TABLE V INFECTION CONTROL PARAMETER OF ADDITIONAL SCENARIOS

Scenario Name	E	E – washing hand	E – wearing mask
Hand Washing	Soap and water	No	Soap and water
Mask	Surgical	Surgical	No
Patient Isolation	Yes	Yes	Yes
Cleaning	Yes	Yes	Yes
HPV Decontamination	No	No	No
Vaccinated Population	300 (3%)	300 (10%)	300 (3%)

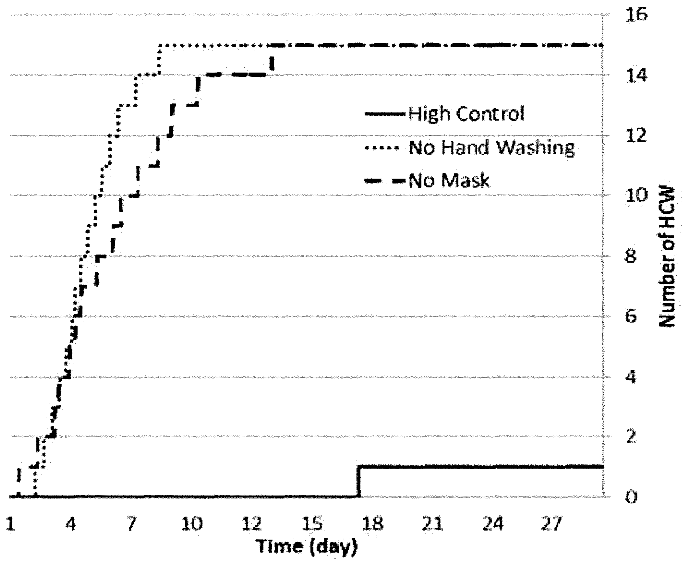

Fig. 5 Variation in average number of infected health care workers (HCW) over time in scenario E, scenario E with no staff washing hand and scenario E with no staff wearing mask.

B. *Micro Analysis*

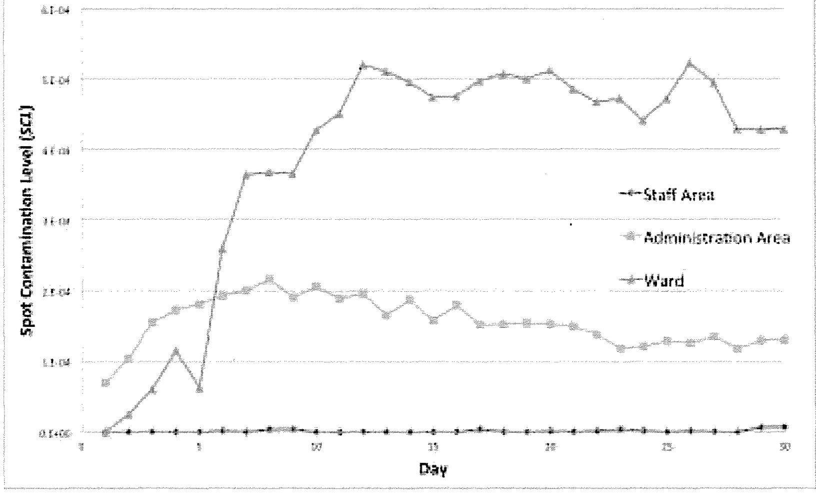

Fig. 6 Variation of Virus Contamination of areas in the hospital in scenario A

In section II.B, we have demonstrated the algorithm to calculate the amount of virtual influenza virus existing in spot and agent. Spot Contamination Level (*SCL*) at the certain time t is the sum of total amount of virus excretion of agents in the spot and the contamination level of the spot at time ($t - 1$). It depends on the number and the disease condition of infected agents existing in the spot. Figure 6 shows the average contamination level of Ward area, Administration area and Staff area in scenario A of High Control and High Vaccine. The results show that the Ward area is the most contaminated.

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The Administration area ranks the second while the Staff area is almost clean. The result implies that wards in hospital are likely to be contaminated with influenza virus when an outbreak of influenza emerges in the community.

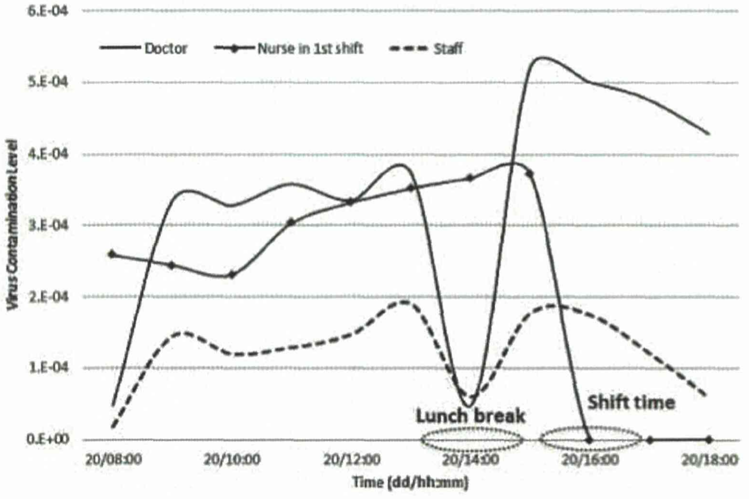

Fig. 7 Variation of virus contamination level of HCW in a working day in scenario A

Agent Contamination Level $ACL[i](t)$ is the amount of virus that an agent i has at the specific time t. Figure 7 describes the average virus contamination level of doctors, nurses and other staff in working time in 20^{th} day when the number of inpatients reaches its peak in the scenario of A [High Control High Vaccine]. The average virus contamination level of doctors and nurses are higher than those of other staff. This could be explained by the fact that doctors and nurses work in ward area more than other staff. Sharp drops recorded in the contamination level among HCW strongly correlate with daily routines of the HCW concerned. The virus contamination level of doctors and other staff falls to their troughs at the time of lunch break (from 13:00 to 14:00). The virus contamination level of nurses also decreases rapidly when they change their shift and leave the hospital.

The conclusion of micro analysis is that doctors and nurses, who provide direct care to influenza patients have higher risk of catching influenza virus within the hospital. This conclusion supports long-standing belief in hospital infection control that annual influenza vaccination should be required for every health care worker who has direct contact with patients.

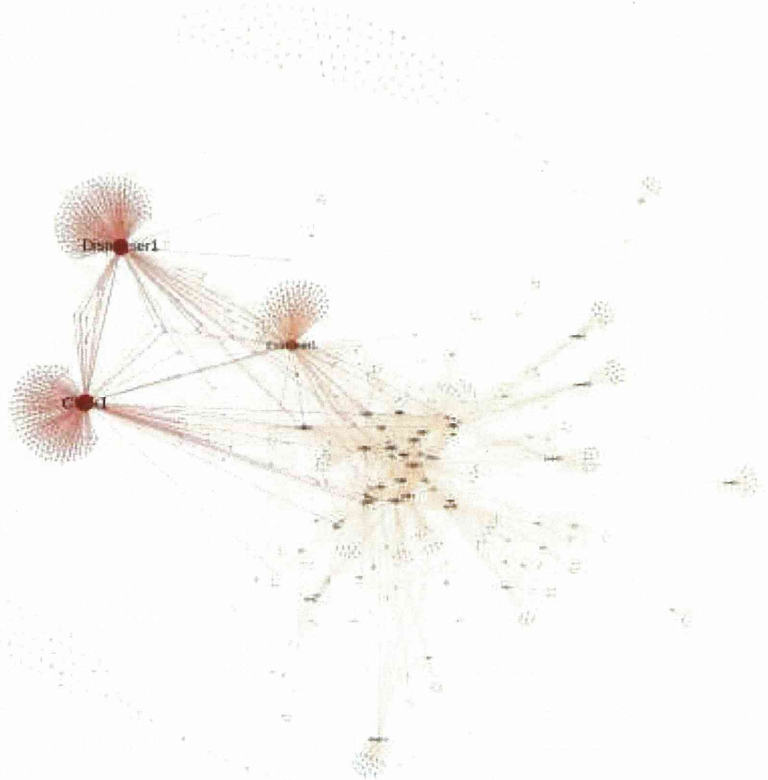

Fig. 8 Visualization of contact network in scenario D

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V. ANALYSIS ON CONTACT NETWORK

We analyze the contact network, which is generated by interactions of agents in the simulation of scenario D. We assume that once two agents come into the same spot, one contact is made between them. Each agent carries a contact list of agents who are in the same spot with him at the time *t*. The contact lists vary by time when agents are moving inside the hospital. The log of contact lists is converted to .csv file in order to be imported to Gephi [27], an open source graph visualization software.

Figure 8 illustrates the visualization of contact network, which we call "risk graph". Each node in the graph represents an agent in the simulation model. Lines in the graph illustrate aggregate of contact between agents the simulation of scenario D. The thicker the line, the more frequent contact between the agents has been made. The size of the node is proportional to the degree, which indicates amount of contact that he had made. The layout of the graph is Force Atlas, in which the connected nodes are attracted into the center of the graph and unconnected nodes are pushed out off the outside.

Visual conclusions of the risk graph:

- The dispenser, the clerk and the examiner (there is only one dispenser, one clerk and one examiner in the hospital) nodes are the three biggest nodes (in degree). It implies that the three heath care workers have made the most contacts with patients. However, most of the contacts were made with outpatients, so the nodes represent them are pulled out off center of the graph.
- Nodes that represent nurses, doctors and inpatients are attracted into the center of the graph (Figure 9). It implies that frequent close contacts were made between them.

Figure 9 shows the center of the risk graph, in which close contacts between doctors, nurses and inpatients are illustrated. The nodes, which are marked by blue explosion shapes, represent health care workers who have been infected during the simulation. We can see that those agents are at the center of the risk graph and have frequent contacts with inpatients. The nodes, which represent doctors, and nurses who have been infected during the simulation arose on top of the list of nodes in descending order of degree. However, the dispenser and the clerk were not infected, even though nodes representing them have a high degree. It can be explained that most of the contacts they made were with outpatients, so their risk of infection was low. The risk can also be evaluated by Spot Contamination Level of the place that the two staff were working in Figure 6. The Figure shows that staff area and administration area where the two staff work are less contaminated than ward area. It means that infection risk of those staff is lower than that of nurses who mostly work with inpatient in ward area.

Several conclusions can be drawn from the analysis on risk graph:

- Two nodes are spatially closer if they have a close and frequent contact.
- Close and frequent contacts between agents will attract them into center of the graph.
- Risk of infection can be assessed not only by the degree of the nodes but also by the amount of close contacts.

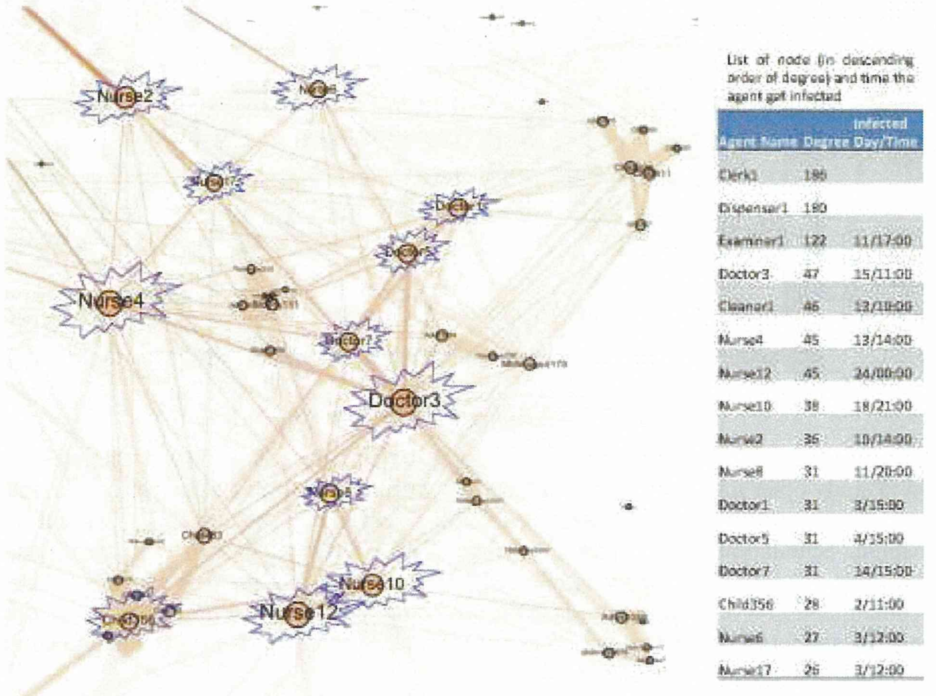

Fig. 9 Center of the risk graph and list of infected health care workers in scenario D

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VI. CONCLUSION AND DISCUSSION

We have built a simulation model for infection of an influenza-like illness in an artificial hospital and quantitatively assessed infection risk of the diseases. The simulation results have shed more light on epidemiological belief of that direct patient care HCW have high risk of catching nosocomial influenza virus and that washing hand and wearing mask are effective to prevent an outbreak of the disease in the hospital. The methodologies of quantification and visualization the infection risk have been demonstrated. The original approach has provided us with a potential methodology for risk management in infection control of nosocomial infection.

The great advantage of simulation model is that they are able to conduct experiments which are impossible or undesirable. It provides a flexibility of changing parameters to apply to other diseases rather than influenza-like illness. The computation of dynamical change of virtual influenza virus can assess the risk of infection quantitatively and visually. Even though the computational effort of the modeling method is hard, with the evolution of computing, time execution of the simulation model is constantly reduced.

The methodology of categorizing infection levels into detailed disease states can be used to apply to other pathogens like smallpox, measles and many others by changing state period and state transition probability. Compared to traditional SIR model, in which population is roughly divided in three groups of susceptible, infectious and recovered individuals, our methodology provides a better modeling of infection process.

The visualization of risk graph demonstrated above can be a valid method to assess infection risk but it is not completed. The nature of contacts that transmit virus cannot be seen from the graph. However, thanks to the development of large networks graphs visualization software, such as Gephi, we can highlight and track all contacts of agents in real time. An integration with human real time tracking systems can be potential for tracking and detecting contacts between health care workers or between health care workers and patients.

Although data and knowledge for the model have been constructed based on several field works onsite, empirical validation of the model could not be conducted due to the lack of statistics and impossibility of taking those experiments in a hospital. Although there was no observed data fitted the simulation results, outputs are qualitatively similar to observed phenomenon in the real world.

The future work is to integrate real data collecting by sensor to the simulation framework. The structure of the simulation framework is illustrated in Figure 10. We have developed and used wireless tracking systems to track real-time movement of humans in a building. The real data of movement of patients and health care workers in a real hospital can be achieved.

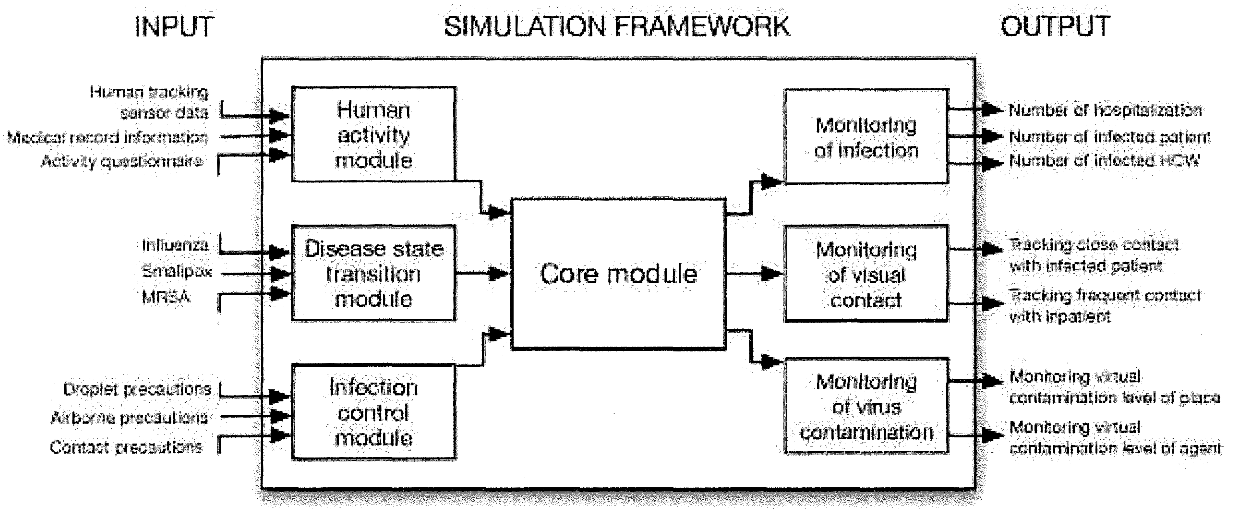

Fig. 10 Structure of the simulation framework

Activity pattern of people can also be collected via activity questionnaire. Changing parameters of the disease transition module can be applied to study other infectious diseases. Infection control measures can be changed in many scenarios depending on infection control resources of the hospital. The core module inherits from the current module but can be rebuilt to fit the structure of a new hospital. Simulation output shows real-time graph of the number of hospitalization, infected patient and HCW. By visualizing contact network, close and frequent contacts with high-risk patients can be tracked and monitored. Variation of virtual virus contamination level of places and agents can be monitored in real time. The simulation framework could be a potential decision-making support tool for hospital administrators to evaluate nosocomial infection control and it can also be used as an educational tool to study nosocomial infection.

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