11eCONGRES INTERNATIONAL DE GENIE INDUSTRIEL – CIGI2015
Québec, Canada
26-28 octobre 2015

Modeling the logistics response to the outbreak of foodborne diseases

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Résumé **- Comme les maladies d'origine alimentaire peuvent avoir de graves conséquences et exigent rapidement des ressources médicales, un plan de gestion des urgences pouvant réduire le nombre de personnes infectées doit être étudié. Toutefois, les papiers dans ce domaine sont encore peu nombreux et aucun papier ne propose un modèle qui prend en compte l'aspect logistique. Cet article propose un modèle qui fait le lien entre la progression de la maladie, les mesures d'intervention médicale associées et le déploiement de la logistique pour venir en support au processus de prise de décision à un niveau stratégique. Notre étude de cas se base sur une intoxication alimentaire causée par du lait contaminé. Le nombre de patients aux différents stades de la maladie et les ressources médicales nécessaires pour chaque période de temps peuvent être estimés grâce à notre modèle. Les facteurs qui ont un grand impact sur le nombre de décès peuvent également être évalués par ce modèle.**

Abstract**- As foodborne diseases have serious consequences and demands medical resources suddenly, an emergency management plan which can reduce the number of non-recovery people should be studied. However, the papers in this area are still few and no paper proposes a model which can pay attention to the logistic response aspect. This paper proposes a model which links the disease progression, the related medical intervention actions and the logistics deployment altogether to support the decision making process in case of the logistics response to a foodborne disease caused by contaminated milk from a strategic level. The number of the patients in different disease stages and the required medical resources for each period can be estimated by our model. The factors which have a great impact on the number of deaths can also be evaluated by this model.**

Mots clés**- Programmation linéaire, Chaîne logistique, Aide à la décision**
Keywords**- Linear programming, Emergency logistics, Decision making**

1. INTRODUCTION

Foodborne diseases is an illness resulting from the consumption of contaminated food, pathogenic bacteria, as well as chemical or natural toxins such as poisonous mushrooms (Olsen et al., 2000). Foodborne diseses is also called foodborne illness, foodborne infection, or food poisoning. The outbreak of foodborne diseases is a common, costly, yet preventable, public health problem. According to America of center for disease control and prevention (CDC), in 2013, foodborne disease affect about 48 million people in U.S. (one out of six), resulting in 128,000 hospitalizations and 3,000 deaths (Kowalcyk, 2014). In developing countries, outbreak of foodborne diseases can cause more severe consequences on public health than in developed countries due to lack of medical resources. An effective response to outbreak of foodborne diseases can reduce the number of casualties and the serious consequences obviously. Realizing the importance of an efficient and quick response to such situations, some countries have elaborated emergency management plans according to the specificities of their own countries. For example, in Canada, the Minister of Health by the Chief Public Health Officer of the Public Health Agency of Canada (PHAC) and the

Deputy Minister of Health Canada (HC) issue the Health Portfolio's Food-borne Illness Emergency Response Plan (FI ERP) to meet the legislative requirements outlined in the Emergency Management Act.

Even though several plans have been done about the response to the outbreak of foodborne diseases from different perspectives, the research in this field is far from being enough. Cassin et al. (1998) and Singer et al. (2007) test the relationship between the outbreak of foorborne diseases and pathogens. Cassin et al. (1998) use Monte Carlo simulation to provide insights into foodborne diseases caused by microbial hazards. Singer et al. (2007) present a mathematical model to evaluate relationship between human foodborne illness and food animal health. Van der Gaag et al. (2004) simulate the spread of Salmonella in the pork supply chain. The outbreak of foodborne diseases is a costly public health problem. Scharff (2012), Havelaar et al. (2012) and Hall et al. (2005) investigate the economical cost of foodborne diseases in America, Netherlands and Australia respectively. There are some other interesting papers which are not about foodborne diseases but these papers take into account the impact of logistics during the emergency management plans. Jamrog et al. (2007) used Markov chains to model the response to the anthrax attack and concluded that the antibiotic distribution capacity is a key factor to reduce causalities. Colizza et al. (2007) proposed a stochastic model to investigate how the travel restriction and the capacity of antivirus distribution affect the pandemic transmission.

It can be found that some crucial questions are still open and, in particular these logistics problems, those concerning the impact of the number of admission hospital devoted to relief the affected population, the impact of the distribution capacity of antibiotics distribution centers and the ability to start the medical response quickly.

This paper is devoted to organize the logistic aspects of an efficient response to outbreak of foodborne diseases. To this end, we propose an original modeling approach combining the progress of foodborne diseases, the medical response modes, and the logistic deployment choices together. According to our literature review, there is no paper before which can make such a link among the different parts. In our model, the infected patients are divided into risk patients and non-risk patients, according to the possible hazards caused by foodborne diseases. By using the model, crisis managers could estimate the number of individuals at each of the disease's progress stages for each period, and therefore optimize the resources required to provide the best response. The model is flexible and can be adapted to cope with specific situations and consider various deployment scenarios. The remainder of this paper is organized as follows. Section 2 describes the background of the problem. Models are presented and discussed in Section 3. Section 4 reports preliminary numerical experiments assessing the potential of our approach. Conclusion and future research directions are provided in Section 5.

2. BASIS OF OUR MODEL

In order to give the reader a general view of the situation that we intend to address, this section describes the general situation of outbreak of foodborne diseases and the decisions concerning the logistics problems of medical interventions.

2.1 General Situation of Foodborne Diseases

Foordborne diseases can be caused by bacteria, such as salmonella (non typhoidal), fungus, such as aflatoxin, and chemicals, such as methanol. Different pathogens have different impacts. Some pathogens just lead to the illness and hopitalization. Some pathogens will lead to death. Usually, people are infected by swallowing productions with pathogens. Before the symptoms of illness begin, there is a delay called incubation stage after the pathogens are swallowed. The period of incubation stage may range from hours to days, depending on the different characterise of pathogens, and how many of pathogens were swallowed. During the incubation period, the pathogens pass through the stomach into the intestine, attach to the cells lining the intestinal walls, and begin to multiply there (CDC). After incubation stage, numerous pathogens cause similar symptoms, such as diarrhea, abdominal cramps, nausea and shock. Serious patients can even die. For foodborne diseases, symptoms may break our obviously in a short time. So, most of the medical scientist believe that there is so much overlap between the prodromal stage (the stage with symptoms not obviously) and fulminant stage (the stage with symptoms obviously) for foodborne diseases. Therefore, in our study, the development of foodborne diseases is divided into two stages, incubation (I) and fulminant (U). It should be stressed here that even though not all the foodbornes diseases are deadly disease but the sequela caused by foodborne diseases is terrible and can lead to social problems.

For some pathogens, infected patients may give very different clinical demonstrations because of different health conditions. For people in good health conditions, they may have no or slight clinical demonstration. This kind of people may recover without any medical help. Generally, people in good health conditions are young and strong adults. In our study, this kind of people are called non-risk people. But for children and old people, the clinical demonstration may serious. Even though some of them can recover without medical help, the probability is low. In our study, this kind of people is called risk people. The treatment for the foodborne diseases caused by bacteria can apply antibiotics. The incubation stage patients can be treated by oral antibiotics and the fulminant stage patients can be treated by intravenous antibiotics. The treatment for the diseases caused by fungus and chemicals should use antidote. Most of the antidote are the intravenous antidote.

2.2 Logistics Decisions

The logistics deployment of drugs (antibiotics or antidote) is managed both at national and local levels. At the national level, national strategic stocks are supposed to supply the necessary amount of oral antibiotics to the Antibiotics Distributions Centres (ADCs), as well as the intravenous antibiotics or antidote used by the hospitals. Usually, intravenous antibiotics or antidote are available in the hospital that is appointed or related. In most cases, the national stock is available round the clock every day and can deliver the available medical resources to the local ADCs and hospitals in time. We will therefore focus on the

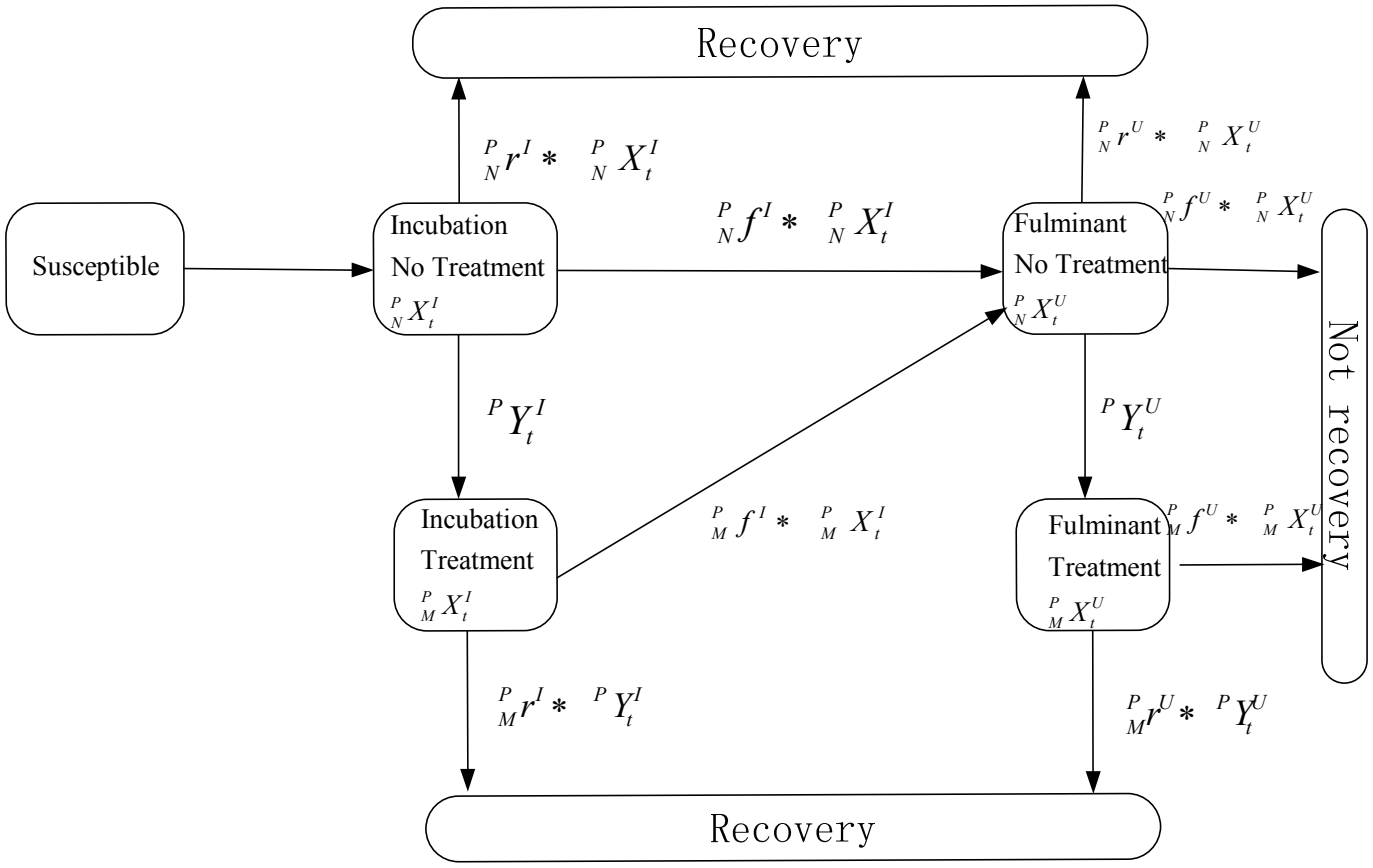

Figure 1 Logistics response to foodborne diseases model

local level decisions in the infected region. At the local level, a complex network delivering both services (diagnose or injection) and products (oral and intravenous antibiotics or antidote) needs to be deployed as soon as possible.

Authorities need to address crucial questions regarding the design and the management of the medical response logistic network. These questions include, but are not limited to, what is the most reasonable distribution capacity (in terms of number of physicians and antibiotics distribution capacity) of each distribution centers? What is the most reasonable number of hospitals to inject intravenous antibiotics and antidote for patients requiring accurate cares? How will the early response affect the consequences caused by outbreak of foodborne diseases? All these questions will be solved in the next section.

3. THE LOGISTICS RESPONSE TO FOODBORNE DISEASES MODEL AND THE MATHMATICAL FORMULATION

This section first discusses our logistics response to foodborne disease model and then the mathematical formulation aiming at minimizing the number of non-recovered people is proposed.

3.1 Logistics Responses to Foodborne Diseases Model

According to CDC's 2011 Estimates for Foodborne Illness, salmonella (non typhoidal) is the top pathogens which can lead to illness, hospitalizations and deaths. For the medical response to foodborn diseases, patients in different stages need different medical responses. The incubation stage patients need oral antibiotics and fulminant stage patients need intravenous antibiotics. In other words, a more complicated logistics network is needed to response to foodborne diseases caused by salmonella. Therefore, the outbreak of foodborne diseases caused by salmonella (non typhoidal) is used as a real case to propose our model. But, our model is flexible and can be adapted to specific situations and various resource deployment scenarios. Salmonella is just used as a real case to test our model.

Our models supposes an outbreak of foodborne disease caused by salmonella in milk at a primary school in China, where pupils and teachers can get a glass bottle of milk distributed from food distribution center every day during the "milk time", from 10:00 am to 10:30 am. Usually, all the people will finish their milk during the "milk time" because the bottle will be retrieved at the end of "milk time". Therefore, we suppose that all the pupils and teachers at the primary school will drink the contaminated milk during the "milk time" and get infected.

The proposed model (Figure 1) takes account of the different disease stages, patients in different health conditions and the potential medical intervention methods. The notations used in Figure 1 are defined in Table 1. This model consists of a set of nodes and oriented arcs. The nodes present people in different health conditions in different stages under different medical treatment stages. The arcs try to show the possible transitions

between different stages. According to the development of disease, the patients are divided into incubation (I), fulminant (U), recovery (R) and non-recovery (E). Non-recovery denote patients who are shocked, have a sequela and even die. According to the situation of medical help, patients are divided into people without related medical treatment (N) and people with medical treatment (M). According to the health conditions (P), individuals are divided into risk patients (O) and non-risk patients (S). Transition between different stages is based on different disease stages, different medical treatment statuses and the results of different medical interventions. The model assumes that logistics decisions (delivery of medical resources) are made at period td because there is a time delay between people are infected and the foodborne disease is detected and the medical interventions begin. Our model assumes the individuals who are in the current stage at the beginning period t may evolve to the following stage at the beginning of period t+1 (at the end of period t) and the medical interventions (administration of the medical treatment) are done at the end of periods.

In Figure 1, the arc from susceptible to incubation denotes the people may be infected by drinking the contaminated milk. After infected, some patients may recover even without medical help (arcs from Incubation No Treatment or Fulminant No Treatment to Recovery). Some patients can get the related medical help. Incubation stage patients can get the oral antibiotics help from Antibiotics Distribution Center (arc from Incubation No Treatment to Incubation Treatment) and the fulminant stage patients can get the intravenous antibiotics help from hospital (arc from Fulminant No Treatment to Fulminant Treatment). For the patients who do not get the medical help and cannot recover themselves, they will develop from incubation stage to the fulminant stage and then may be shocked or have terrible sequela or die. After getting the medical help, some infected patients may recover (arcs between the third line nodes and the recovery). Some of them cannot. For the incubation stage patients who cannot recover after getting medical help, they will develop to the fulminant stage and need intravenous antibiotics help in the hospital (arc from Incubation Treatment to Fulminant No Treatment).

3.2 The Mathematical Formulation

We propose a discrete time mathematical formulation of the logistics response to a foodborne disease model. Our mathematical formulations can be easily extended to cope with other resources, for example, hospitalization beds. It can also be adapted to represent a situation where oral antibiotics are prescribed by pharmacies instead of ADCs. The logistics costs are not taken into the consideration in the model, but financial indicators can be easily calculated. The notations and the mathematical formulations are shown in the followings.

Table 1 Definition of the used notations

Indices and parameters
C: Index for different disease stages, C={I,U, E, R}
A: Index for different medical treatment stages, A={N, M}
P: Index for individuals per different groups, P={O,S}
T: Number of periods, t={1,...,t}
H: Number of available hospitals, h={1,...,H}
D: Number of distribution centers, d={1,...,D}
td: Period in which the medical treatment begins
${}^{P}_{A}f^{C}$: Rate of transition, for P group individuals at A medical stage and C disease stage, from current disease stage to the next disease stage
${}^{P}_{A}r^{C}$: Rate of recovery for P group individuals at A medical stage and C disease stage
sth, std: Number of available intravenous antibiotics and oral antibiotics respectively from strategic stocks
ch, cd: Daily treatment capacity at hospital $_{h}$ or daily distribution capacity at distribution center d respectively (number of doses)
sh, sd: Stock capacity at hospital $_{h}$ or at distribution center $_{d}$ (number of doses)
inh, ind: Initial available intravenous antibiotics or oral antibiotics (number of doses) per hospital or per distribution center at the beginning of the horizon
${}^{P}_{A}num^{C}$: Number of P group individuals at A medical stage and C disease stage at the beginning of period 1
Variables
${}^{P}_{A}X^{C}_{t}$: Number of P group individuals at A medical stage and C disease stage at the beginning of period t
${}^{P}Y^{C}_{t}$: Number of P group individual at C disease stage get the related medical treatment at the beginning of period t
Q_{ht} : Number of intravenous antibiotics doses sent to hospital h by strategic stockpiles at the beginning of period t
Q_{dt}: Number of oral antibiotics doses sent to distribution center d by strategic stockpiles at the beginning of period t
I_{ht}: Number of available intravenous antibiotics doses at hospital h at the beginning of period t
I_{dt}: Number of available oral antibiotics doses at distribution center d at the beginning of period t
G_{ht}: Number of individuals getting the intravenous antibiotics help at hospital h at the beginning of period t
G_{dt}: Number of individuals getting the oral antibiotics help at distribution center d at the beginning of period t

$$\mathrm{Min}\left(\sum_{t=1}^{T} X_t^E\right) \quad (1)$$

$${}^{P}_{A}X^{C}_{1} = {}^{P}_{A}num^{C}$$

$\forall C=\{I,U, E, R\}, \forall A=\{N, M\},$

$\forall P=\{O,S\}$ (2)

$${}^{O}_{N}X^{I}_{t} = {}^{O}_{N}X^{I}_{t-1} - {}^{O}_{N}f^{I} \times {}^{O}_{N}X^{I}_{t-1} - {}^{O}Y^{I}_{t-1} - {}^{O}_{N}r^{I} \times {}^{O}_{N}X^{I}_{t-1}$$

$\forall t=\{2, \dots, T\}$ (3)

$${}^{O}_{N}X^{U}_{t} = {}^{O}_{N}X^{U}_{t-1} + {}^{O}_{N}f^{I} \times {}^{O}_{N}X^{I}_{t-1} + {}^{O}_{M}f^{I} \times {}^{O}_{M}X^{I}_{t-1} - {}^{O}_{N}f^{U} \times {}^{O}_{N}X^{U}_{t-1} - {}^{O}Y^{U}_{t-1} - {}^{O}_{N}r^{U} \times {}^{O}_{N}X^{U}_{t-1}$$

$\forall t=\{2, \dots, T\}$ (4)

$${}^{O}_{M}X^{I}_{t} = {}^{O}_{M}X^{I}_{t-1} + {}^{O}Y^{I}_{t-1} - {}^{O}_{M}r^{I} \times {}^{O}Y^{I}_{t-1} - {}^{O}_{M}f^{I} \times {}^{O}_{M}X^{I}_{t-1}$$

$\forall t=\{td+1, \dots, T\}$ (5)

$${}^{O}_{M}X^{U}_{t} = {}^{O}_{M}X^{U}_{t-1} + {}^{O}Y^{U}_{t-1} - {}^{O}_{M}r^{U} \times {}^{O}Y^{U}_{t-1} - {}^{O}_{M}f^{U} \times {}^{O}_{M}X^{U}_{t-1}$$

$\forall t=\{td+1, \dots, T\}$ (6)

$${}^{S}_{N}X^{I}_{t} = {}^{S}_{N}X^{I}_{t-1} - {}^{S}_{N}f^{I} \times {}^{S}_{N}X^{I}_{t-1} - {}^{S}Y^{I}_{t-1} - {}^{S}_{N}r^{I} \times {}^{S}_{N}X^{I}_{t-1}$$

$\forall t=\{2, \dots, T\}$ (7)

$${}^{S}_{N}X^{U}_{t} = {}^{S}_{N}X^{U}_{t-1} + {}^{S}_{N}f^{I} \times {}^{S}_{N}X^{I}_{t-1} + {}^{S}_{M}f^{I} \times {}^{S}_{M}X^{I}_{t-1} - {}^{S}_{N}f^{U} \times {}^{S}_{N}X^{U}_{t-1} - {}^{S}Y^{U}_{t-1} - {}^{S}_{N}r^{U} \times {}^{S}_{N}X^{U}_{t-1}$$

$\forall t=\{2, \dots, T\}$ (8)

$${}^{S}_{M}X^{I}_{t} = {}^{S}_{M}X^{I}_{t-1} + {}^{S}Y^{I}_{t-1} - {}^{S}_{M}r^{I} \times {}^{S}Y^{I}_{t-1} - {}^{S}_{M}f^{I} \times {}^{S}_{M}X^{I}_{t-1}$$

$\forall t=\{td+1, \dots, T\}$ (9)

$${}^{S}_{M}X^{U}_{t} = {}^{S}_{M}X^{U}_{t-1} + {}^{S}Y^{U}_{t-1} - {}^{S}_{M}r^{U} \times {}^{S}Y^{U}_{t-1} - {}^{S}_{M}f^{U} \times {}^{S}_{M}X^{U}_{t-1}$$

$\forall t=\{td+1, \dots, T\}$ (10)

$$X^{R}_{t} = {}^{S}_{M}r^{U} \times {}^{S}Y^{U}_{t-1} + {}^{S}_{M}r^{I} \times {}^{S}Y^{I}_{t-1} + {}^{S}_{N}r^{U} \times {}^{S}_{N}X^{U}_{t-1} + {}^{S}_{N}r^{I} \times {}^{S}_{N}X^{I}_{t-1} + {}^{O}_{M}r^{U} \times {}^{O}Y^{U}_{t-1} + {}^{O}_{M}r^{I} \times {}^{O}Y^{I}_{t-1} + {}^{O}_{N}r^{U} \times {}^{O}_{N}X^{U}_{t-1} + {}^{O}_{N}r^{I} \times {}^{O}_{N}X^{I}_{t-1}$$

$\forall t=\{2, \dots, T\}$ (11)

$$X^{E}_{t} = {}^{S}_{M}f^{U} \times {}^{S}_{M}X^{U}_{t-1} + {}^{S}_{N}f^{U} \times {}^{S}_{N}X^{U}_{t-1} + {}^{O}_{M}f^{U} \times {}^{O}_{M}X^{U}_{t-1} + {}^{O}_{N}f^{U} \times {}^{O}_{N}X^{U}_{t-1}$$

$\forall t=\{2, \dots, T\}$ (12)

$$G_{ht} \leq cd$$ (13)

$$I_{d,td} = ind \quad \forall d = \{1, \dots, D\}, \ \forall t = \{td, \dots, T\}$$ (14)

$$I_{dt} + Q_{dt} \leq sd \quad \forall d = \{1, \dots, D\}, \ \forall t = \{td, \dots, T\}$$ (15)

$$I_{d,t+1} = I_{dt} - G_{dt} + Q_{dt}$$

$\forall d = \{1, \dots, D\}, \forall t = \{td, , \dots, T-1\}$ (16)

$${}^{O}Y^{I}_{t} + {}^{S}Y^{I}_{t} = \sum_{d=1}^{D} G_{dt}$$

$\forall t=\{td, \dots, T\}$ (17)

$$\sum_{d=1}^{D} \sum_{t=td}^{T} Q_{dt} \leq std$$ (18)

$$G_{ht} \leq ch$$

$\forall h = \{1, \dots, H\}, \forall t = \{td, \dots, T\}$ (19)

$$I_{h,td} = inh \quad \forall h=\{1, \dots, H\}$$ (20)

$$I_{ht} + Q_{ht} \leq sh$$

$\forall h = \{1, \dots, H\}, \forall t = \{td, \dots, T\}$ (21)

$$I_{h,t+1} = I_{ht} - G_{ht} + Q_{ht}$$

$\forall h = \{1, \dots, H\}, \forall t = \{td, \dots, T-1\}$ (22)

$${}^{O}Y^{U}_{t} + {}^{S}Y^{U}_{t} = \sum_{h=1}^{H} G_{ht} \quad \forall t = \{td, \dots, T\}$$ (23)

$$\sum_{h=1}^{H} \sum_{t=td}^{T} Q_{ht} \leq sth$$ (24)

$${}^{P}Y^{C}_{t}, {}^{P}_{M}X^{C}_{t}, Q_{dt}, Q_{ht} = 0$$

$\forall t = \{1, \dots, td-1\}, \forall h = \{1, \dots, H\}, \forall d = \{1, \dots, D\},$

$\forall C=\{I,U, E, R\}, \forall A=\{N, M\},$

$\forall P=\{O,S\}$ (25)

$${}^{P}_{A}X^{C}_{t}, \ {}^{P}Y^{C}_{t}, I_{dt}, Q_{dt}, I_{ht}, Q_{ht} \geq 0$$

$\forall t = \{1, \dots, T\}, \forall h = \{1, \dots, H\}, \forall d = \{1, \dots, D\},$

$\forall C=\{I,U, E, R\},$

$\forall A=\{N, M\}, \forall P=\{O,S\}$ (26)

Equation (1) aims at minimizing the number of non-recovery people. Equations from (2) to (26) consist of three main sets constraints in a broad sense: disease development flow constraints, medical intervention flow constraints and the linkage constraints between disease development flow and medical intervention flow. In the set of disease development flow constraints, equations (2) give the number of people in different stages at the beginning. Constraints (3) and (4) are the flow conservation constraints of the risk patients who do not get the medical help per disease stage. Constraints (5) and (6) are the flow conservation constraints of the risk patients who get the medical help. Constraints (7) and (8) are the flow conservation constraints of the risk patients who do not get the medical help. Constraints (9) and (10) are the flow conservation constraints of the risk patients who get the medical help. Equations (11) and (12) present the recovery and non-recovery people respectively. In the set of medical intervention flow constraints, constraints (13) and (19) are the constraints of distribution capacity at ADC and treatment capacity at hospital respectively. Constraints (14) and (20) are the initial status constraints. Stock capacity constraints are the constraints (15), (18), (21) and (24). Constraints (16) and (22) are the flow conservation constraints of oral antibiotics and intravenous antibiotics respectively. Constraints (17) and (23) make a linkage between the development of diseases and the logistics deployment. Constraints (25) present that the medical treatment begin from period td. The non-negativity conditions on the variables are enforced by constraints (26).

4. NUMERICAL EXPERIMENTS

This section shows how to use our model to solve the logistics questions in Section 2.2 and gain insight into logistics deployment with the help of our model.

4.1 The Choice of Data

Data used in the model were collected from a variety of works. Based on the size of primary school in a middle city in China, we suppose that there are 2160 pupils (One primary school has 6 grades and each grade has 6 classes, one class has 60 pupils: 60*6*6=2160) and 70 teachers. In our model, pupils are risk patients and teachers are non-risk patients. Since the incubation time of salmonella can range from 2 hours to 8 hours and the length of "milk time" is 0.5 hours, the length of one period is 0.5 hours. The fulminant stage can range from 1 hours to 2 hours. So, the total horizon of our model is 24 periods (12 hours>8 hours +2 hours+0.5 hours). The transition rate for incubation stage patients without medical help can range from 0.25 to 0.0625 (Stepanović, 2003). Therefore, we suppose the transition rate for risk patients and non-risk patients are 0.25 and 0.0625 respectively. The transition rate for fulminant stage patients without medical help can range from 0.5 to 0.8. So, in our experiment, the transition rate for non-risk patients and risk patients without medical help from fulminant to the next disease stage is 0.8 and 0.5 respectively. Because no official paper record the transition rate for patients with medical help but cannot recover, the transition rate for people with or without medical help is supposed to be the same in our study. According to Centers for Disease Control and Prevention in America (CDC), most of the non-risk patients can recover without medical help and the risk patients should get the related medical interventions in the earlier stage. Therefore, recovery rate for non-risk patients and risk patients in the incubation stage without medical help is assumed to be 0.9 and 0.5 respectively. But, when patients develop to the fulmiant stage, they cannot recovery without medical interventions. So, the recovery rate for both risk patients and non-risk patients in fulmiant stage without medical help is 0. For patients in the incubation stage, the recovery rate with medical help is 0.9 and 1 for risk patients and non-risk patients respectively. For patients in the fulminant stage, the recovery rate with medical help is 0.7 and 0.8 for risk patients and non-risk patients respectively. Values of all logistics parameters were collected after discussion with local health workers in China. In the base case experiment, 3 ADC and 6 hospitals is available. During half hour, one ADC can distribute 20 people oral antibiotics and one hospital can receive 5 people. Usually, the national stockpile is enough. ADCs and the hospitals can pre-stock some antibiotics in case of emergency. So, we set the national stockpile for oral and intravenous antibiotics are 2000 and 1500 respectively. The pre-stock for both kinds of antibiotics is 100. The medical intervention begins at the beginning of period 4.

4.2 Experiment results

All our experiments are coded in OPL language and solved by CPLEX 12.6 with the simplex method. The number of constraints is 1693 and the number of variables is 962. 2.3 seconds is used to solve the problem. The number of non-recovery patients is 1250. In the following section, the impact of distribution capacity of ADC, the impact of the number of admission hospitals and the impact of early response ability will be tested. From Figure 2 to Figure 4, decision makers will have a clear idea about how different factors affect the number of non-recovery people.

The impact of the change of dispensing capacity is shown in Figure 2. We assume that the dispensing capacity of each oral antibiotics distribution center can be increased from 10 to 30. Among these scenarios, the national stockpile is always enough to support the local oral antibiotics distribution. The number of deaths decreases rapidly with the increase of distribution capacity because the increase of the dispensing capacity of oral antibiotics distribution center can enable more patients, especially the risk patinets, to get the medical help early and then the disease can be better controlled. When we do the experiment with the assumption that, each antibiotics distribution center pre-stocks some drugs before the medical intervention, the number of non-recovery people does not change because the national stockpile can deliver the drugs in time. So, if the national stockpile can support each antibiotics distribution center in time, the pre-stock of the drugs in each antibiotics distribution center will not affect the number of deaths.

During the outbreak of foodborne diseases, a lot of hospital will increase the point to inject the intravenous antibiotics to patients. Hence, we assume that the treatment capacity of each hospital is the same. The number of admission hospital can be increased from 3 to 9. The impact of the number of admission hospitals is presented in Figure 3. Under the assumption that the national stockpile of intravenous antibiotics is 2000, the increase of the number of available hospitals decreases the number of non-recovery patients and the intravenous antibiotics is always enough during these scenarios.

Compared Figure 2 with Figure 3, the number of non-recovery patients is more sensible to the distribution capacity of oral distribution centers than the number of available hospitals for two main reasons: first, the recovery rate of the oral antibiotics is higher than the intravenous antibiotics. Second, the treatment capacity of each hospital is limited.

The impact of the period of the beginning of medical interventions has been shown in Figure 4. The impact of the period when the medical intervention begins is higher than the others. It is because the foodborne disease is a kind of diseases which have a really short incubation stage, just 2 to 8 hours, and a very short fulminant stage, just 1 to 2 hours. Therefore, a quick medical response is really in time. Otherwise, the patients will develop to the shock state which will need more complicated treatment.

5. CONCLUSION

This paper proposed a logistic response model to a foodborne disease which combines the progress of the disease, the medical response methods, and the logistic deployment together. This model can, but is not limited to, estimate the number of patients in different stages in any given period, decide the amount of medical resources that should be delivered to the oral antibiotics

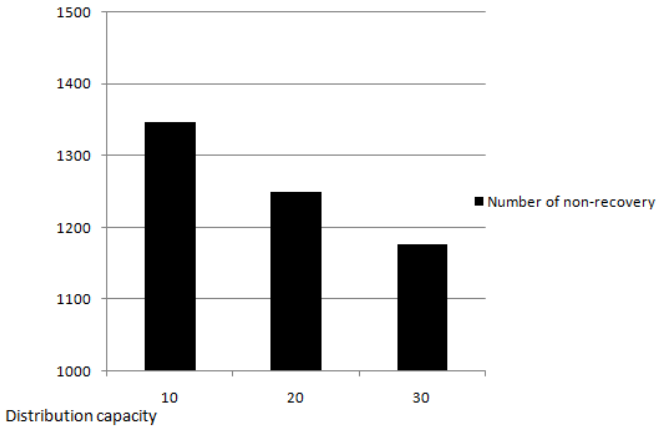

Figure 2 The impact of the change of the dispensing capacity

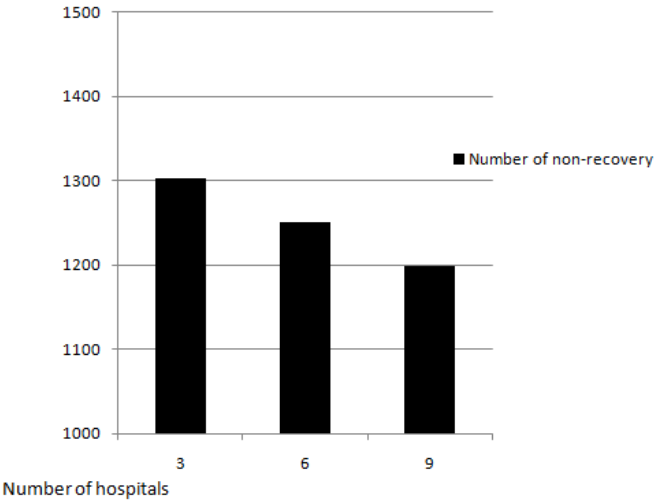

Figure 3 The impact of the change of the number of hospitals

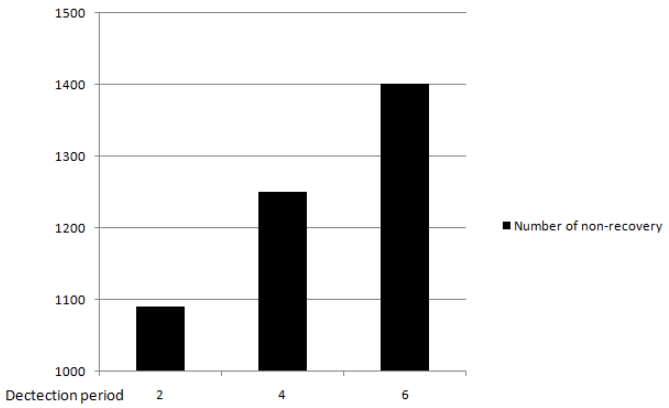

Figure 4 The impact of the period when the medical intervention begins

distribution centers or to the hospitals per period, find out which factors may affect the number of deaths. This model can be extended to several situations easily, be applied to most kinds of infectious diseases, such as Anthrax, and be extended to some other infectious diseases as well. There are two main limitations of our model. First, the uncertainty values of parameters have not been taken into account. Second, the durations of stages are constant without consideration of different treatment periods. In the future, our model will be extended to a stochastic programming model, taking into account the uncertainty of parameters and the change of the durations of stages because of different periods in which the patients get treatment.

ACKNOWLEDGEMENT

This paper is sponsored by the Threats project (http://www.threatsproject.eu/index.html) which is part of the CIPS program of the European Community. More information can be found on the website: http://ec.europa.eu/dgs/home-affairs/financing/fundings/security-and-safeguarding-berties/terrorism-and-other-risks/index_en.htm.

REFERENCES

Cassin, M. H., Paoli, G. M., & Lammerding, A. M. (1998). Simulation modeling for microbial risk assessment. Journal of Food Protection®, 61(11), 1560-1566.

Colizza, V., Barrat, A., Barthelemy, M., Valleron, A.-J., Vespignani, A. (2007): Modeling the worldwide spread of pandemic influenza: baseline case and containment interventions. PLoS Medicine, 4(1), e13

Havelaar, A. H., Haagsma, J. A.,Mangen, M. J. J., Kemmeren, J. M., Verhoef, L. P., Vijgen, S. M., ... & van Pelt, W. (2012). Disease burden of foodborne pathogens in the Netherlands, 2009. International journal of food microbiology, 156(3), 231-238.

Hall, G., Kirk, M. D., Becker, N., Gregory, J. E., Unicomb, L., Millard, G., ... & OzFoodNet Working Group. (2005). Estimating foodborne gastroenteritis, Australia. Emerg Infect Dis, 11(8), 1257-1264.

Jamrog, D. C., Shatz, M. P., Smith, C. (2007). Modeling Responses to Anthrax and Smallpox Attacks, 17(1), 115–129.

Kowalcyk, B. (2014). Monitoring Trends in Foodborne Disease Using US Poison Center Data: 2000–2011. In 2014 Annual Meeting. Iafp.

Ram, D., Karthikeyan, V. S., Sistla, S. C., Ali, S. M., Sridhar, P., & Rajkumar, N. (2014). Spontaneous cecal perforation secondary to acute fulminant gastroenteritis: report of a rare case. Annals of Pediatric Surgery, 10(1), 12-13.

Stepanović, S., Ćirković, I., Mijač, V., & Švabić-Vlahović, M. (2003). Influence of the incubation temperature, atmosphere and dynamic conditions on biofilm formation by Salmonella spp. Food Microbiology, 20(3), 339-343.

Scharff, R. L. (2012). Economic burden from health losses due to foodborne illness in the United States. Journal of Food Protection, 75(1), 123-131.

Singer, R. S., Cox, L. A., Dickson, J. S., Hurd, H. S., Phillips, I., & Miller, G. Y. (2007). Modeling the relationship between food animal health and human foodborne illness. Preventive veterinary medicine, 79(2), 186-203.

Todd, E. C. (1996). Epidemiology of foodborne diseases: a worldwide review.World health statistics quarterly. Rapport trimestriel de statistiques sanitaires mondiales, 50(1-2), 30-50.

Olsen, S. J., MacKinnon, L. C., Goulding, J. S., Bean, N. H., & Slutsker, L. (2000). Surveillance for foodborne-disease outbreaks—United States, 1993–1997. MMWR CDC Surveill Summ, 49(1), 1-62.

Van der Gaag, M. A., Vos, F., Saatkamp, H. W., van Boven, M., van Beek, P., & Huirne, R. B. (2004). A state-transition simulation model for the spread of Salmonella in the pork supply chain. European Journal of Operational Research, 156(3),782-798.