2 SEIR model, behavior define and system design

By the nature of infection cycle, after exposure of rabies virus, changes in behavior of the dog progress in the following steps: When the dog is bitten and infected with the virus, it will show no explicit symptoms and behavior change for a short period of time. The latent period of rabies is typically around 10-30 days, and in some rare cases may vary up to six months [19]. After that, the change of its behavior will become more visible. It may start biting other dogs with potential risk to spread the disease. Lifespan after the symptom appeared is around 10 days before death, without chance for recovery [20].

The understanding of each stage of rabies is crucial for the simulation of the epidemic scenario. One can correlate each stage of the symptom as a state in SEIR model [21]. Susceptible (S) state, or the normal healthy dog behavior in the simulation, is an equivalent of dog behavior in the world base system, with additional situations when the dog has contacted rabies-infected dog whether it will fight or flee. Exposed (E) state is a state of the dog that is bitten and infected with the virus, but still asymptomatic and behaves normally. Hence the design of Exposed state is still the same as S state. Infected (I) state alters the behavior of the dog, becoming more ferocious, and start biting other dogs in its contact range while roaming around their home range. However, the wandering distance is much greater than normal dogs. Remove (R) state indicates dead dog, which is not demonstrated in the simulation but remains as a kept data instead.

Each state of SEIR model may change into the next state with some specific conditions as the following: transition from susceptible into exposed state occurs when the subject is contacted and bitten by the infected dog, transition of exposed into infected state takes place when the amount of latent period has passed in the simulation, and dogs in infected state will be removed once the system time reaches the end of rabies-infected dogs lifespan.

Finite state machine is used for the integration of SEIR (Fig. 3) into the system. Susceptible state is accepted and defined as the initial state of the system. The condition of changing states is also defined as transition of each state. The SEIR state machine is shown in Fig. 4.

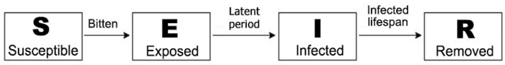

Fig. 3. SEIR Model state and state transition.

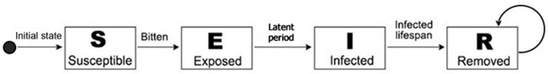

Fig. 4. SEIR Model as finite state machine.

Although the design of the system comprises all states needed, a period of time during transition can be a problem when multiple dogs are added into the simulation. For instance, a dog that stays in exposed state for a few days and another dog that has just changed into exposed state are in the same group. When the latent period has passed, both dogs will be changed to infected state even though the latter had not passed a required period. To solve the problem, exposed state is adjusted by establishing substates to keep track of lifespan of each dog. The substates are defined by dogs' day counts of their lifespan, which will progress forward to the next day as the system day has passed. It will change its state upon reaching the final day of the state. Changes in day count of substates are also applied on infected state with the same method. The updated design is shown in Fig. 5.

3.3 Dog data structure

In the world base system, the area of interest is divided into a square grid with defined grid size. The grid is kept as two-dimension arrays within the spatial data. For the dog data, the system keeps

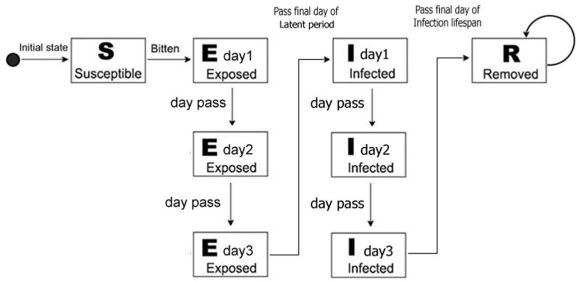

Fig. 5. Sample of SEIR state machine with the substate when both latent period and infection lifespan is 3 days long.

it as separate information to keep track of dogs of each group. When calculated data is assigned to the map grid, it is kept as a data of the dog in the same group, but stored as a different position. The epidemic system needs to separate each group in order to keep track of each individual infected dog from different groups. Therefore, all of dog data are assigned in a separate array of structure labeled by group. Each group structure contains details of quantity, positions, and states of dogs following above mentioned SEIR state machine. Moreover, positions of each group's home range are also kept in separate arrays. As a result, the system can track each group of dogs on the same grid, along with the quantity, positions, and states of each dog in the group. The system can also assign an infected dog input into nearest group determined by home range. The data structure is shown in Fig. 6.

3.4 Movement method

In the world base system, home range of each group is calculated by simulating the healthy dogs distributed around the target area via normal distribution with consideration of the incline, thus creating a unique shape. The dog in the grid can move only to an adjacent grid. Distribution

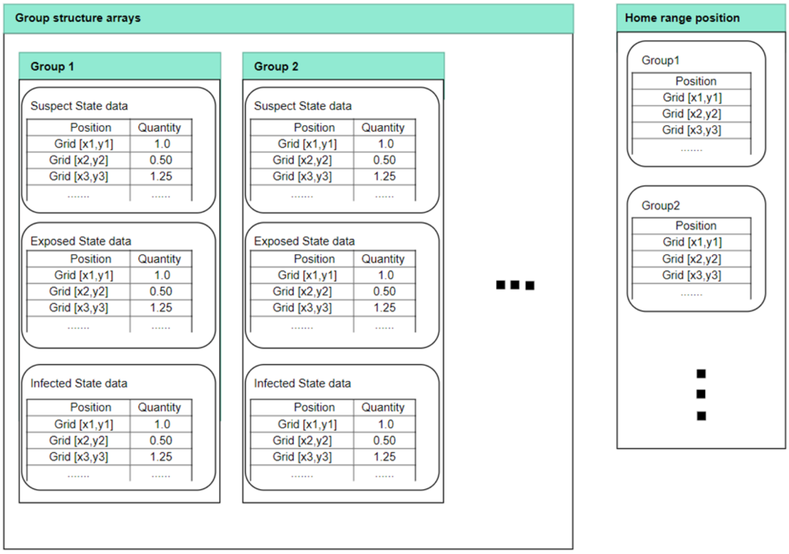

Fig. 6. New data structure diagram.

criteria are also set to prevent endless expansion of home range. The dog walking paths are also created within the home range. From these steps, wandering paths of normal healthy dog are also created. The density of dogs in the group is adjusted along the time frame of each system day, but their walking paths remain unchanged as the population of the group is fixed. Hence the system generates results for one day in the simulation.

On the other side, after adding rabies-infected dogs into the system, they can transmit the disease to other healthy dogs, which become infected and later dead. As a result, the dog population may decrease over the course of system time. Furthermore, infected dogs have a different behavior from healthy dogs, as they can wander away from their home range. Thus different walking method is needed to be designed specifically for the simulation of infected dogs. Day count system is also developed to be able to keep record for the current time in the system, and to change

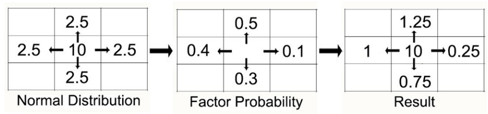

Fig. 7. Distribution of infected dogs based on the normal distribution of 4 possible walking directions and the distribution of incline factor.

the state of the rabies transmission.

Recalculated home range, walking path, position of each group, and population density are used as the initial data of the system. When infected dogs are assigned into the system, the height of the area and home position affecting their walking behavior are calculated into factor probability. Normal distribution is also used in combination with factor probability previously calculated. The sample is shown in Fig. 7 below.

To calculate the distribution of infected dogs, given that N dogs can walk in D directions with an equal probability of $\frac{1}{D}$, the probability distribution (P_d) of N dogs into the direction d is computed as in the below equation.

$$P_d = \frac{1}{D} \times I_d, \qquad (3.1)$$

where I_d is an incline factor of the inclination map in the direction d from the current dog position. The sample calculation of $N = 10$, $D = 4$, and $I_d = 0.1, 0.3, 0.4, 0.5$ is shown in Fig. 7, where the distribution result to 4 directions is shown in the final block. This result will be then normalized before being used in the further step.

This distribution step occurs on every grid in the map, but the result is kept without applying the change to the current map yet. Dogs in each state are also distributed separately with different factor probability and distribution criteria calculated in proportion between healthy and infected dogs. On top of that, susceptible and exposed dogs can be distributed only in their home range. When the calculation of distribution in each grid is complete, changes in kept computed values will be applied to each grid in the map. The system repeats the calculation process for the whole day in the time frame. As a result, possible walking paths of infected dogs of the current day are created.

However, each infected dog may transmit the disease to others within its reach, generating newly infected dogs, which have their walking pattern altered. Sometimes they can also stray around the area for more than a day, thus the system needs to simulate the walking path for multiple days accordingly in order to see the whole image of epidemic transmission. After completing possible walking area of each day, the system will perform simulation of bites and infection, changing the state of dogs that meet the transitional criteria, and repeating the calculation process using the data from previous day as initial data.

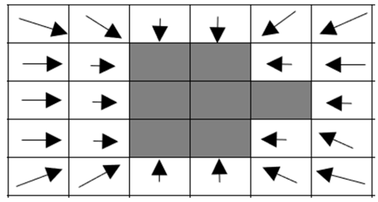

Fig. 8. Visualization of the vector field around a sample home range.

3.5 Time frame

By default of the world base system, a period of a day in the system is divided by 30 second per time frame; therefore, one system day contains 2880 time frames. When the system finishes simulating changes of dog density in the home range for 2880 times, it will be counted as one day. Nonetheless, this time frame count cannot be used with the updated walking method calculation. When normal distribution process is completed for one time, the dog will be distributed to one adjacent grid. The system will simulate a different outcome when users adjust the grid size. In other words, the simulated epidemic area will become larger when users increase the grid size or become smaller when users decrease the grid size. Hence, an updated time frame to be applied in line with new walking method is calculated by possible moving distance of infected dogs. The calculation method is shown in the Eq. (3.2) below.

$$\text{Time frame per day} = \frac{r}{G_{size}} \times W, \qquad (3.2)$$

where r is a radius that an infected dog may wander for a day, G_{size} is a size of the grid, W is a weight coefficient used to adjust the distribution range which can be decreased due to the distribution criteria.

Meanwhile, the generated epidemic area in the first day can be large, but on the next day, the distribution can be expanded to only a few grids due to low intensity of the infected dogs at the edge. To show a clearer change within each day, the distribution process will be stopped when no change in size of epidemic area has been made for four time frames consecutively, which means that it has reached the convergence of distribution. In conclusion, time in system will be counted as one day when the system can run through the whole time frame or the result generated has reached the convergence four times consecutively.

3.6 Factor and probability calculation

With the new walking method, factors such as area inclination and group destination become the important parts to create the walking behavior of infected dogs. These factors are calculated by distribute probability corresponding to each grid that has been distributed and processed via normal distribution. Each factor is calculated separately and combined altogether with different set of weight to create final factor probability. These factors, including incline and group factor, will be described as follows.

For an incline factor, dogs are routinely roaming around or moving directly to their home by choosing a path that is either accessible or attentive. An incline is one of the key factors that affect the walking behavior. So, the height of areas in the map is used to calculate an incline factor probability.

It starts with computing an average height of each grid. Then, an incline level is determined by comparing the height of the interested grid to the height of its adjacent grid, as shown in the Eq. (3.3).

$$\text{Factor}_{incline} = |\cos(\tan^{-1}|(\frac{y_2 - y_1}{x_2 - x_1})| \times \frac{180}{\pi}|, \quad (3.3)$$

where y_1 is a height of the center grid position, y_2 is a height of the target location's grid, x_1 and x_2 is a landscape position of each grid and the differential of these two positions is equal to the defined grid size.

Group factor is determined by dogs' home territory, where they inhabit, socialize, and rest. The infected dogs that often wander outside their territory may also return to their home. While healthy dogs only walk within their home range, infected dog tend to move away from their home range. They should be handled with a restriction to control their recovery movement with high chance of moving out. Vector field is used for calculating home factor probability value (shown in Fig. 8). The map size 2d arrays are created on every group of normal dogs to determine the strength and direction in which dogs move.

After completing the initialization of vectors directed toward the home range $\{V_d\}_{d=1}^{D}$ of all possible D walking directions, all vectors are normalized and modified to be utilized as another probability value designating the tenacity and trend of distribution, as shown in the equation below. This process could increase the likelihood of dogs going back to their territory. The sample scenario is shown in Fig. 9, where vectors of the 3 sample positions are normalized to be 1.

$$V_d = \frac{V_d}{\sum V_{d}{}_{d=1}^{D}} \quad (3.4)$$

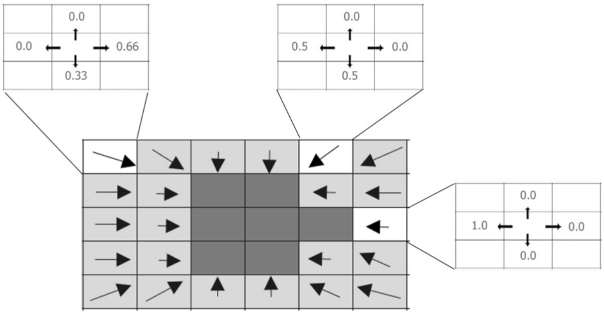

Fig. 9. An example of calculated group factor at each grid of the map.

3.7 Infection and state change

Rabies infection from dog bites is the major part of epidemic scenario creation. To simulate the dog bites, when dogs in both susceptible and infected state are on the same grid at the end of the system day, their interactions are determined by probabilities. Only 20% of susceptible dogs choose to fight back while others decide to flee. Susceptible dogs that got into fight with the dog in the infected state have a chance to shift their state, thus becoming exposed. The calculation is shown in the Eqs. (3.5)-(3.6).

$$E_{state} = S_{state} \times B_{rate} \times In_{rate} \times F_{rate} \times I_{state} \quad (3.5)$$

$$E_{state} \ngtr S_{state} \quad (3.6)$$

where S_{state}, E_{state}, I_{state} is a quantity of each state dog in the same grid, B_{rate} is a bite rate of the infected dog, In_{rate} is an infection rate per bite and F_{rate} is a fighting rate between S_{state} and I_{state} dog.

Another part of creating an epidemic scenario is a state changing of the dog. After a day in simulation and infection process is completed, the process of state change occurs. The exposed dog in each substate of day will be moved to the next substate. An infected dog also undergoes the same process. State of exposed dogs on final day of latent period will be changed into infected at the day 1 substate, while infected dogs on their final day of the lifespan will be systematically removed from the simulation. Latent period is set to 10 days [19], and infected lifespan is also set to 10 days [20].

3.8 Map representation and report

After completing the simulation process for each day, dog positions are visualized to portray an epidemic scenario. Grids where dogs reside are represented with color pixel. Dogs in each state are visualized separately with different colors. In addition, the edge of visualized area also is created for better visibility. After completing the simulation process, pictures of each state corresponding to the day are placed over the virtual map. The images are scaled to match the system grid size. The sample of the process is shown in Fig. 10.

Overall data of epidemic scenario on each day is written down into .txt file format. These text files contain a size of the map, quantity of dogs in each state, calculated R_0 value, quantity of dogs in each state in each group, and a radius of epidemic area in each group. The report is also displayed in the simulation program after the completion of the simulated process, and also collected in the application folder.

4. Validation and Adjustment

To validate the result, the simulated epidemic scenario is compared with the rabies reported case data in Songkhla province collected by Department of Livestock Development. The selected

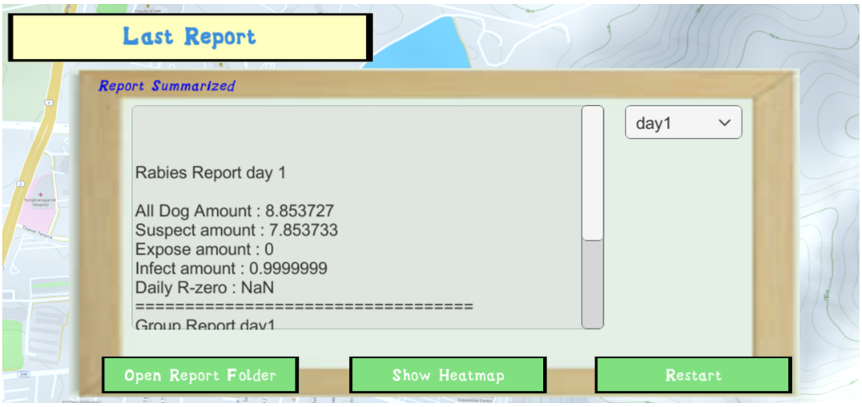

Fig. 10. Sample of the final report appeared at the end of simulation process.

cases need to be occurred in the same outbreak, determined by the duration between each incident being less than one month. Ta Chang and Klong Ree area in Songkhla province are chosen as there are few case reports, making it easier to validate. The result is measured by the coverage of the epidemic area created from the first reported case of the outbreak. The simulated area should cover another report case in the same outbreak. In addition, the radius of the epidemic area is also measured and compared with the standard radius set by Ministry of Public Health vaccination guideline at 3 km. [6].

For parameter settings, the map size is set to be $4 \times 4\ km^2$. This is because the searching space must be larger than the conventional vaccination-area used in practice. Based on the study in [22], bite rate and infection rate are set to be 0.71 and 0.5 respectively. The simulation period is set to 30 days, as a possible SEIR period recommended by the experts. The initial dog population is set by default, and the grid size is set to $25 \times 25m^2$, as stated in [12]. This will result in $\frac{4km}{25m} \times \frac{4km}{25m} = 25,600$ grids. Each run of the simulation would take about 8 hours to finish the whole process.

5. Simulation Result

5.1 Evaluation

Analysis of the system focuses on shape, size and comprehensiveness of generated epidemic area. First, the shape of epidemic area should be generated mostly on reachable areas, not extended much into unreachable areas such as lake or ocean. Second, radius of generated area is measured and compared with 3 km. radius established by Ministry of Public Health vaccination guideline [6]. Third, the accuracy of generated epidemic area is compared with the percentage of rabies reported cases in the same outbreak area that calculated area can cover during 30-days of simulation.

The simulation area for evaluation was chosen from reported outbreak cases within Songkhla province provided by Department of Livestock Development. Five areas of the followings were chosen; Ta Chang, Klong Ree, Kuan Lung, Tung Tam Sao, and Tung Wang, as reported cases from these areas came from the same outbreak and the duration between each incident was less than one month.There was one reported case in each area, except Tung Wang with two reported outbreak cases. A total of six outbreaks were chosen to evaluate the simulation. The result generated during a 25-30 day period which yield the best coverage area will be chosen for evaluation.

For parameter setting, the map size was set depending on each outbreak as some reported cases occurred far apart. Grid size is set to 25 m^2. Bite rate and infection rate were set with 0.71 and 0.5 respectively [22]. The simulation period was set to 30 days. The dog population data was set on default data, calculated from provided data from Department of Livestock Development, in the world base system.

5.2 Result

First, beginning with the Ta Chang area, 2 case reports were found during the outbreak. The resulted epidemic area in day 30 had average radius around 2.15 km. and covered all reported cases. Next, in the Klong Ree area, 2 case reports were found during the outbreak. The resulted epidemic area at day 30 had average radius around 3.25 km. which was larger than the proposed guideline standard at 3 km. However, it still covered the reported case. Furthermore, around 1 km^2 from 12.9 km^2 area was expanded into the sea, calculated to be around 7.75% of the simulated area. On the other hand, simulated epidemic area was capable of covering the other infected report case. Next, in the Kuan Lung area, 7 reported cases were found in the outbreak with 2 cases occurring at the same point. The resulted epidemic area in day 28 had average radius around 2.35 km. and covered all other report cases.

Next, in the Tung Tam Sao area, 5 reported cases were found in the outbreak. The resulted epidemic area in day 28 had average radius around 2.14 km. and covered all other 4 report cases. Finally, in the Tung Wang area, 2 outbreaks were reported. For the first outbreak, 4 reported cases were found. The resulted epidemic area in day 28 had average radius around 2.07 km. The simulated epidemic area, however, did not cover any other reported cases from the same outbreak. While, for the result of the second outbreak at Tung Wang area, 2 reported cases were found. The resulted epidemic area in day 28 had average radius around 3.18 km. which was larger than the proposed guideline standard at 3 km. The result covered all other reported cases. All results are shown in Figs. 11-12. The summary is also stated in Table 1.

In summary, the simulation is evaluated in three aspects. In terms of shape, only the result from Klong Ree area has some simulated outbreak area expanded into the sea, which is unreachable area. In terms of radius size, Ta Chang, Kuan Lung, Tung Tam Sao, and the first outbreak at Tung Wang provided lower radius than the guideline at 3 km., given radius length at 2.15 km., 2.35 km., 2.14 km. and 2.07 km. respectively. Meanwhile, Klong Ree, and the second outbreak at Tung Wang provided larger radius than the stated guideline standard, given radius length at 3.25 km. and 3.18 km. respectively. In terms of area coverage, only the first outbreak at Tung Wang cannot cover other cases during 30-day period.

To conclude the study, the simulation has a slight chance of generating the outbreak onto unreachable areas at average of 1.29%. Average epidemic radius calculated is around 2.52 km., around 84% from the guideline standard at 3 km. In other words, it can decreasing expect vaccination area size around 26%. Finally, from the 6 outbreaks, only the first outbreak at Tung Wang cannot cover other cases, so average accuracy of the simulation

Table 1. A summary table of resulted epidemic area in 6 outbreaks.

Outbreak no.	District name	No. of cases reported	Resulted radius (km)	Coverage of cases reported
1	Ta Chang	2	2.15	Yes
2	Klong Ree	2	3.25	Yes
3	Kuan Lung	7	2.35	Yes
4	Tung Tam Sao	5	2.14	Yes
5	Tung Wang #1	4	2.07	No
6	Tung Wang #2	2	3.18	Yes

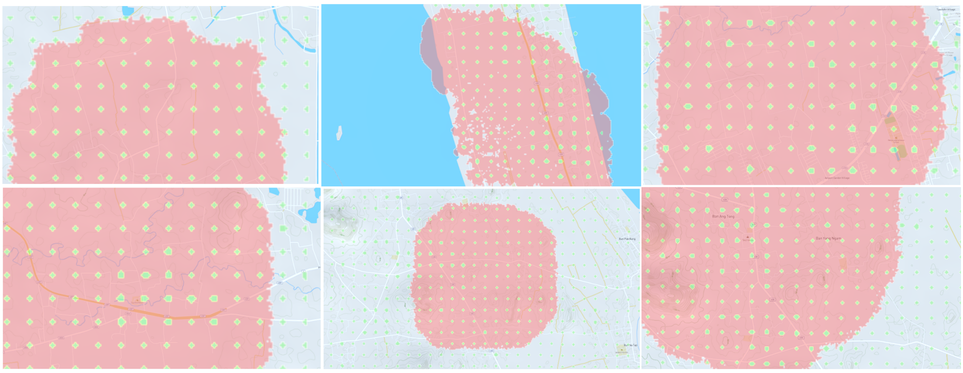

Fig. 11. Result of rabies epidemic simulation. The result sorted in the order from left to right, Ta Chang,Klong Ree,Kuan Lung,Tung Tam Sao,Tung Wang first out break and second outbreak

measured from the coverage percentage is around 83.33%.

6. Discussion

There are several findings and limitations observed from the result of the simulation. First, error of unreachable zone resulted at Klong Ree epidemic area came from Mapbox spatial data and default dog placement from the base system. Mapbox spatial data does not contain any parameters to designate each area whether it is aquatic area. The system also indicated heights of those areas, portraying as a simple terrain. Default placement of dogs and their home range were also appointed in the ocean, thus producing errors in the epidemic simulation. Moreover, the narrow shape of the Klong Ree area made the epidemic area expand into a vertical oval shape rather than a square or circle like other places (shown in Fig. 13), rendering the radius size longer than expected.

Next one is the error in underestimation in Tung Wang first outbreak result. The underestimation error in Tung Wang first outbreak was due to the large distance between the first case and another case. The longest distance between the first and second reported case is around 3 km., thus making it easier to underestimate the case. Furthermore, the top left part of the area consists of high hills and forest, which are uneven terrains to walk to other reported cases. The area is shown in Fig. 14.

Meanwhile, the simulation result of Tung Wang second outbreak could cover

Fig. 12. Roughly epidemic area drawing and rabies report case pinpoint with first case of outbreak outlined with the white circle ,sorted in the order from left to right, Ta Chang,Klong Ree,Kuan Lung,Tung Tam Sao,Tung Wang first out break and second outbreak.

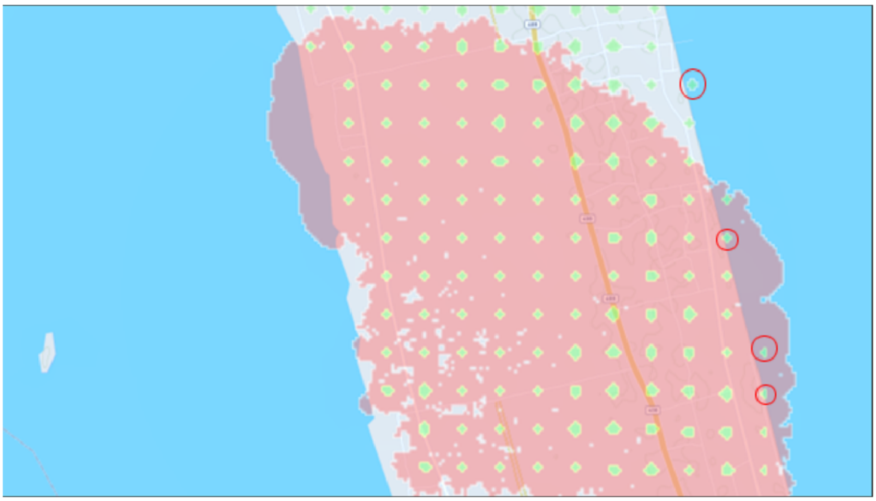

Fig. 13. Error of default dog distribution at Klong Ree area.

other nearby cases within the area of the first outbreak because of roads connected between two reported areas, unlike the first outbreak with rougher terrains. The area is shown in Fig. 15.

The last one is a reason that R_0 value is not use in system evaluation even though it has capability to. R_0 value was not employed in this simulation because of difficulties in validation. Normally, R_0 value of the rabies disease should be in the range of $1 < R_0 < 4$ [23] for dogs, while the system is capable of calculating an excessively high value around 10-60, and increasing more than 100 in some cases. Such high R_0 value was produced from the distribution of default settings of normal dog group, infection process, and probability model. In the real situation, infected dogs have average bites around 2.15 times during their lifespan [22], or around 0.7 times per day. Meanwhile, the process of the simulation calculated biting possibilities for every dog in the epidemic

Fig. 14. Hill and forest area at Tung Wang, highlight with the white line.

area, covered numbers of group of normal dog. Furthermore, the dogs may bite other dogs in the same group again, increasing the chance of spreading. In addition, dog groups by default were distributed evenly in the map, thus extending epidemic area. With all reasons above, R_0 is very difficult to validate with current method.

7. Conclusion

The epidemic simulation is developed from the world base and normal dog behavior system by adding and revising various features. First, spatial data, pre-calculated walking habit, and home range are used as initial data of the system. Second, rabies-infected dogs have their behavior defined in accordance with SEIR model to create a disease transmission model. Normal dog behavior is also revised with the new infected dog fighting behavior. Third, data structure of the system is restructured for easier dog tracking. Fourth, new walking method is adapted with dynamic population of dog. Normal distribution method is used for calculating epidemic area and possible walking paths from inclination of the area. Fifth, infections from biting and change-of-state system are developed to portray the rabies transmission in the simulation. Lastly, visual and text reports are presented and kept in the application storage for further use.

Six outbreaks that occurred in Songkhla province, including Ta Chang, Klong Ree, Kuan Lung, Tung Tam Sao, and two outbreaks at Tung Wang, are chosen for the evaluation of the system. In terms of area shape, Klong Ree is the only place that has an expanded epidemic area into the sea. In terms of radius of epidemic area, the outbreak at Klong Ree and Tung Wang second outbreak has an overestimated radius of 3.25 km and 3.18 km respectively, which is larger than

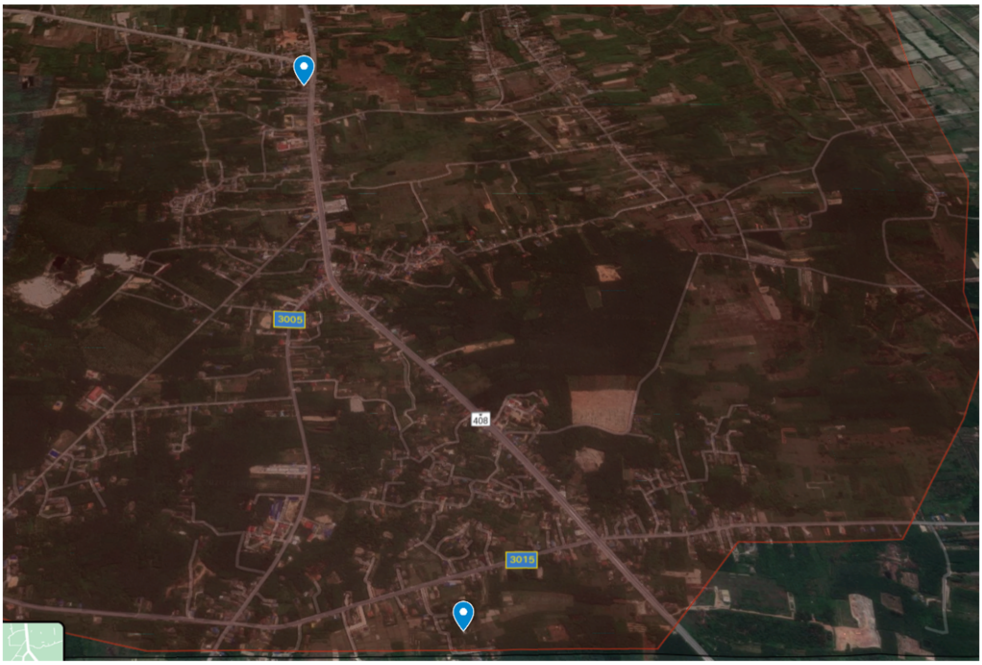

Fig. 15. Road between report case at Tung Wang.

the guideline standard at 3 km, while other cases have relatively smaller radius. Lastly, in terms of the accuracy, epidemic area established from the first outbreak at Tung Wang is the only case that cannot cover all of the report cases in the same outbreak, thus making average accuracy of the system to be at 83.33%.

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