A Simulation System for HPAI Diseases Control

ABSTRACT

As Highly Pathogenic Avian Influenza (HPAI) had become an issue in Korea, Korean Government has decided to make a complete defense system of HPAI using system dynamics and agent based modeling techniques after a preliminary research. This paper summarizes the simulation part of the Korean Government efforts on HPAI.

KAHIS (Korea Animal Health Integration System) is designed to help government agencies to perform their HPAI (and other animal diseases) related tasks on their computers. The simulation part of KAHIS(KAHIS-Sim in short) is designed to support tasks such as HPAI possibility evaluation, retrospective analysis, diffusion analysis, defense line analysis, and social cost evaluation.

KAHIS-Sim consists of a user interface, and two models (AIR Model; and AID Model), which are programmed using Vensim DSS. AIR Model forecasts the possibility of HPAI occurrence for 4967 regions and more than 20,000 farms in Korea. AID Model simulates the diffusion processes of HPAI and estimates the economic impacts. The user interface summarizes and shows the simulation results using geometry information system.

After test trials of the system, a few issues have been raised, including the simulation time, lacking data, and linkage with the weather forecast. Nevertheless, they have decided to use the system as references for their tasks. They have planned to upgrade the system for another next 4 years.

INTRODUCTION

Highly Pathogenic Avian Influenza (HPAI) has become a hot issue recently. This nationwide concern stems from three HPAI cases; year 2003-2004 winter, year

2006-2007 winter, and 2008 spring as summarized in the Table 1. There have been huge social concerns not to speak of economic impacts since chickens are major food materials.

<Table 1> History of HPAI Events in Korea

Year	Number of Infected Farms	Remarks
2003/12 – 2004/3	19	
2006/11 – 2007/3	7	
2008/4 – 2008/5	33	11 Cities and Provinces
Sum	59	

Sources: [1], [2], [3]

When a HPAI case occurs, many government agencies from local government to central government with diverse expertise become involved in the case. Sometimes it is not easy to maintain consistencies between them especially if the viruses are spread over many local governments.

The spread of HPAI viruses follows the general rule of diffusion, which is a typical feedback problem. In other words, the spread of HPAI diseases cannot be simply guessed or assessed. Furthermore, every decision has to be made quickly since the timeliness is a key factor for controlling the diseases [4].

Korean Government has decided to make a complete defense system using system dynamics technique and agent based modeling technique after 6 month preliminary research.[4] This paper summarizes the simulation part of the Korean Government efforts on HPAI.

OVERVIEW OF THE SYSTEM

KAHIS (Korea Animal Health integration System) is designed to help government agencies to perform their HPAI related tasks on their computers. Therefore the simulation is one of the major functions of the system KAHIS. However, every feature is designed to make the simulation function workable since all the information is required to perform simulations before or after HPAI occurrences.

The simulation part of KAHIS (from now on, KAHIS-Sim in short) is designed to perform tasks as shown in Table 1(defined from the previous research [4]). Most of the time they are interested in the HPAI possibility since HPAI has been occurred once in couple of years.

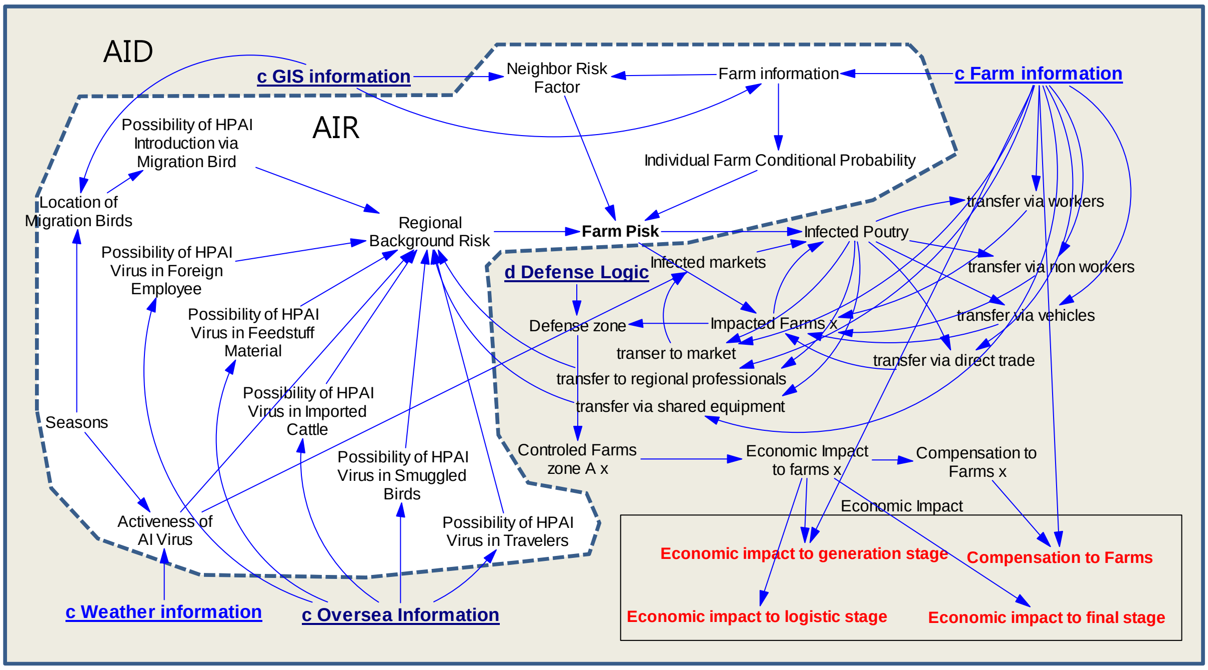
<Table 2> Tasks and Models

Tasks	Usages	Models	Inputs
HPAI Possibility Evaluations	Before Occurrence	AIR	Seasons, Surveillances Evidences, etc.
Retrospective Analyses	After Occurrence	AID	Reported Cases
Diffusion Analyses		AID	
Defense Line Analyses		AID	
Social Cost Evaluations		AID	

OVERVIEW OF THE MODELS

Although two models are involved with KAHIS-Sim, the two models can be merged into one big model. Since simulation time has become an issue, the model is divided into two models (AIR Model; Aviation Influenza Risk Model and AID; Aviation Influenza Diffusion Model) to reduce the memory used.

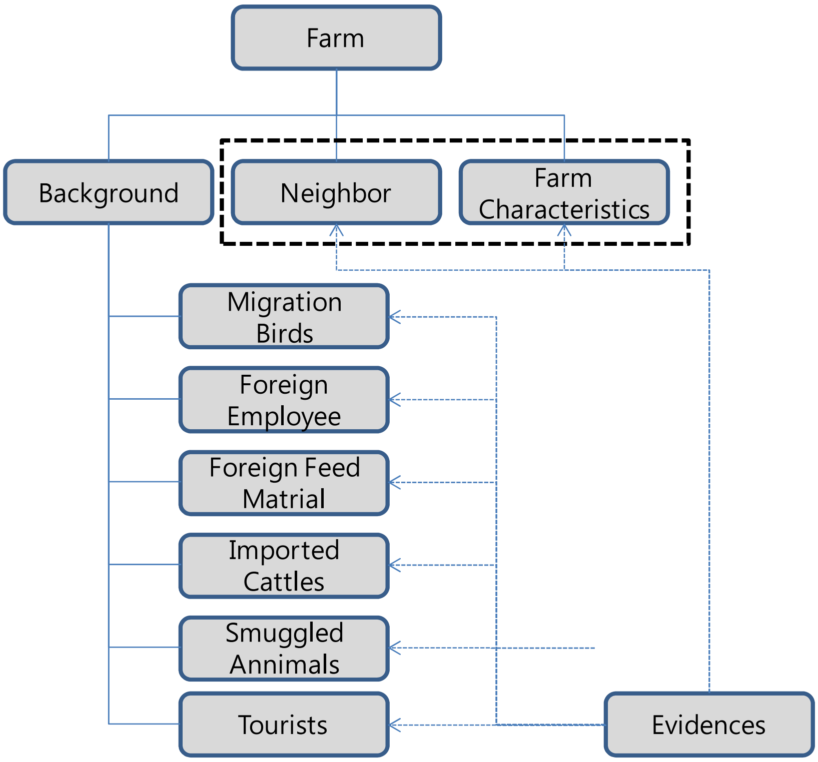
Figure 1 shows the overall causal loop diagram of KAHIS-Sim. As shown in the figure, conceptually AID Model covers AIR Model. AIR Model is applied only for forecasting of HPAI occurrence possibilities before any real HPAI situation occurs. On the other hand, AID Model is for the situation where any real HPAI case occurs. Since we do not know if the original HPAI virus sources are still active, all logics in AIR Model should be included in the model as shown in the figure. However, since there is no infected case before HPAI occurrences, AIR Model does not need diffusion logics.



<Figure 1> Overall Causal Loop Diagram

HPAI Occurrence Possibilities (AIR Model)

The main purpose of AIR Model is to forecast the possibility of HPAI occurrence. The model assumes 6 pathways for HPAI to be introduced into Korea as shown the Figure 2(summarized from previous researches; [1], [2], [3], [5], [6], [7]). The model predicts risk factors for both 4967 regions and 1500 poultry farms (7000 farms are empty for future uses) using subscript variables.



<Figure 2> HPAI Occurrence Possibility Structure (Pathways of Introduction)

Once calculated via models, the simulation results are stored in the database. Then users may access the data in various forms using user interfaces. For example, users can play a video for one year period changing colors as the risk level does on the map of Korea with zoom in and out functions.

Diffusion Model (AID)

Diffusion model (AID Model) is prepared to analyze the diffusion processes of HPAI after the first reporting of HPAI case. The model assumes that there must be at least one influenza source among the 6 pathways of introduction, which no one knows when the first infected farm is reported. For example, the HPAI source could be a wetland near the first reported farm. It means that diffusions could be made through that wetland without noticing if we neglect the fact.

Therefore the usage of the AID Model should be extended to the retrospective analyses. The assumed methodology of retrospective analyses is Monte Carlo simulation technique starting with random sampling of initial conditions with maximum utilization of the information of the first reported farm as well as surveillance information gathered so far. For example, the closer wetland from the farm may have more chance of existence of HPAI than the further one.

As for the diffusion processes between farms, 8 diffusion modes (see Table 3) are taken into account. Parameters characterizing the diffusion processes may vary depending upon the types of farms. AID Model can describe up to 15,000 poultry farms, and the types of farms described in the model is summarized in Table 4.

<Table 3> Diffusion Modes

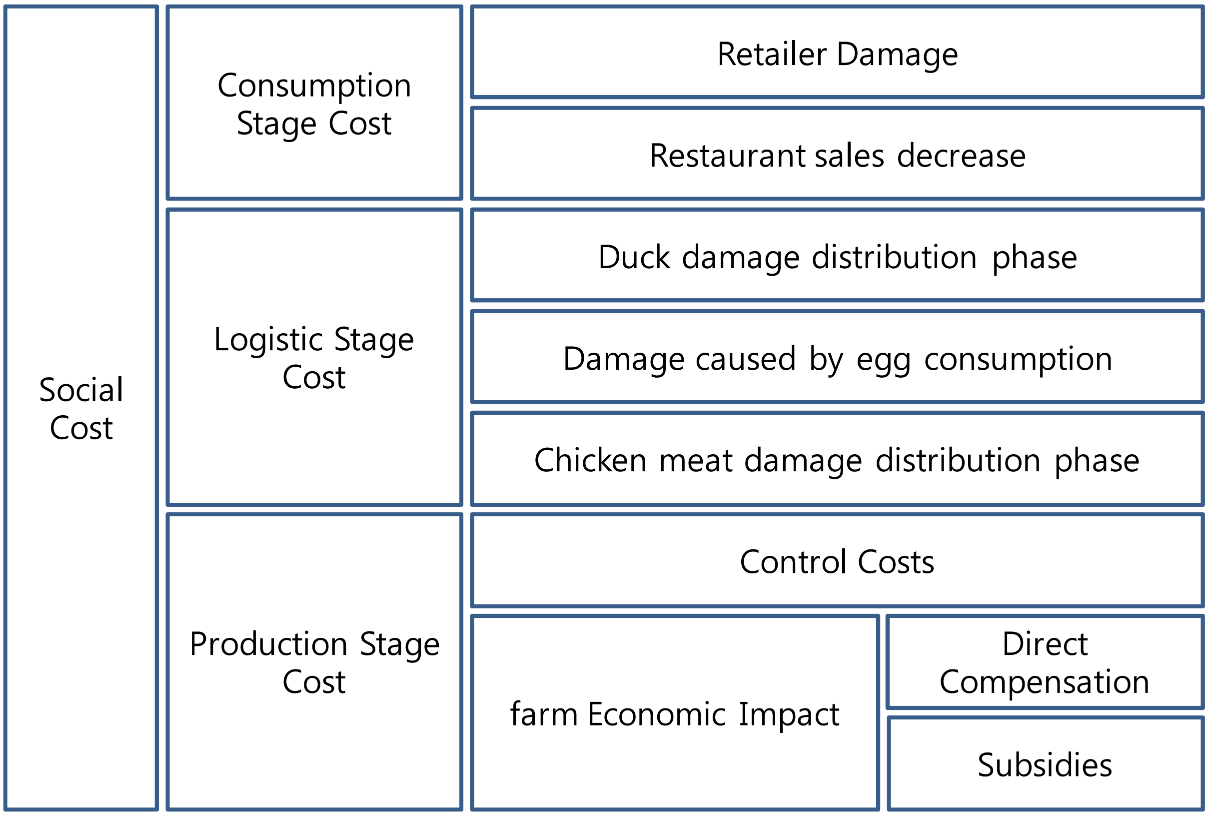
Modes		Examples	Remarks
Human	Workers	Transfer via clothes, shoes, etc.	
	Non-Workers		
	Professional Visitors		Vet., etc.
Equipments	Material Vehicles		
	Equipment Share		
Trades	Direct Trade		
	Market		Only for traditional chickens
	Origin		

<Table 4> Farm Types

Species	Groups		Numbers	Remarks
Chicken Farms	Ordinary	Egg Chickens		
		Meat Chickens		
		Traditional Chickens		
	Origin	Egg Chicken Origin		
		Meat Chicken Origin		
		Traditional Chicken Origin		
Duck Farms	Ordinary	Meat Ducks		
	Origin	Egg Duck Origin		
		Meat Duck Origin		
Pig Farm			~20,000	

Social Cost Model

HPAI diseases results in catastrophic situation for the infected farms because of the strong contagiousness. If we consider the side effects, it becomes more serious. All together, the social costs of HPAI diseases can be summarized as shown in Figure 3.



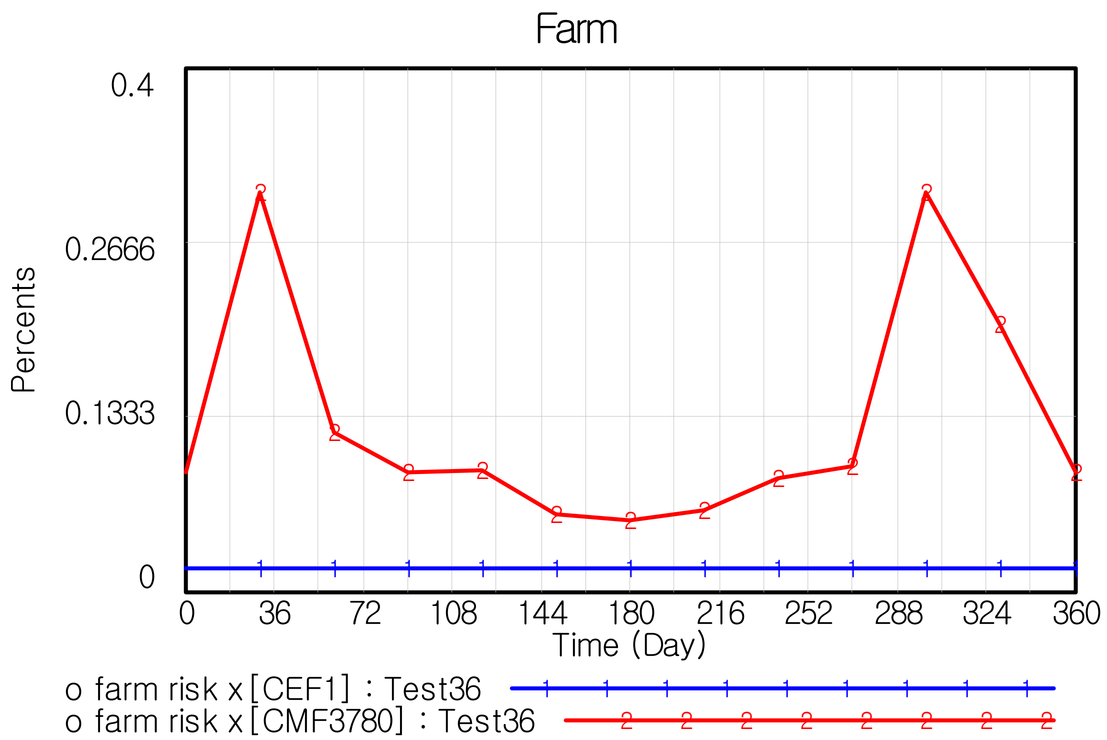
<Figure 3> Social Cost Structure

As soon as the Government concludes "a new HPAI case," it declares three defense circles centering the reported farm. Within the first defense circle, all poultries will be killed with some compensation. Between the first and second lines, local government can decide whether to kill the poultries or not. Around the third largest circle, Government will post guards and limit the all the transportation of poultries. Therefore the production stage costs directly depend on the defense activities. Since the third circle covers huge area, the logistic stage cost is also very dependent on the Government decisions. Besides the direct effects on the all restaurants in the defense area, there will be psychiatric impact across the whole country for a while. In short, as the defense area becomes large, the direct costs become larger, and the potential risk decreases. The model takes the sizes and shapes as decision variables so that users can simulate the impact of those decision variables.

SIMULATION RESULTS

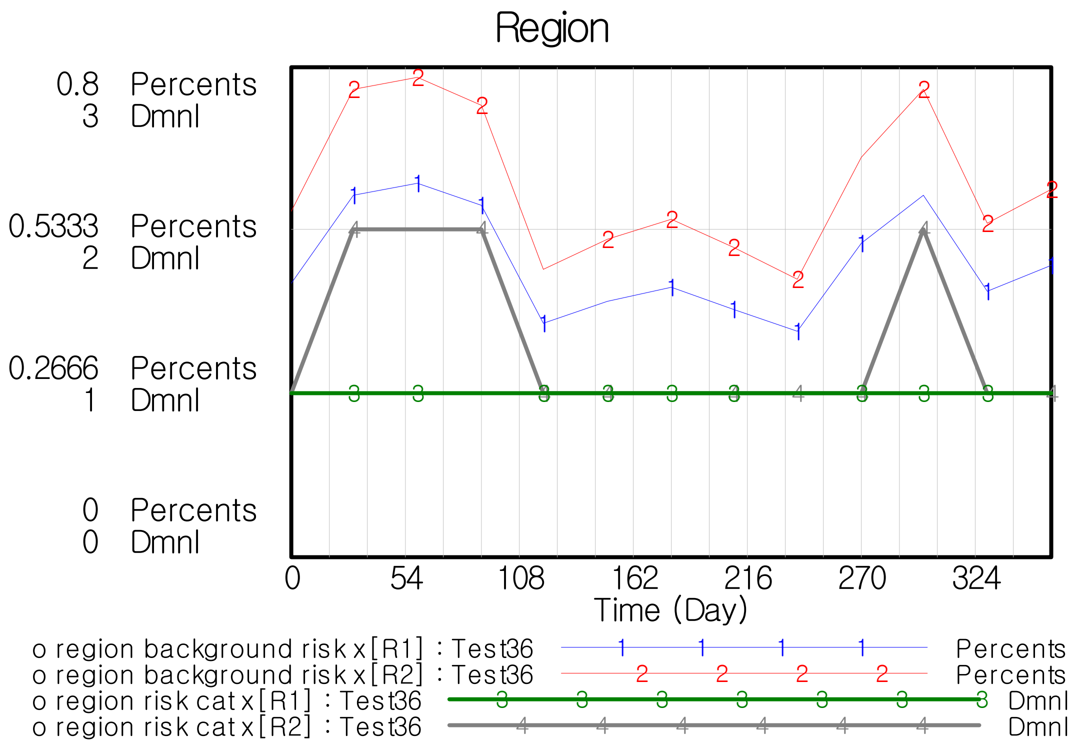
HPAI Occurrence Possibilities

Risks involved with HPAI diseases are strongly seasonal mainly because of migration birds as well as the temperature. Figure 4 shows risks (o farm risk) for two farms in different locations. The figure shows that farm "CEF1" varies a lot, while farm "CMF3780" stays in low values.

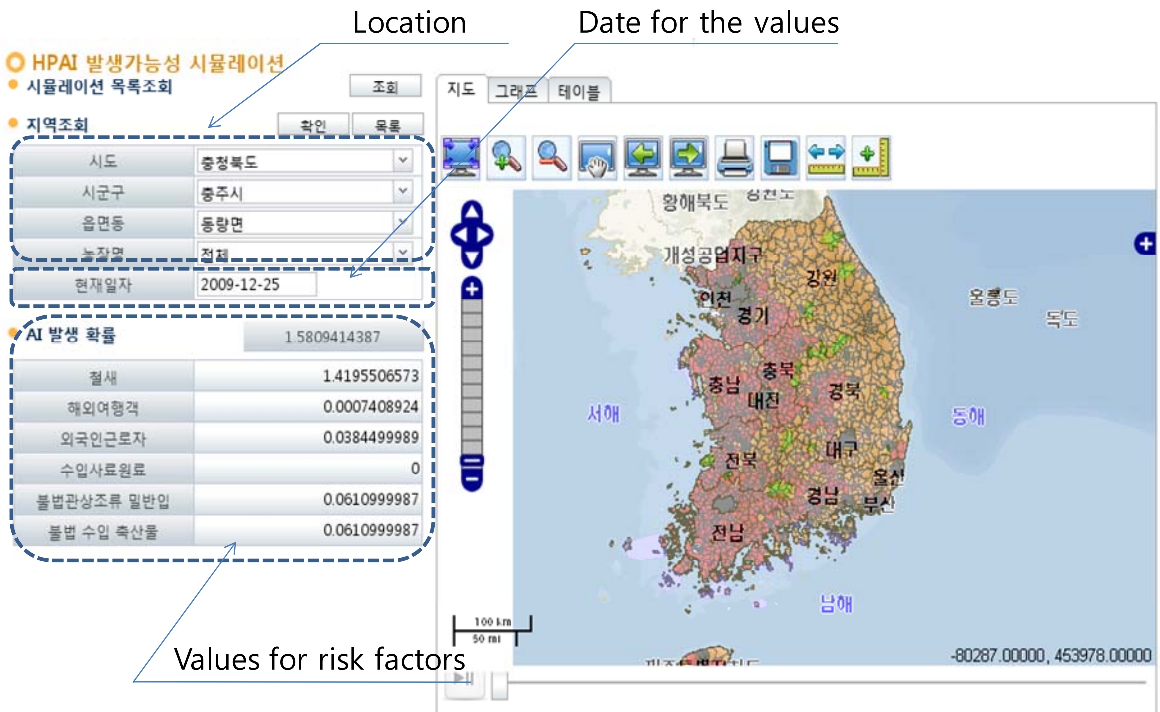


<Figure 4> A Simulation Example of Farm HPAI Occurrence Possibilities

Figure 5 shows risk factors for two regions (respectively related farm CEF1 and CMF3780). The variables with "cat" in their names give, through user interfaces, one of the four different colors as shown in Figure 6.



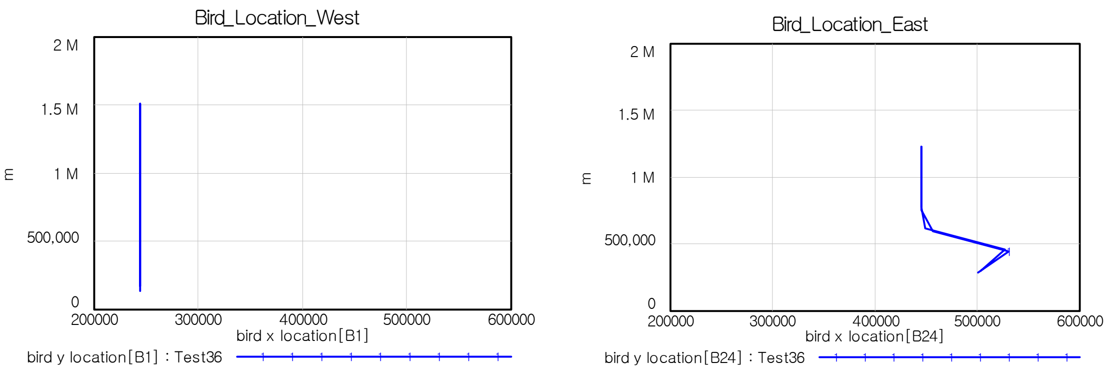
<Figure 5> A Simulation Example of Regional HPAI Occurrence Possibilities



<Figure 6> Regional HPAI Occurrence Possibilities in User Interface

If a user selects a specific region or farm, as well as time of the year, the values will shows up on the left hand side. The right hand side shows a Korean map which is composed of 4963 local areas. Each local area has its own color matching with the simulation results.

The major contributors for the variations of the values are the locations of migration birds. Hundred kinds of birds exist in Korea. However, 31 kinds are considered important for HPAI diseases, and most of them migrate along the wetlands. Most wetlands are located either in the west coast or east coast. Figure 7 shows two types of bird migrations described in the model. The migration paths are designed as external variables, which means system managers can upgrade the paths any time. At the time point when the system is developed, no detailed researches have been made about bird migrations. Therefore we adopted two major migration paths as shown in the figure with random variations.



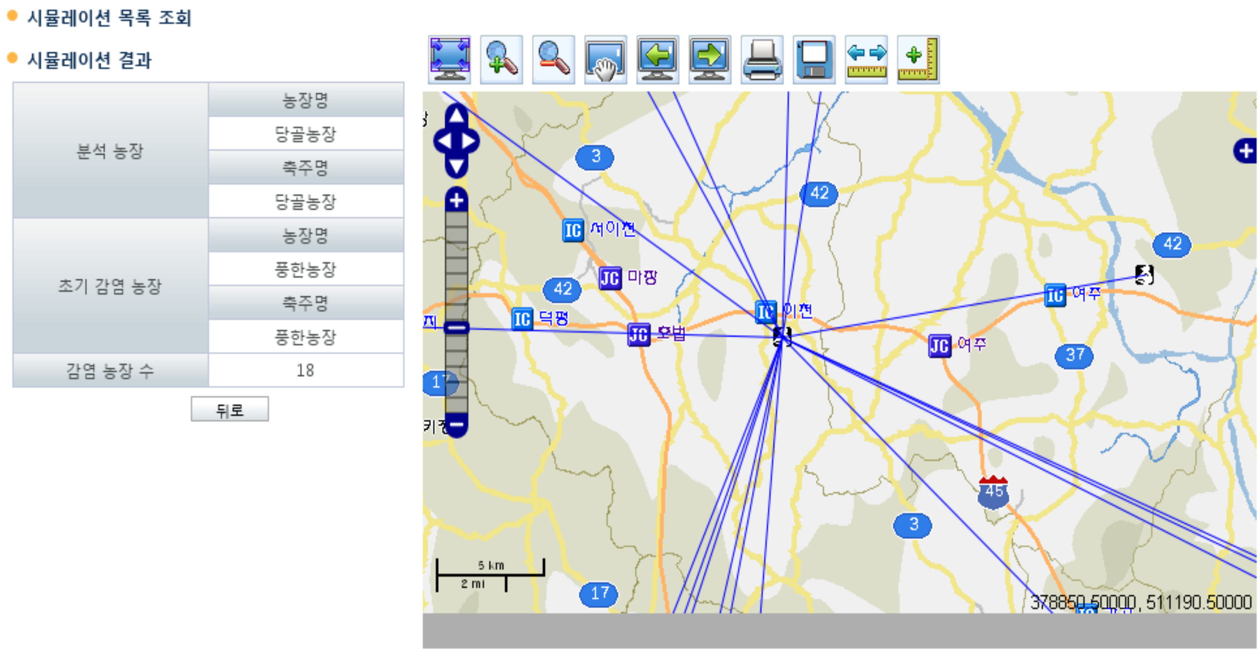
<Figure 7> A Simulation Example of Birds' Migration (East Coast Birds)

Retrospective Analyses

Retrospective analysis is a process to figure it out how the reported farm was infected. Mote Carlo simulation technique is adopted for retrospective analyses. However, more intelligence has to be involved in order for the simulation numbers to be controllable.

They believe that the compensation for HPAI infection is large enough that the farmers are willing to report if they knew the fact. Therefore it is very likely that the reported farm is the first infected farm. Furthermore, although we are considering 6 pathways, introduction of HPAI virus through the migration birds is the most likely pathway. So random sampling of initial values is made with higher weighting factors for those variables related to bird migration and nearest wetlands.

After 200 simulations, the user interface summarized the cases where the reported farm is infected with optional additional conditions. Figure 8 is an example of those cases. In this case the first infected farm and the reported farm are different.

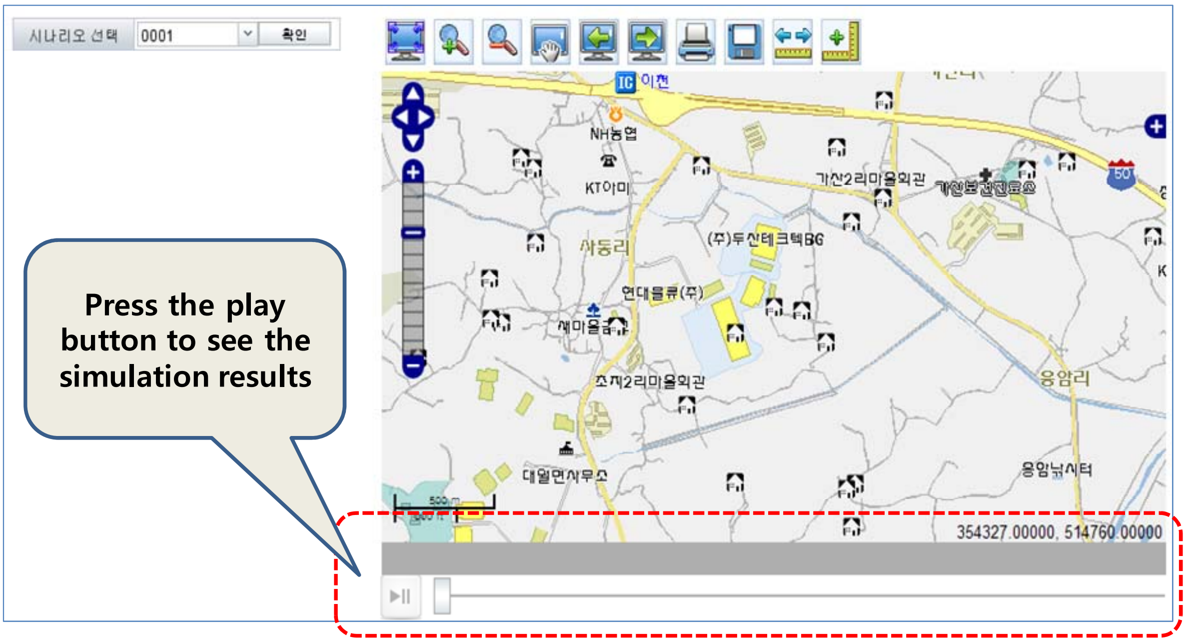


<Figure 8>   A Simulation Example of Retrospective Analysis

Diffusion Analyses

After the potential pathway and the first infected farm are assumed via the retrospective analysis, diffusion analysis starts from those assumptions with evidences. Obvious evidence is that the reported farm is infected. As time goes many facts will be informed, and evidences have to be reflected into diffusion analyses. For example, as time goes on a farm may report the infection to the authority, or the suspected wetland has been proved that it contains HPAI. These facts have to be reflected in the model and reflection of them results in less uncertainty.

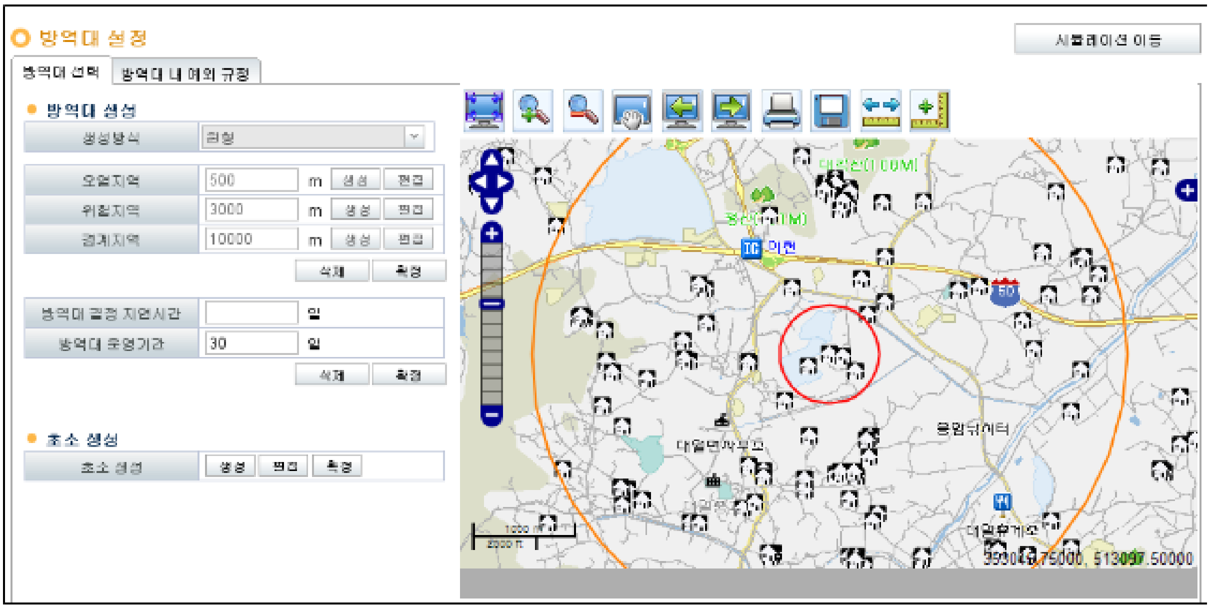
Figure 9 shows the mechanism to see the simulation results. If users press the video play button, the infected farm will turn into red color as time goes on.



<Figure 9>   A Simulation Example of Diffusion Analysis

Defense Line Analyses

The model also includes defense mechanism. Centering the reported farm, the authority will announce 3 defense lines, which limits transportations across the lines, and all the poultries and pigs inside the smallest defense line will be killed. Figure 10 shows two of the three defense lines. As shown in the figure, users can identify the farms inside defense lines as well as the details of the farms including heads of poultries.

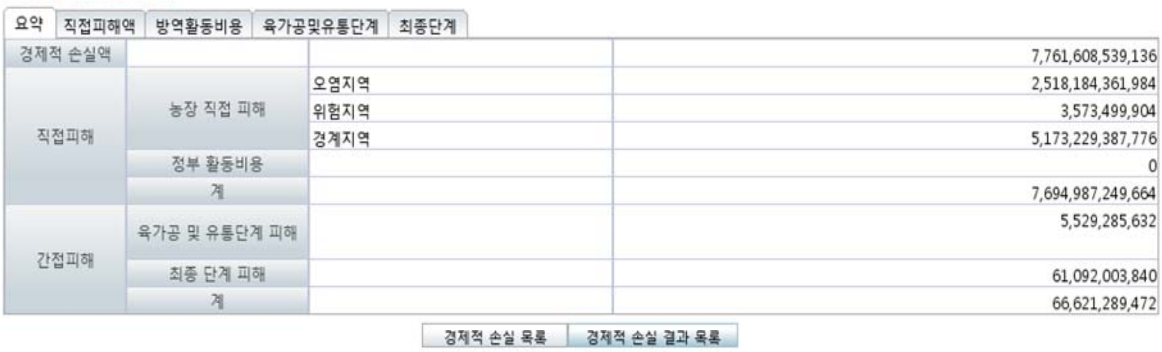


<Figure 10>   A Simulation Example of Diffusion Lines

Social Cost Evaluations

As mentioned earlier, the social costs are divided into three categories; production stage, logistic stage and consumption stage. The calculation of the social costs in the production stage is straightforward since all the infected farms and numbers of infected poultries are in the simulation results. Social costs in the logistic stage and consumption stage need many assumptions. All the assumptions are designed to be modeled as constants, which are listed in the database table. Users may test those assumed constants with their own values. Figure 11 shows examples of the social cost evaluations.

a) Summary



요약 | 직접피해액 | 방역활동비용 | 육가공및유통단계 | 최종단계

경제적 손실액			7,761,608,539,136
직접피해	농장 직접 피해	오염지역	2,518,184,361,984
		위험지역	3,573,499,904
		경계지역	5,173,229,387,776
	정부 활동비용		0
	계		7,694,987,249,664
간접피해	육가공 및 유통단계 피해		5,529,285,632
	최종 단계 피해		61,092,003,840
	계		66,621,289,472

경제적 손실 목록 | 경제적 손실 결과 목록

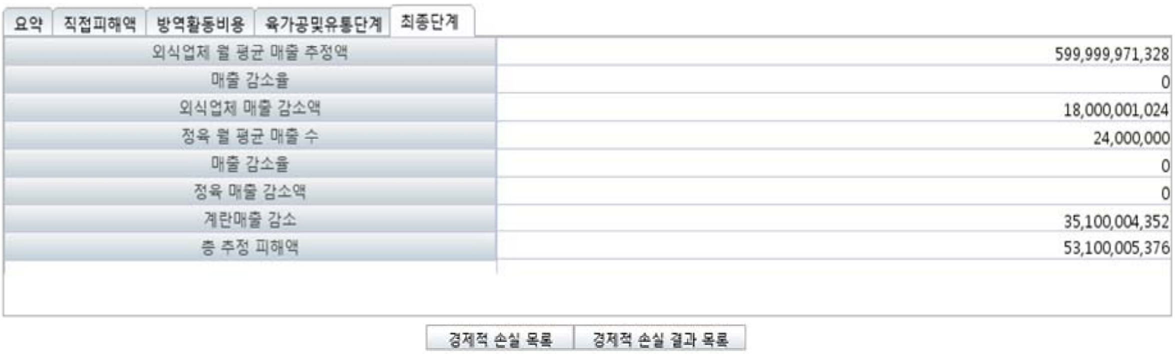
b) Direct costs

지역구분	농장수	살처분 두수(마리)			살처분 보상금	생계안정자금	소득안정자금
		닭	오리	기타			
오염지역	0	253,635,248	0	0	2,422,216,589,312	95,967,698,944	
위험지역	0	0	0	0	0	3,573,499,904	
경계지역	8,050						0
계	8,050	253,635,248	0	0	2,422,216,589,312	99,541,198,848	0

c) Logistic costs

닭 유통단계 피해	4,111,428,608
오리 유통단계 피해	1,027,857,152
계란 유통단계 피해	390,000,000
총 추정 피해액	5,529,285,760

d) Consumption stage costs



외식업체 월 평균 매출 추정액	599,999,971,328
매출 감소율	0
외식업체 매출 감소액	18,000,001,024
정육 월 평균 매출 수	24,000,000
매출 감소율	0
정육 매출 감소액	0
계란매출 감소	35,100,004,352
총 추정 피해액	53,100,005,376

<Figure 11> A Simulation Example of Social Cost Evaluation

CONCLUSIONS

After test trials of the system, following issues have been raised;

- Simulation time is too long to perform any meaningful Monte Carlo simulations.

- Some data are missing including farms and migration birds
- The connection with weather system needs to be improved

Nevertheless, they have decided to use the system as references for their tasks. The current KAHIS-Sim is not the end of the Korean Government efforts. They have planned to upgrade the system for the next 4 years.

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