1. INTRODUCTION

1.1 Problem statement

Salmonella is a common cause of food borne disease in humans. Therefore Salmonella criteria have been laid down for minced meat, meat preparations and meat products by Commission Regulation. Official controls on the production of meat are necessary to inspect on food business operators' own controls and to verify that food business operators comply with hygiene rules and respect criteria and targets laid down in Community legislation. The community legislation requires the approval of establishments and the competent authority should make an on-site visit (EC No 853/2004). Regulation (EC) No 854/2004 requires that modern meat inspection should be based on risk assessment and that cross contamination in the slaughter hall should be prevented. However, it has been shown that salmonella is readily transmitted from one carcass to the next by the various manipulations that are required to be performed during the traditional meat inspection procedures (Dwinger et al., 2007). The traditional post-mortem meat inspection procedures are directed towards lesions which are of more qualitative variations than public health importance, and therefore may be better handled by the quality control system of the slaughterhouse (Ellerbroek, 2007). Further more, SCVM (2007) states that the quality of meat inspection can be monitoring for its outcome, rather than being exclusively governed by rigorously prescribed procedures (SCVM, 2000). Bondt et al. (2007) introduced a new governmental control system, supervision of control, which is concerned with the changing role of the control activities of government in the transitions towards increased self-regulation by private companies. They indicated that a reduction in the procedures of public meat inspection may save costs for the slaughterhouses. However, it is doubtful whether the choice of food business operators in selecting control strategies will be altered by the reduction of public meat inspections so that the prevalence levels of macro organisms in meat product is altered.

1.2 Objectives and research questions

This research is aimed to analyze the impact of pubic meat inspections on the choice of the meat slaughter plant in selecting control strategies; as well as to find out the factors that may also change their choices in selecting control strategies.

The following questions will be answered in this research:

What is the effect of a reduction in public meat inspections on the choice of meat slaughter plants in selecting the optimal control strategies?

Are there any influential factors that may also change the decision makings of meat slaughter plants?

If those influential factors are existed, then what is their effect on meat laughter plants' decision makings?

How does the intensity of meat inspections together with the influential factors alter the food business operators' decision makings?

What is the effect on the expected prevalence levels of Salmonella in meat products when the different control strategies are selected by the food business operators?

What is the effect of the intensity of meat inspections and the influential factors on the expected Salmonella prevalence levels in meat product?

CHAPTER 2 SALMONELLA CONTROL

This chapter introduces the background of salmonella control, include: the prevalence transitions in herds and carcasses, the control measures and the prevalence levels.

2.1 Salmonella transmission dynamics among herds and between carcasses

An animal that is infected with Salmonella can start shedding bacteria and therefore become infectious within four hours (Fedorka-Cray et al., 1994). The sero-conversion period of reaching the detectable antibody levels after infection is about two weeks. The animal can remain in a carrier state where the bacteria are in intestines or lymph nodes, without shedding it, and may become serological negative again. At the slaughter stage, bacteria from the intestines or lymph nodes can contaminate the carcass and thereby contaminate the meat product (Lettelier et al., 1999).

The spread of Salmonella in the sojourn time on the finishing farms is designed by the stochastic susceptible infectious recovered (SIR) model as described by Van der Gaag, et al.(2004b). As illustrate in table 2.1, an animal can be assigned to one of three states: the susceptible state, the infectious state and the recovered state.

Table 2.1. State description in the spread of salmonella on farm level

Code	State	Animal description	Carcass	Serological test result
S_1	Susceptible 1	salmonella free animals	salmonella free carcass	negative serology
S_2	Susceptible 2	susceptible again	salmonella free carcass	positive serology
I_1	Infectious 1	infected and infectious	contaminated carcass	negative serology
I_2	Infectious 2	infected and infectious	contaminated carcass	positive serology
I_3	Infectious 3	infected and infectious	contaminated carcass	>1st infection
C	carrier	carrier animals,not shedding	carrier,not a state of a carcass	positive serology

sources: M.A.van der Gaag, 2004b

The two susceptible states are S_1 and S_2, the three infectious states are I_1, I_2 and I_3; and there is one carrier state C. For instance, S_1 denotes Salmonella free animal that results in a salmonella free carcass and will be tested negative with a serological test; and S_2 is the notation for that will result in a Salmonella free carcass but that will be tested serological positive.

As illustrated in figure 2.1, a Salmonella free herd in state S_1 can be infected and move to state I_1. After the seroconversion period, it will be in state I_2. When the animal stops shedding, it then moves to state C and becomes susceptible again S_2. An animal in state S_2 may be infected again

I_3 or becomes serological negative S_1. It is assumed that there is no infection induced morality (e.g. Fedorka- cracy et al., 1994). However, after the animal is slaughtered, several transitions are impossible to happen, such as seroconversion. The serology of the animal does not change anymore during or after slaughter, although in the blood or meat drip of the carcass the serology status is detectable. Therefore, the transition between I_1 and I_2 is unable to occur.

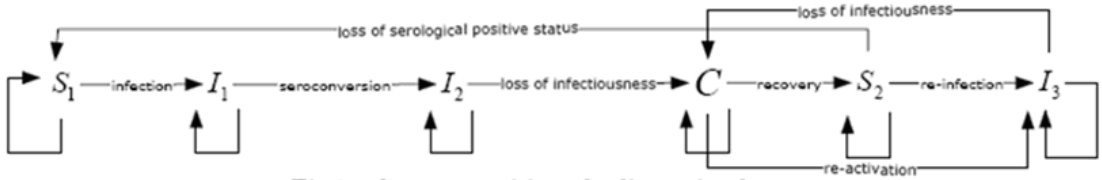


Fig 2.1 States transitions for live animals

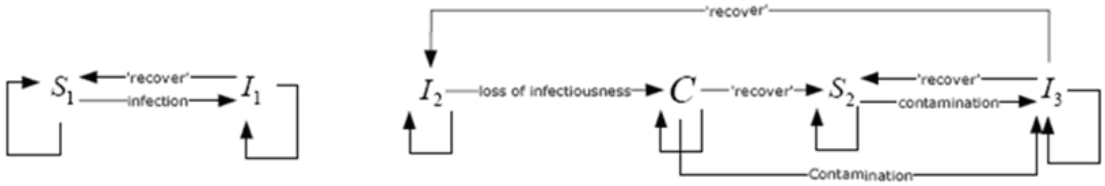


Fig 2.2 States transitions for carcasses

The possible transitions for the carcass during slaughter are outlined Fig 2.2 the interpretation of several states in this figure differs slightly from those in Fig 2.1. For instance, the infected animal in Fig 2.1 should be interpreted as a contaminated carcass, which may be caused by bacteria from the intestines or lymph nodes during evisceration or by cross-contamination at the slaughter time. An infected herd (I_1, I_2 and I_3) may become a carcass free of Salmonella (S_1 or S_2), if the evisceration is carried out very carefully and no bacteria contaminate the carcass. Besides, salmonella free pig (S_1 or S_2) may also become infected, because of cross contaminations by bacteria of other infected carcasses or by bacteria on the slaughter equipment. The carrier state (C) does not exist after slaughter, due to a carrier carcass is either a contaminated (I_2 and I_3) or an uncontaminated carcass (S_2).

2.2 Salmonella prevalence control measures and prevalence level

On the farm-level, control measures include the purchase of Salmonella free animals, rodent control, careful cleaning and disinfection of facilities, strict separation of groups of hogs and all-in-all-out routings and acidification of feeds and or water. Although, some of these measures can be quite effective most notably acidification of feeds and water are costly and of them will eliminate the possibility that some animals are infected.

On the slaughter-plant level, control measures include daily cleaning of equipment, careful evisceration and logistic slaughtering practices whereby groups of low prevalence hogs are

slaughtered early in the day to minimize cross –contamination (King, et al., 2007).

One or several control measures are combined as a control package, where different combinations of control measures have different costs. When the more costly control packages are selected, more intensive Salmonella control is achieved (Van der Gaag et al., (2004b)). The prevalence (i.e. percentage of infected herds or carcasses in a population) of salmonella in herds or carcasses can be measured by serological or bacteriological testing. For instance, based on serology, at population level the mean prevalence of tissues or carcasses after slaughter is 11% in the Netherlands (Swanenburg et al., 2001). In this research, the prevalence levels of herds or carcasses are measured by the percentage of infected herds or carcasses in a sample of population. On the farm-level, the samples of finishing herds are tested by serological prevalence distributions; and on the slaughter plant-level, the samples of carcasses are tested by bacteriological prevalence distributions.

Table 2.2 represents the costs and the bacteriological prevalence distributions resulted from using three slaughter plant-level control packages. Table 2.3 illustrates the costs and the serological prevalence distributions that resulted from using four farm-level control packages.

Table 2.2 Costs and expected bacteriological prevalence for Salmonella control packages

cost (€/carcass)	control packages		
	1	2	3
Total package cost (€/carcass)	1.10	1.21	1.80
prevalence probabilities			
0	0.9437	0.9719	0.9899
10	0.0518	0.0259	0.0079
20	0.0037	0.0018	0.0018
30	0.0007	0.0004	0.0004
40	0.0001	0.0001	0.0001
50	0	0	0
60	0	0	0
70	0	0	0
80	0	0	0
90	0	0	0
100	0	0	0
expected prevalence level (%)	0.6174	0.1286	0.1287
probability of exceeding 10 per cent prevalence	0.0896	0.0282	0.0102

Slaughter plant-level prevalence probability distributions for the three control packages are shown in table 2.2. These bacteriological prevalence distributions for one carcass on a finishing slaughter plant were calculated using an epidemiological simulation model described by Van der Gaag et al.(2004b). The algorithm is demonstrated in chapter 4.Some modifications in calculations in the costs of control packages are made to reflect realities more. The table shows that bacteriological prevalence distributions of three Salmonella control packages are centered to a zero percent level, but package 3 has the most centered distributions on this level. The cumulative distributions above ten percent level of control package 3 is 0.0102, this means a slaughter plant who used control

package x_3 in Salmonella control would have a 0.0102 probability of exceeding the Salmonella prevalence threshold of ten percent. When comparing this probability with the probability of exceeding 10 percent by using control package 1, which is 0.0896, control package 3 produces a higher chance to pass a quality test.

Table 2.3 Cost and expected serological prevalence for Salmonella control pacakges

	cost (€/herd) contorl packages			
	1	2	3	4
Total package cost (€/herd)	0.00	0.72	1.14	2.92
prevalence probabilities				
0	0.0100	0.0300	0.1800	0.7200
10	0.0200	0.0600	0.2400	0.1700
20	0.0400	0.0900	0.2200	0.0600
30	0.0700	0.1200	0.1500	0.0300
40	0.0900	0.1800	0.1000	0.0200
50	0.1500	0.2100	0.0600	0
60	0.2200	0.1500	0.0300	0
70	0.1700	0.0800	0.0100	0
80	0.1100	0.0500	0.0100	0
90	0.0800	0.0200	0	0
100	0.0400	0.0100	0	0
Expected prevalence level (%)	59.3	45.1	21.6	4.6
probability of exceeding 20 per cent prevalence	0.07	0.18	0.64	0.95

Farm-level serological prevalence probability distributions for the four control packages are shown in table 2.3. These bacteriological prevalence distributions for one herd on a finishing farm were originally estimated using an epidemiological simulation model described by Van der Gaag et al.(2004b). The table shows that the prevalence distribution for package 2 is quite dispersed and is centered on 50 percent; the distribution for package 3 is more concentrated and has more of its probability mass at levels below 30 percent. The distribution for packages 4 is still more concentrated at lower end of the prevalence range, whit the probability of a test result of zero exceeding 70 percent. If a producer used package 2 would have a 0.82 probability of exceeding the salmonella prevalence threshold of 20 percent and having a production history level of zero in the next period and a 0.18 probability of having a production history level of one in the next period.

CHAPTER 3 MODEL DESCRIPTION

This chapter introduces the conceptual structure and the theoretical background used for this research. Dynamic Programming, steady state distribution theory and the cumulative experience system theory are introduced based on literature review.

3.1 Conceptual structures

Assume there is a slaughter plant delivers carcasses in the Netherlands and it is required by the official authority to participate in a program of Salmonella control. During this program, the slaughter plant has to select one control package to reduce the prevalence of Salmonella in the carcasses each month. At the end of each month, the bacteriological prevalence of carcasses may be tested by the official authority. Intensity of Salmonella control is increased with the costs of the selected control package. If carcasses are tested negative, the slaughter plant is rewarded by on extra point on its reputation of Salmonella control. And if carcasses are tested positive, the slaughter plant looses all its reputation points and must pay for a penalty. At the start, all control procedures are inspected by the official authority on a daily basis. The inspecting and testing costs are completely paid by the slaughter plant. To reduce the intensities of inspections and testing, the slaughter plant can save the total costs. The intensity of inspections and testing both depend on the number of reputation points. The more reputation points, the less inspections and tests are carried out. Furthermore, the adoption of effective control packages can reduce the chance of having positive test results and thus increase the number of reputation point, with the consequence that the intensity of testing is reduced. Without an investment on Salmonella control, the slaughter plant can neither reduce the inspecting costs, nor save the testing costs. Thus, the selection of control packages to balance the costs of Salmonella control and the costs of inspections and testing is essential for the slaughter plant.

The slaughter plant's problem can be solved under two different conditions: under the first condition, there is the no governmental intervention and under the second condition, the governmental intervention is active and influential to the slaughter plant's decision makings. Under the first condition, the optimal control packages are selected aim to minimize the slaughter plant's total costs; under the second condition, the optimal control packages are selected aim to minimize the slaughter plant's total costs based on the changes in governmental policies.

Table 3.1 summarizes the calculations of the model in three steps: Dynamic Programming (DP) is applied to determine the optimal control packages in the first step; in the second step, the expected total costs of the slaughter plant and the expected Salmonella prevalence levels of carcasses will be calculated with the steady-state situation; and in the last step, a series of incentive parameters will be introduced to simulate the impact of governmental intervention on the slaughter plant's decision makings.

Table 3.1 Three-steps calculations of the model

	First step	Second step	Third step
Aim	Determining the optimal control pacakges without governmental intervention	Economic analysis in the long-run transitions	Simulating the governmental impact on the slaughter plant's decision making
Method	Dynamic programming	Long-run markov chain properties	Dynamic programming

3.2 The optimal control strategies determination

The slaughter plant's problem can be analyzed in a discrete time, discrete sates and stochastic Markov decision model with the time measured in months. Miranda and Fackler (2005) denoted that discrete Markov decision models may be solved by the dynamic programming (DP) methods developed by Richard Bellman (1957). Application of DP methods requires six-step decision makings; includes determining the state variables, the decision variables, the stochastic variables, the transitions, the cost functions and the Bellman equation.

- ***State variables***

The model defines the state variables s, $s \in S$ as the numbers of reputed records obtained by the slaughter plant. Every month, the slaughter plant may hold one of three possible states: the state with two reputed testing records s_2, the sate with one reputed testing record s_1 and the sate with no reputed testing record s_0,. For the simplicity, in this study, the maximum number of the reputed testing records is two.

- ***Decision variables***

The decision variables are the Salmonella control packages x_k, $x_k = \begin{pmatrix} x_1 & x_2 & x_3 \end{pmatrix}$. There are three control packages are available in this study; each control package x_k is associated with a cost $c(x_k)$, a probability of testing p_{test} and a probability of passing the test $p_{pas}(x_k)$. Costs are increased from control package x_1 to control package x_3 and the intensities of control are increased with costs. The adoption of the more intensive control packages produces more chances of passing the quality test.

- ***Stochastic variables***

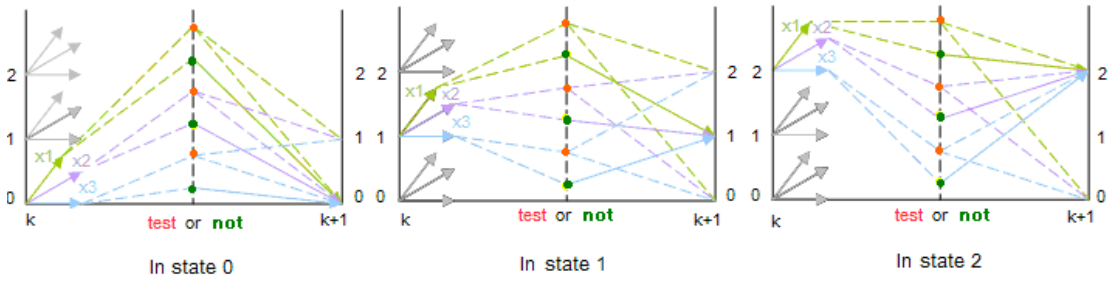
The stochastic variables r are analyzed in two phases: phase-one concerns about whether carcasses will be tested by the official authority, and phase-two refers to whether carcasses could pass the test. Phase one is conditional on phase two. The outcome of random variable in phase one

depends on the state s_i occupied by the slaughter plant and the control package x_k selected for Salmonella control. The outcome of random variable in the first phase and the effectiveness of the selected control package x_k determine the outcome of the random variable in the second phase together.

- ***Transitions***

In this study, the control actions of the slaughter plant are assumed as irreversible. The different control packages can be opted for different months. There is not correlated effect on outcomes between the different months. In figure 3.1, Each month, the slaughter plant occupies a state s_i, $s_i \in S$. By choosing a control package x_k, he may move to a new state s_j, $s_j \in S$. Transitions among states are monthly performed and denoted by T_{ij}. Given the stating state s_i, the selected control package x_k and the random variable r; one write the ending state s_j as: $s_j = T_{ij}(s_i, x_k, r)$. The transition probabilities of moving from state s_i to state s_j are denoted by P_{ij} and determined by the state variable s, the decision variable x_k and the outcome of the random variables r. Notation $P_{ij}(s_j \mid s_i, x_k, r)$ can be used to express this dependency.

Figure 3.1 States transitions



In figure 3.1, the first part represents the transitions started in state s_0, the second part represents the transitions started in state s_1 and the last part represents the transitions are started in state s_2. The red dots in the figure stand for carcasses are tested by the official authority, and the green dots shows that carcasses are exempted from the test. By choosing one of three control packages, the slaughter plant receives a probability of being tested p_{test} and a probability of passing the test p_{pas}. If the test are performed and carcasses are past in the test, the slaughter plant will move to state $s_i + 1$, when the next transition is started; if the carcasses are failed in the test, the slaughter

plant will move to state s_0 and pay for an amount of penalty $c(p)$; in case of carcasses are exempted from the test, the slaughter plant will stay in state s_i when the next transition is started. .

- ***Cost function and Bellman equation***

The cost optimality policies can be formulated in the form of Bellman equation $V(s_i)$. the model defines $V(s_i)$ in this study is :

$$V(s_i) = \max\left\{c(x_k) + \delta \sum_{s \in S} P_{ij}(s_j | s_i, x_k, r)\, V(s_j)\right\},\ \ s_i \in S,\ \ s_j \in S \qquad (3.1)$$

Where, s_i and s_j represent the starting states and the ending states in the transitions respectively, $c(x_k)$ stands for the cost function, δ is the discount factor, $0 \le \delta \le 1$, $V(s_j)$ represents the costs associated in the ending state s_j and $\delta \sum_{s \in S} P_{ij}(s_j | s_i, x_k, r)\, V(s_j)$ is the expected costs received in transitions.Due to the model has an infinite time horizon characteristics, therefore, the value function $V(s)$ is not dependent on the time and the Bellman equation is a vector fixed-point equation whose single unknown is the common value function V.

3.3 Steady-state probabilities

In an irreducible Markov chain, the steady-state probabilities exist after a huge number of transitions. The term steady-state probability means that the probability of finding the process in state s_j after a large number of transitions is independent of the initial probability distribution defined over the states s_i and tends to the value π_j. No matter where the transitions started, the probabilities of reaching all the ending states s_j are equivalent. With this property, the steady-state-probabilities matrix π can be constructed as:

$$\pi = \begin{bmatrix} \pi_1 & \pi_2 & \pi_3 \\ \pi_1 & \pi_2 & \pi_3 \\ \pi_1 & \pi_2 & \pi_3 \end{bmatrix}$$

There are three rows and three columns in matrix π. The rows represent the starting states s_i and the columns represent the ending states s_j. After the long-run transitions, If the distribution over states has reached the steady-state distribution represented by the $\pi_j s$ at time n, then the distribution over states at time n+1 is the same. This

characteristic can be used to derive directly the vector $\prod$ containing the stationary probabilities π_j, instead of making all the necessary time steps. Constructing the short-term transition matrix p with the optimal transition probabilities p_{ij}:

$$P = \begin{bmatrix} p_{11} & p_{12} & p_{13} \\ p_{21} & p_{22} & p_{23} \\ p_{31} & p_{32} & p_{33} \end{bmatrix}$$

The steady-state probabilities π_j can be obtained by the solving the equation $\prod = \prod P$ together with the property $\sum_{j=0}^{j=2} \pi_j = 1$. These include:

$$\pi_1 = p_{11} * \pi_1 + p_{21} * \pi_2 + p_{31} * \pi_3$$
$$\pi_2 = p_{12} * \pi_1 + p_{22} * \pi_2 + p_{32} * \pi_3$$
$$\pi_3 = p_{13} * \pi_1 + p_{23} * \pi_2 + p_{33} * \pi_3$$
$$1 = \pi_1 + \pi_2 + \pi_3$$

In matrix P, all the transition probabilities are calculated for using control package x_1, due to the minimum costs are accrued from using x_1 in each state s_i.

3.4 The impact of governmental interventions on the optimal control strategies

The aim of the slaughter plant is to reduce the intensity of the inspections and the intensities of the tests to realize cost minimization in the Salmonella control. Enlarging the probabilities of the test exemption and the probabilities of inspection release, the slaughter plant is impelled to invest on the costly control packages. Due to diminutions in either the inspections or the quality tests are determined by the intensities of Salmonella control. Incentive parameters defined in this study afford the chances to the government to adjust the testing and inspecting intensities on the slaughter plant. The impact of governmental interventions and the changes in the slaughter plant's decision makings will be demonstrated in this chapter.

3.4.1 Incentive parameters design

Base on the incentive parameters developed by King. et al., (2005), the set of parameters defined for this study is illustrated in table 3.2:

Table 3.2 Incentive parameters and relevant values

Definitions	parameters	Minimum value	Step size	Maximum value
Maximum testing probability parameter	α_0	0.1	0.01	0.9
Reduction testing probability parameter	α_1	0.1	0.01	0.9
Minimum testing probability parameter	α_2	0.1	0.01	0.6
Maximum inspecting probability parameter	β_0	0.1	0.01	0.9
Reduction inspecting probability parameter	β_1	0.1	0.01	0.9
Minimum inspecting probability parameter	β_2	0.1	0.01	0.6
Threshold of allowable serological prevalence	t_{sero}	1	1	4
Threshold of allowable bacteriological prevalence	t_{bac}	1	1	4
Penalties (€/carcass)	$c(p)$	0.0	0.5	4
Share of testing costs paid by the slaughter plant	γ	0.1	0.1	1
Share of inspecting costs paid by the slaughter plant	θ	0.1	0.1	1
State parameter	ns	2	1	2

Where, parameters α_0, α_1 and α_2 are defined for adjusting the testing probabilities; parameters β_0, β_1 and β_2 are defined for adjusting the inspecting probabilities; parameter t_{sero} is used to alter the strictness of the serological test on the farm level, parameter t_{bac} is for altering the bacteriological test on the slaughter plant level, and parameters $c(p), \gamma$, θ and ns are defined for regulating the ending state costs $V(s_j)$,. The values of these parameters are altered between the upper bound and the lower bound with the relevant step sizes illustrated in table 3.2. The network of the set of incentive parameters are demonstrated in figure 3.2.

Figure 3.2 Network of incentive parameters

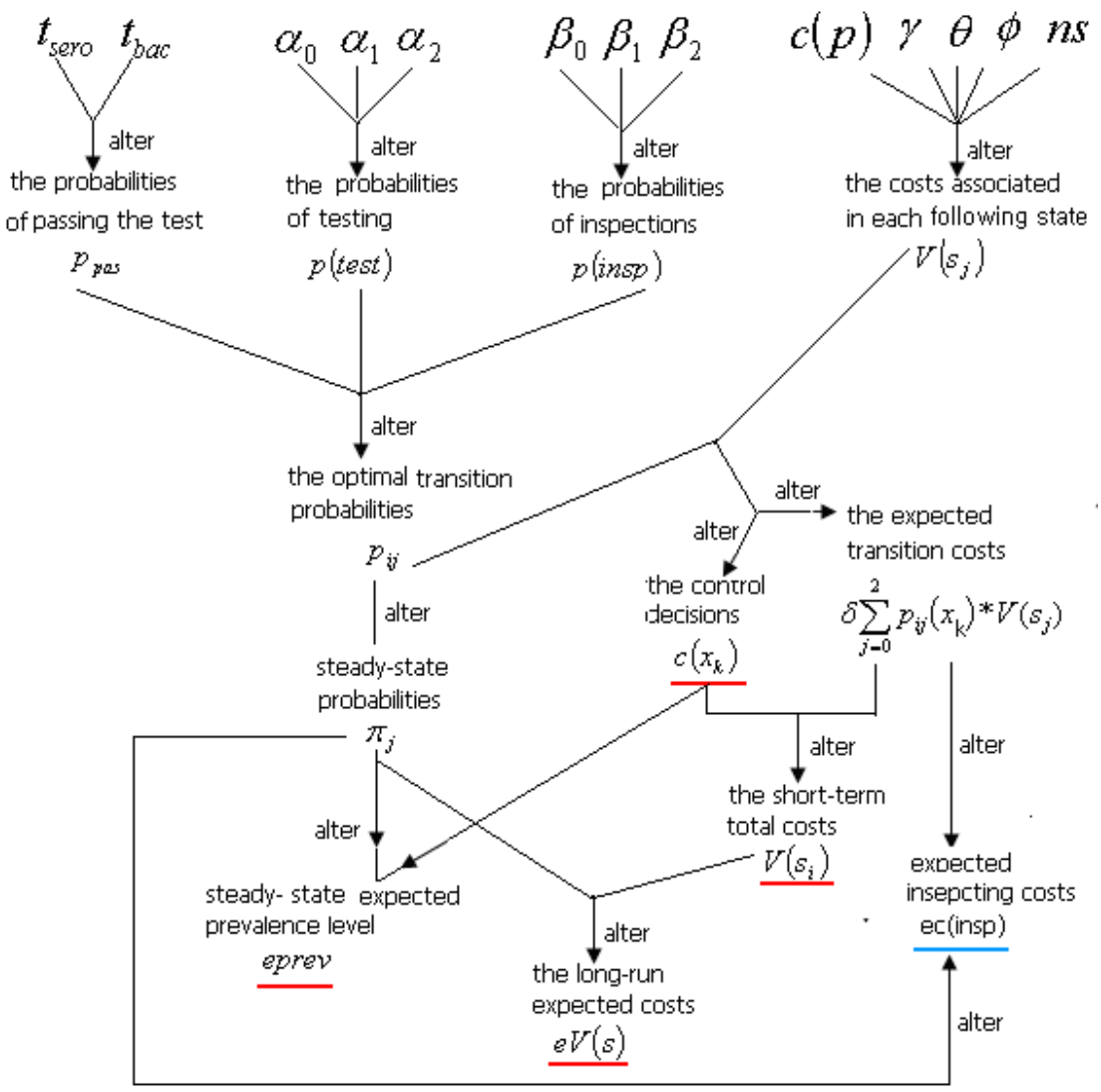


Figure 3.2 is read from the top down. During the transitions, parameter $c(p)$, γ, θ and ns may directly change the costs $V(s_j)$ associated in the ending states. And parameter t_{sero}, t_{bac}, α_0, α_1, α_2, β_0, β_1 and β_2 may indirectly alter the value of transition probabilities p_{ij}. Through changing the value of p_{ij} and the value $V(s_j)$, the government can influence the slaughter plant's decision making and therefore change the short-term total costs $V(s_i)$, the long-run expected prevalence level $eprev$, the long-run expected costs $eV(s)$ and the expected inspecting costs $ec(insp)$. The focus of this study is to analyze the changes in the slaughter plant's expected inspecting costs, the changes in the short-term total costs, the changes in the slaughter plant's decision making, and the changes in the long-run expected prevalence level

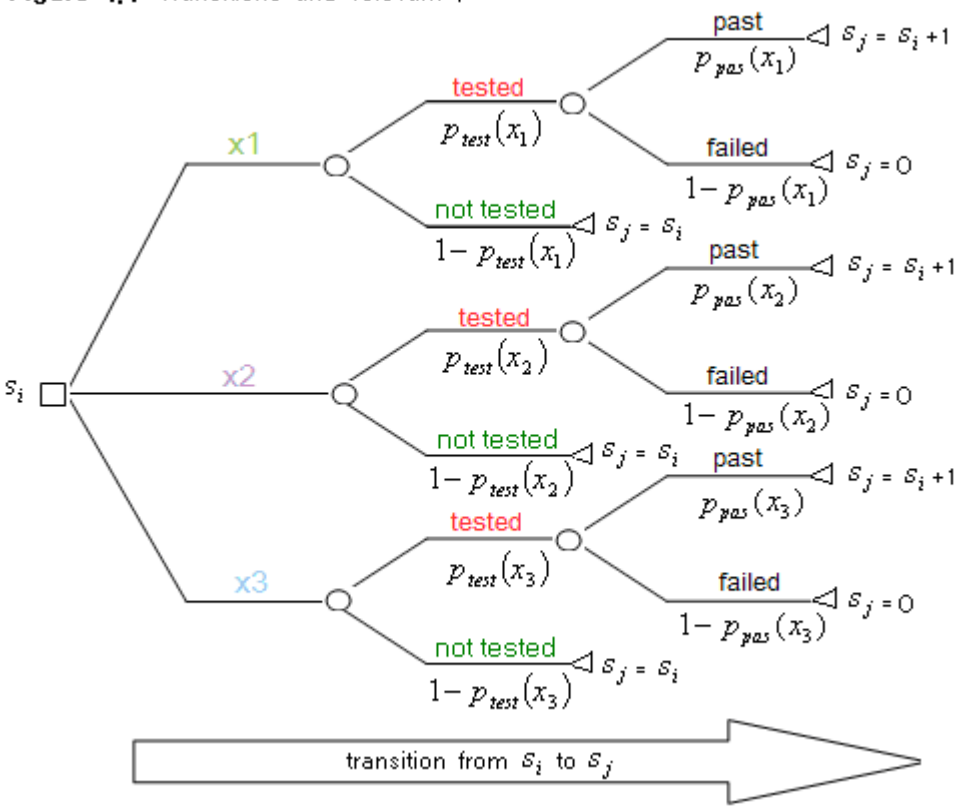
and expected total costs, through assigning the different values to the set of parameters.

Chapter 4 Empirical study

4.1 Transition probabilities

The empirical calculations of transition probabilities p_{ij} are illustrated in figure 4.1 and table 4.1.

Figure 4.1 Transitions and relevant probabilities



This decision tree is consisted of three parts: the left part represents the decision variables x_k; the middle part represents the testing probabilities $p_{test}(x_k)$; and the right part represents the probabilities of passing the test $p_{pas}(x_k)$. The ending points of the tree stand for the ending sates s_j in the transitions. Values of these transition probabilities p_{ij} can be calculated in table 4.1:

Table 4.1 Following states and transition probabilities

Following state s_j	Transition probabilities p_{ij}	
$s_j = s_i + 1$	$p_{test}(x_k) * p_{pas}(x_k)$	Testing probability * passing probability
$s_j = s_i$	$1 - p_{test}(x_k)$	Probability of exempting from the test
$s_j = s_0$	$p_{test}(x_k) * (1 - p_{pas}(x_k))$	Testing probability * failing probability

The transition probabilities p_{ij} are distinct from the long-run transition (steady-sate) probabilities π_j. The long-run transition probabilities for calculating the expected Salmonella prevalence levels will be described later.

- ***Inspecting probabilities & testing probabilities***

The model defines the intensities of official inspections p_{insp} are dependent on the state variables s_i. The number of the reputed records s_i declined, the intensities of inspections are increased. This relation is written by equation 3.2.

$$p_{insp} = e^{-s_i} \qquad (4.1)$$

$$p_{test} = e^{-(s_i + p_{pas}(x_k))} \qquad (4.2)$$

In equation 3.3, the probability of testing is dependent on both of the state variables s_i and the effectiveness of control package p_{pas}. Beside the impact of the state variable s_i performed on the testing probabilities p_{test}, the effectiveness of control p_{pas} may also swing the testing intensities. At the moment of transitions are started in the low state s_i, such as $s_i = s_0$, the adoption of the intensive control packages may compensate the testing probabilities that enlarged by the weak states s_i.

- ***Probabilities of passing the test (effectiveness of control)***

The probabilities of passing the quality test p_{pas} represent the effectiveness of the selected control package x_k. Calculation of the passing probability p_{pas} requires five

vectors and five matrixes that constructed from the previous research conducted by van der Gaag et al.,(2004b) and by king et al., (2005). Table 3.3 shows the required matrixes and the relevant notations as follows:

Table 4.2 Matrixes & vectors for calculating the probabilites of passing the test

Matrixes & vectors	Notations
The vector of the probabilities of using each farm control package y_k	$\underline{a}$, $\underline{a} \in R^4$
The matrix of farm-level (serological) prevalence probability distributions for four control package y_m, $m = 1,2,3,4$	$A^{11\times4}$
The vector of expected serological prevalence probability distributions	$\underline{b}$, $\underline{b} \in R^{11}$
The matrix of serology - bacteria transition probabilities for slaughter plant control package x_1	$B_1^{11\times11}$
The matrix of serology - bacteria transition probabilities for slaughter control package x_2	$B_2^{11\times11}$
The matrix of serology - bacteria transition probabilities for slaughter control package x_3	$B_3^{11\times11}$
The vector of expected bacteriological prevalence probability distributions for slaughter control package x_1	$\underline{c}_1$, $\underline{c}_1 \in R^{11}$
The vector of expected bacteriological prevalence probability distributions for slaughter control package x_2	$\underline{c}_2$, $\underline{c}_2 \in R^{11}$
The vector of expected bacteriological prevalence probability distributions for slaughter control package x_3	$\underline{c}_3$, $\underline{c}_3 \in R^{11}$
The matrix of slaughter plant-level (bacteriological) prevalence probability distributions for three control package x_k, $k = 1,2,3$	$C^{11\times3}$
The matrix of cumulative allowable prevalence probability distributions for three control package x_k, $k = 1,2,3$	$D^{4\times3}$

Matrix A, matrix B_1, matrix B_2 and matrix B_3 are consisted of the result of the epidemiological simulation model that described by van der Gaag et al., (2004b). Vector $\underline{b}$, $\underline{c}_1$, $\underline{c}_2$, $\underline{c}_3$ and matrix C and D are calculated by the existing results. The algorithms of the serology-bacteriology transitions and the effectiveness p_{pas} of the slaughter plant control package x_k are illustrated as follows:

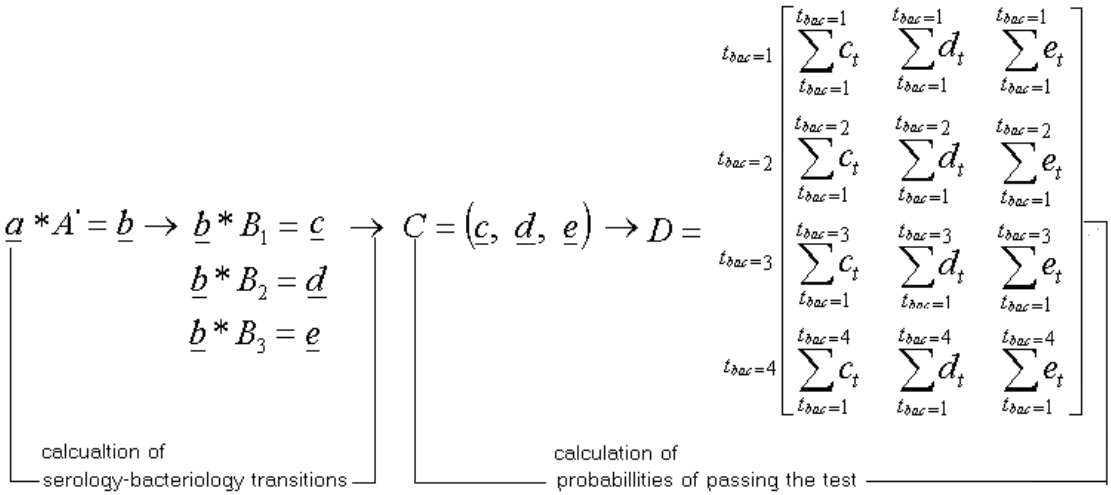


Figure 4.2 Serology-bacteriology transitions and the probability of passing the test

Figure 4.2 consisted of two parts of calculations. The first part is to calculate the serology-bacteriology transitions between herds and carcasses. The second part is to calculate the effectiveness p_{pas} of control packages x_k with the result obtained in the first part. Where, parameter t_{bac} denoted in matrix D represents the bacteriological threshold set to the slaughter plant by the government. Explanations for each step calculation are illustrated as follows.

--- *Calculations of the serology-bacteriology transitions*

This part of calculation is aimed to acquire the bacteriological prevalence distribution matrix C, through calculating the serology-bacteriology transition distributions. The relevant vectors $\underline{a}$, $\underline{b}$, $\underline{c}$, $\underline{d}$, $\underline{e}$ and the required matrixes A, B_1, B_2, B_3 in this part will be described in turn.

Vector $\underline{a}_{t_{sero}}$

$$\underline{a}_{t_{sero}} = \begin{pmatrix} a_{y_1} & a_{y_2} & a_{y_3} & a_{y_4} \end{pmatrix}$$

Vector $\underline{a}_{t_{sero}}$, $\underline{a}_{t_{sero}} \in R^4$ is constructed by the result of the existing model that developed by king et al., (2005). It is related to the farm-level serological prevalence control. In that model, there are four serological control packages y_m, $y_m = (y_1, y_2, y_3, y_4)$ are distinguished, each control package associated with a cost. Intensities of control are increased with costs. From y_1 to y_4, the intensities of control

are gradually increased. Each control package y_m has a probability of being used on farms. For instance, the element a_{y1} represents the probability of control package y_1 is used by farmers, and element a_{y1} represent control package y_2 is used by farmers.

Matrix A

$$A^{11\times4} = \begin{array}{c} \\ 0 \\ 10 \\ \vdots \\ 100 \end{array} \begin{array}{c} \begin{array}{cccc} y_1 & y_2 & y_3 & y_4 \end{array} \\ \begin{bmatrix} a_{0y_1} & a_{0y_2} & a_{0y_3} & a_{0y_4} \\ a_{10y_1} & a_{10y_2} & a_{10y_3} & a_{10y_4} \\ \vdots & \vdots & \vdots & \vdots \\ a_{100y_1} & a_{100y_2} & a_{100y_3} & a_{100y_4} \end{bmatrix} \end{array}$$

Matrix A applies the result of the Van der Gaag's survey conducted in 2005. it denotes the serological prevalence distributions of herds for each control package y_m .The rows of the matrix represent the eleven serological prevalence levels, $sprev \in (0 \quad 10 \quad \cdots \quad 100)$. The columns of the matrix represent the four distinct control packages y_m . The elements of the matrix, for instance, a_{10y_2} , represent the probability of realizing the prevalence is ten in herds by using control package y_2

Vector $\underline{b}$

$$\underline{b} = \underline{a} * A' = (b_0 \quad b_{10} \quad \cdots \quad b_{100})$$

The inner product of vector $\underline{a}$ and matrix A' generates vector $\underline{b}$. There are eleven elements contained in vector $\underline{b}$, represent the expected serological prevalence distributions in the long-run transitions. For instance, b_{10} represents the probability of realizing the prevalence is ten in herds in the long-run transitions, and b_{20} represents probabilities of realizing the prevalence is twenty in herds in the long-run transitions.

Matrix B_1 , B_2 and B_3

$$B_1 = \begin{array}{c} \\ 0 \\ \vdots \\ 100 \end{array} \begin{bmatrix} & & \\ bac_{0_{ser\,0}} & \cdots & bac_{100_{ser\,0}} \\ \vdots & \cdots & \vdots \\ bac_{0_{ser\,100}} & \cdots & bac_{100_{sero100}} \end{bmatrix}$$

Matrix B_1, B_2 and B_3 are the serology-bacteriology transition matrixes. B_1, B_2 and B_3 represent the prevalence transition distributions for using bacteriological control package x_1, x_2, and x_3 on the slaughter-plant level respectively. The transition matrixes are unit matrixes. There are eleven rows and eleven columns in all the transition matrixes: rows represent the serological prevalence of the slaughtered herd and columns denote the bacteriological prevalence of carcasses. For matrix B_1, the element $bac_{10_{ser\,20}}$ represents the bacteriological prevalence distribution of carcasses on the ten per cent level when the serological prevalence of the herd slaughtered is twenty per cent by using bacteriological control package x_1 on the slaughter plant-level.

Vector $\underline{c}$, $\underline{d}$, $\underline{e}$ and matrix C

$$\underline{c} = \begin{pmatrix} bac_{0y_1} \\ \vdots \\ bac_{100y_1} \end{pmatrix} \underline{d} = \begin{pmatrix} bac_{0y_2} \\ \vdots \\ bac_{100y_2} \end{pmatrix} \underline{e} = \begin{pmatrix} bac_{0y_3} \\ \vdots \\ bac_{100y_3} \end{pmatrix} \rightarrow C = \begin{bmatrix} \underline{c} & \underline{d} & \underline{e} \end{bmatrix}$$

The inner product of vector $\underline{b}$ and matrix B_1 produces vector $\underline{c}$; the inner product of vector $\underline{b}$ and matrix B_2 produces vector $\underline{d}$ and the inner product of vector $\underline{b}$ and matrix B_3 produces vector $\underline{e}$. There are eleven elements in all the vectors $\underline{c}$, $\underline{d}$ and $\underline{e}$ represent the bacteriological prevalence distributions after serology-bacteriology transitions by using bacteriological control package on the slaughter plant-level. Vector $\underline{c}$ denotes the distributions for control package x_1; vector $\underline{d}$ denotes the distributions for control package x_2 and vector $\underline{e}$ denotes the distributions for control package x_3. Constructing matrix C with vector $\underline{c}$, $\underline{d}$ and $\underline{e}$, matrix C is the bacteriological prevalence distribution matrix after prevalence serology-bacteriology transitions.

-- *Calculating the probabilities of passing the test*

This part of calculation is aimed to get the effectiveness (passing probabilities) of each control package x_k. Symbol t in matrix D denotes the threshold level of the allowable prevalence in carcasses. The official authority can assign the different values to t to alter the strictness of the quality tests.

$$C = \begin{array}{c} \\ 0 \\ 10 \\ \vdots \\ 100 \end{array} \begin{array}{c} \begin{array}{ccc} x_1 & x_2 & x_3 \end{array} \\ \begin{bmatrix} c_0 & d_0 & e_0 \\ c_{10} & d_{10} & e_{10} \\ \vdots & \vdots & \vdots \\ c_{100} & d_{100} & e_{100} \end{bmatrix} \end{array}$$

In matrix C, there are eleven rows and three columns. The rows represent the bacteriological prevalence probability distributions and the columns represent the bacteriological control packages x_k. For instance, column $\underline{c}$ stands for the prevalence distribution of using control package x_1 and column $\underline{d}$ is the prevalence distribution of using control package x_2.The element c_{10} in column $\underline{c}$ represents the probabilities of carcasses' prevalence reaches in the second level, ten, by using control package x_1. And the element d_{30} in column $\underline{d}$ represents the probabilities of carcasses' prevalence reaches in fourth level, thirty, by using control package x_2. The rows of matrix D stand for the different threshold level t and are calculated by summing up one or several rows in matrix C. For instance, the second row of matrix D is calculated by summing up the first two rows of matrix C. And the third row of matrix D is calculated by summing up the first three rows of matrix C. The cumulative probabilities in matrix D express the effectiveness p_{pas} of the selected control package x_k. The first column of matrix D stands for the effectiveness of control package x_1, and the second and the third columns of matrix D strand for the effectiveness of control package x_2 and x_3. When the allowable threshold t is one, the slaughter plant receives the lowest cumulative probabilities p_{pas} of passing the test (symbolized by the first row of matrix D). And when the threshold t_{bac} is four, the largest probabilities p_{pas} (symbolized by the fourth row of matrix D) are

received by the slaughter plant.

4.2 Following states and associated costs

During the sate transitions, each following (ending) sate s_j associated with one or several costs, include the testing costs $c(test)$, the expected inspecting costs $ec(insp)$ and the penalties $c(p)$. The amounts of the costs are altered with the ending sates s_j as illustrated in table 3.3.

Tabel 4.3 Following states and associated costs

Following states s_j	$s_j = s_i + 1$	$s_j = s_i$	$s_j = s_0$
Testing costs $c(test)$	✓		✓
Expected inspecting costs $ec(insp)$	✓	✓	✓
Penalty $c(p)$			✓
Costs $V(s_i)$	$c(test) + ec(insp)$	$ec(insp)$	$c(test) + ec(insp) + c(p)$

The model defines the testing $c(test)$ and the expected inspecting costs $ec(insp)$ are associated in the ending state $s_i + 1$; the single payment of the expected inspections $ec(insp)$ is associated in the ending state s_i and the testing costs $c(test)$, the inspecting costs $ec(insp)$ together with the penalties $c(p)$ are associated in the ending state s_0. Therefore the highest costs are appeared in the ending state s_0 and the lower costs are occurred in the ending states s_i and $s_i + 1$. Besides, the expected inspection costs are decreased as the state variable s_j is improved. In the high ending state $s_j = s_{i+1}$, the intensities of inspections are dropped down to lowest level $p(insp) = e^{s_i+1}$, whereas, in the low ending state $s_j = s_0$, the intensities of inspections are raised to the highest level $p(insp) = e^0$.

4.3 The total expected costs in the long-run transitions

The long-run expected costs are denoted by $eV(s_i)$ and calculated by multiplying the steady-state probabilities π_j with the total costs $V(s_i)$:

$$eV(s_i) = \sum_{i=0}^{i=1} \sum_{j=0}^{j=1} V(s_i) * \pi_j \qquad (4.4)$$

It is notable that the total costs $V(s_i)$ appeared in equation 4.4 are the minimum costs that generated by using the optimal control package x_1 in the current transitions.

4.4 The expected prevalence level in the long-run transitions

The expected prevalence levels in the long-run transitions are denoted by *eprev* and calculated by multiplying the vector $\underline{l}$ with the inner product of the prevalence vector *bprev* and matrix C:

$$eprev = bprev * C * \underline{l} \qquad (4.5)$$

Where, *bprev* represents the eleven bacteriological prevalence levels: $bprev = (0 \quad 10 \quad \cdots \quad 100)$. Matrix C denotes the bacteriological prevalence distributions calculated in figure 4.2, and vector $\underline{l}$, $\underline{l} = (l_1 \quad l_2 \quad l_3)$ represents the probabilities each control package x_k will be used by the slaughter plant. Algorithm of $\underline{l}$ can be demonstrated with figure 4.3 and figure 4.4 as follows:

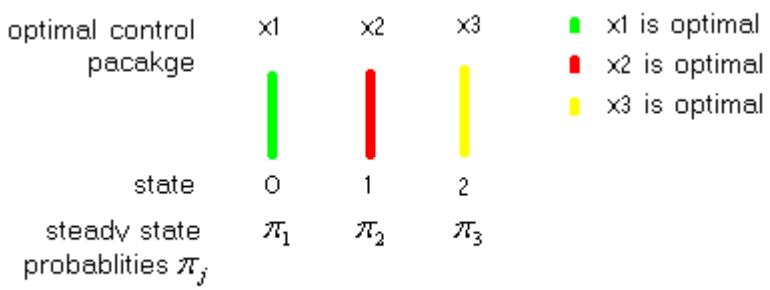


Figure 4.3 Optimal control package for each state

The green line of figure 4.3 represents the optimal control package x_1, the red line represents the optimal control package x_2 and the yellow line represents the optimal control package x_3. In case of figure 4.3, the optimal control package is x_1 in state s_0, x_2 in state s_1 and x_3 in state s_2. The steady-state probabilities for state s_0, s_1 and s_2 are π_1, π_2 and π_3 respectively. Therefore,

The probability of using control package x_1 is $l_1 = \pi_1$;

The probability of using control package x_2 is $l_2 = \pi_2$;

The probability of using control package x_3 is $l_3 = \pi_3$.

However, in the case calculated in this study, the optimal control package is x_1 for all the states s_i, as illustrated in figure 4.4 below. Therefore:

The probability of using control package x_1 becomes $l_1 = \pi_1 + \pi_2 + \pi_3 = 1$;

The probability of using control package x_2 becomes $l_2 = 0$;

The probability of using control package x_3 becomes $l_3 = 0$.

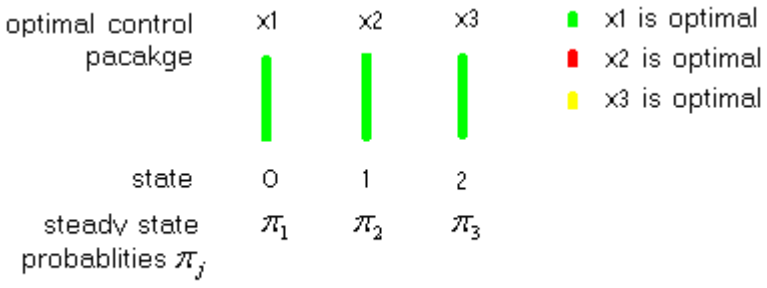


Figure 4.4 Optimal control package for each state in this study

In equation 4.5, Vector $\underline{f}$ represents the eleven bacteriological prevalence levels:

$$\underline{f} = (0 \quad 10 \quad \cdots \quad 100)$$

From zero to a hundred, the increased step of the prevalence levels is ten. The inner product of matrix C and vector $\underline{f}$ generates the short-term expected prevalence

vector $\underline{v}$, $\underline{v} \in R^3$.

$$\underline{v} = \underline{f} * C^{11\times 3} = (v_1 \quad v_2 \quad v_3)$$

Each element of $\underline{v}$ represents the expected prevalence level for using control package x_k in a short-term transition. After multiplying vector $\underline{l}$ with $\underline{v}$, the long-run expected prevalence level *eprev* is calculated.

4.5 Incentive parameters application

4.5.1 Testing and inspecting probabilities parameters

Appending the parameters β_0, β_1 and β_2 to equation 4.1 and the parameters α_0, α_1 and α_2 to equation 4.2, the new expressions of inspecting probabilities $p(insp)$ and testing probabilities $p(test)$ are defined as:

$$p(insp) = \max(\beta_0 * e^{-\beta_1 * s}, \beta_2) \qquad 4.6$$

$$p(test) = \max(\alpha_0 * e^{-\alpha_1 * (s + p_{pas}(x_k))}, \alpha_2) \qquad 4.7$$

$$p(insp) = \begin{cases} \beta_0 * e^{-\beta_1 * s} & if \quad \beta_0 * e^{-\beta_1 * s} \geq \beta_2 \\ \beta_2 & if \quad \beta_0 * e^{-\beta_1 * s} \leq \beta_2 \end{cases} \qquad 4.8$$

$$p(test) = \begin{cases} \alpha_0 * e^{-\alpha_1 * (s + p_{pas}(x_k))} & if \quad \alpha_0 * e^{-\alpha_1 * s} \geq \alpha_2 \\ \alpha_2 & if \quad \alpha_0 * e^{-\alpha_1 * s} \leq \alpha_2 \end{cases} \qquad 4.9$$

In equation 4.6, there are four variables determine the inspecting probabilities $p(insp)$: the maximum inspecting probability β_0, the reduction probability β_1, the minimum inspecting probability β_2 and the starting state of transitions s_i. If keep the state variable s_i constant, then the inspecting probabilities $p(insp)$ are determined with β_0 and β_1, when $\beta_0 * e^{-\beta_1 * s} \geq \beta_2$ exist, and determined with β_2, when $\beta_0 * e^{-\beta_1 * s} \leq \beta_2$ exist. In case of $\beta_0 * e^{-\beta_1 * s} \geq \beta_2$, the inspecting probabilities

$p(insp)$ are decreased with β_1 and increased with β_0. The smaller values of β_0 together with the larger values of β_1 generate the lower inspecting probabilities $p(insp)$. In case of $\beta_0 * e^{-\beta_1 * s} \leq \beta_2$, the inspecting probabilities $p(insp)$ are increased with β_0. Lessening the value of β_0 reduces the probabilities of inspections $p(insp)$. The same theorem is also applied to the equation 4.8 and 4.9 for parameters α_0, α_1 and α_2.

4.5.2 Test threshold parameters

- *Serological threshold parameter* t_{sero}

The serological threshold parameter t_{sero} has four possible values, $t_{sero} = (1, \ 2, \ 3, \ 4)$. Each value associated with a vector $\underline{a}_{t\,sero}$ which is obtained from the existing model.

Table 4.4 Serological thresholds and relevant vectors

Threshold		Associated vectors			
		y1	y2	y3	y4
$t_{sero} = 4$	$\rightarrow \underline{a}_4$	$\underline{a}_4 =$ (0.67	0	0.33	0)
$t_{sero} = 3$	$\rightarrow \underline{a}_3$	$\underline{a}_3 =$ (0.61	0	0.39	0)
$t_{sero} = 2$	$\rightarrow \underline{a}_2$	$\underline{a}_2 =$ (0.01	0	0.99	0)
$t_{sero} = 1$	$\rightarrow \underline{a}_1$	$\underline{a}_1 =$ (0.00	0	0.00	1)

The first element in each vector represent the probabilities of serological control package y_1 is used on farms; the second element represent the probabilities of serological control package y_2 is used on farms; the third and the fourth element represent the probabilities of y_3 and y_4 are used respectively. When the allowable threshold t_{sero} is set by one, only the most intensive control package y_4 can be

selected and the rests have no possibilities of being used on farms. When the allowable threshold t_{sero} is set by the highest value, four, the least intensive control package y_1 associated with the largest probability of being used on farms, whereas, the most intensive control package y_4 will not be used on farms. Therefore, the probability of adopting the most intensive control package is reduced as the value of threshold parameter t_{sero} is increased.

It is notable that the value of vector $\underline{a}_{t_{sero}}$ determines the bacteriological prevalence distributions of carcasses. Remember the algorithm of bacteriological prevalence distribution matrix C demonstrated in figure 3.3

$$\underline{a}_{t_{sero}} * A^{\cdot} = \underline{b} \rightarrow \begin{matrix} \underline{b} * B_1 = \underline{c} \\ \underline{b} * B_2 = \underline{d} \\ \underline{b} * B_3 = \underline{e} \end{matrix} \rightarrow C = (\underline{c},\ \underline{d},\ \underline{e})$$

calcualtion of serology-bacteriology transitions

The lower threshold value produces the fewer chances of passing the test, and thus increases the slaughter plant's incentives of adopting the costly control packages.

- *Bacteriological threshold parameter* t_{bac}

Parameter t_{bac} is related to the matrix D which is illustrated in figure 3.3.

$$C = (\underline{c},\ \underline{d},\ \underline{e}) \rightarrow D = \begin{matrix} & x1 & x2 & x3 \\ t_{bac}=1 \\ t_{bac}=2 \\ t_{bac}=3 \\ t_{bac}=4 \end{matrix} \begin{bmatrix} \sum_{t=1}^{1} c_t & \sum_{t=1}^{1} d_t & \sum_{t=1}^{1} e_t \\ \sum_{t=1}^{2} c_t & \sum_{t=1}^{2} d_t & \sum_{t=1}^{2} e_t \\ \sum_{t=1}^{3} c_t & \sum_{t=1}^{3} d_t & \sum_{t=1}^{3} e_t \\ \sum_{t=1}^{4} c_t & \sum_{t=1}^{4} d_t & \sum_{t=1}^{4} e_t \end{bmatrix}$$

When the threshold equals t_{bac} four, the probabilities of passing the bacteriological

test p_{pas} for using each bacteriological control package x_k are represented by the fourth row of matrix D:

$p_{pas}(x_1) = \sum_{t_{bac}=1}^{t_{bac}=4} c_{t_{bac}} = c_1 + c_2 + c_3 + c_4$, probability of passing the test by using x_1

$p_{pas}(x_2) = \sum_{t_{bac}=1}^{t_{bac}=4} d_{t_{bac}} = d_1 + d_2 + d_3 + d_4$, probability of passing the test by using x_2

$p_{pas}(x_3) = \sum_{t_{bac}=1}^{t_{bac}=4} e_{t_{bac}} = e_1 + e_2 + e_3 + e_4$, probability of passing the test by using x_3

When the threshold t_{bac} equals two, the probabilities of passing the bacteriological test p_{pas} for using each bacteriological control package x_k are represented by the second row of matrix D:

$p_{pas}(x_1) = \sum_{t_{bac}=1}^{t_{bac}=2} c_{t_{bac}} = c_1 + c_2$, probability of passing the test by using x_1

$p_{pas}(x_2) = \sum_{t_{bac}=1}^{t_{bac}=2} d_{t_{bac}} = d_1 + d_2$, probability of passing the test by using x_2

$p_{pas}(x_3) = \sum_{t_{bac}=1}^{t_{bac}=2} e_{t_{bac}} = e_1 + e_2$, probability of passing the test by using x_3

Therefore, the value of threshold t_{bac} determines the strictness of the bacteriological test and influences the probabilities of passing the bacteriological test p_{pas}. the lower threshold value brings more incentives to slaughter plant to apply the more intensive control package.

4.5.3 Cost sharing parameters and penalties

After adding the cost sharing parameter γ and θ into the model, the testing cost $c(test)$ and the inspecting cost $c(insp)$ becomes:

$c(test) = \gamma * c(test)$ testing costs

$c(insp) = \theta * c(insp)$ inspecting costs

Increasing the penalties $c(p)$ and the value of parameter γ and θ, the slaughter plant's incentives in adopting the more intensive control packages are increased.

4.5.4 State parameter *ns*

The model described above, there are three states are available for the state transitions. The parameter *ns* equals two and the minimum testing and inspecting probabilities are e^{-2} and $e^{-(2+p_{pas})}$ respectively. If the government determines that there are six states can be available for transitions, then the parameter *ns* becomes five and the minimum testing and inspecting probabilities are reduced to e^{-6} and $e^{-(6+p_{pas})}$ respectively. Therefore, increasing the value of the state parameter *ns*, the slaughter plant gets the more incentives of adopting the intensive control package to obtain the least probabilities of being inspected and tested.

4.5.6 Altering tendencies of parameters

The impact of governmental intervention is analyzed for each bacteriological threshold level. From the left to the right, the values of the parameter α_0, β_0 and $c(p)$ are gradually increased, whereas, the values of parameters α_1, β_1 and t_{sero} are gradually declined and the parameters α_2, β_2 γ, θ and *ns* are kept on constant. The larger value of parameter α_1 and β_1 and the smaller value of parameter α_0, β_0 and $c(p)$ are always set under the smaller value of serological threshold. By this way, the government has increased the slaughter plant's incentives of adopting the costly control packages on each bacteriological threshold level from the left to the right.

5. RESULT

5.1 No governmental interventions

The results illustrated in this section represent the situation when there is no governmental intervention. It is presented to compare the results of other scenarios.

Table 5.1 Restult for there is no governmental intervention

State s_i	The optimal control package x^*	Steady-state probabilities π_j	Steady-state expected total costs $eV(s)$	Steady-state expected prevalence levels $eprev$
$s_i = s_0$	$x^* = x_1$	0.006		
$s_i = s_1$	$x^* = x_1$	0.016		
$s_i = s_2$	$x^* = x_1$	0.978		
			3.55 (€/ carcass)	1.22 (€/ carcass)

5.2 With governmental intervention

Threshold for slaughter plant t_{bac}		4	4	4	4	3	3	3	3	2	2	2	2	1	1	1	1
Threshold for farmers t_{sero}		1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4
Incentive parameters																	
Maximum testing parameter α_0		0.25	0.48	0.70	0.90	0.27	0.42	0.64	0.75	0.21	0.46	0.66	0.87	0.18	042	0.64	0.78
Reduction testing parameter α_1		0.67	0.43	0.21	0.19	0.64	0.51	0.33	0.40	0.62	0.48	0.24	0.20	0.59	043	0.27	0.21
Minimum testing parameter α_2		0.00	0.00	0.00	0.00	0.00	0.00	0.0	0.0	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Maximum inspecting parameter β_0		0.24	0.46	0.68	0.90	0.27	0.41	0.59	0.73	0.20	0.44	0.63	0.74	0.19	0.39	0.60	0.71
Reduction inspecting parameter β_1		0.64	0.41	0.18	0.17	0.62	0.49	0.31	0.18	0.68	0.35	0.25	0.19	0.67	0.43	0.31	0.25
Minimum inspecting parameter β_2		0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Penalties **c(p)**		0.5	1.0	2.0	2.5	0.5	1.0	1.5	2.0	0.5	1.0	1.5	2.0	0.5	1.5	2.0	2.5
Sharing of testing costs γ		1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
Sharing of inspecting costs θ		1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
Maximum state **ns**		2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2
Performance measures																	
Optimal control package x^*	State S_0	1	1	1	1	1	1	1	2	1	1	1	3	1	1	1	3
	State S_1	1	1	1	1	1	1	1	2	1	1	1	3	1	1	1	3
	State S_2	1	1	1	1	1	1	1	2	1	1	1	2	1	1	1	3
Short-term total costs	State S_0	1.1425	1.1869	1.2479	1.2530	1.1474	1.1750	1.2155	1.2650	1.1364	1.1827	1.22678	1.2445	1.1338	1.1749	1.2195	1.2729

$V(s_i)$	State s_1	1.1227	1.1589	1.2236	1.2239	1.1260	1.1470	1.1861	1.2381	1.1192	1.1571	1.200	1.2137	1.1180	1.1500	1.1911	1.2463
	State s_2	1.1120	1.1395	1.2031	1.1999	1.1141	1.1291	1.1637	1.2151	1.1100	1.1392	1.1799	1.1899	1.1095	1.1330	1.1691	1.2237
Steady-state probabilities π_j	State s_0	0.007	0.020	0.056	0.038	0.006	0.016	0.013	0.039	0.007	0.017	0.015	0.027	0.008	0.018	0.014	0.062
	State s_1	0.012	0.029	0.064	0.044	0.012	0.025	0.017	0.045	0.013	0.026	0.019	0.037	0.013	0.027	0.018	0.069
	State s_2	0.981	0.951	0.880	0.918	0.982	0.959	0.970	0.916	0.980	0.958	0.967	0.936	0.979	0.955	0.968	0.869
Expected inspecting costs		0.512	0.520	0.528	0.522	0.512	0.515	0.514	0.522	0.508	0.516	0.515	0.519	0.512	0.516	0.514	0.530
Long-run expected total costs		1.1136	1.1410	1.2069	1.2030	1.1243	1.1303	1.1647	1.2181	1.1103	1.1404	1.1810	1.1923	1.1098	1.1342	1.1702	1.2283
Expected prevalence level for using each control package in the short-term transitions	x_1	0.6174	1.2725	3.3497	3.5502	0.6174	1.2725	3.3497	3.5502	0.6174	1.2725	3.3497	3.5502	0.6174	1.2725	3.3497	3.5502
	x_2	0.3087	0.6362	1.6749	1.7751	0.3087	0.6362	1.6749	1.7751	0.3087	0.6362	1.6749	1.7751	0.3087	0.6362	1.6749	1.7751
	x_3	0.1287	0.5913	1.6558	1.7586	0.1287	0.5913	1.6558	1.7586	0.1287	0.5913	1.6558	1.7586	0.1287	0.5913	1.6558	1.7586
Probabilities of each control package being used by the slaughter plant $\underline{l}$	x_1	1.0	1.0	1.0	1.0	1.0	1.0	1.0	0.0	0.0	1.0	1.0	0.0	1.0	1.0	1.0	0.0
	x_2	0.0	0.0	0.0	0.00	0.0	0.0	0.0	1.0	0.0	0.0	0.0	0.064	0.0	0.0	0.0	0.0
	x_3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1.0	0.0	0.0	0.936	0.0	0.0	0.0	1.0
Steady state expected prevalence level in the long-run transitions *eprev*		0.6174	1.2725	3.3497	3.5502	0.6174	1.2725	3.3497	1.7751	0.6174	1.2725	3.3497	1.7597	0.6174	1.2725	3.3497	1.7586

Table 3.8

From the result present in section 5.1 and the result present in section 5.2, we can see the changes of the slaughter plant in selecting the optimal control strategies. In section 5.1, the slaughter plant chooses the cheapest control package for each state and generates the relative high expected prevalence levels. After adding the governmental interventions, in the section 5.2, the slaughter plant keeps using control package one when bacteriological threshold value t_{bac} is relaxed and the serological threshold value t_{sero} is strict. However, when the bacteriological threshold is strict and the serological threshold is relaxed, the slaughter plant changed the optimal control strategies to the more costly control packages x_2 and x_3, and thus reduces the expected prevalence level in carcasses. On each bacteriological

threshold level, form the left to the right, the probability of meat inspection is gradually reduced, but this reduction is consistent with the adoption of the costly control packages.

5.3 Impact of the governmental intervention on the slaughter plant's optimal control decisions

The result shows: 1) the adoption of the more costly Salmonella control packages at the slaughter plant level increases as the bacteriological threshold is reduced; 2) when serological threshold is set strict to the farms, the slaughter plant looses the incentives of adopting the costly control packages, whereas, 3) when the serological threshold is set relaxed to the farms, the slaughter plant is impelled to invest on the costly control packages.

In table 3.7, the least incentives of adopting the costly control packages to the slaughter plant appear in the first column and the most incentives to the slaughter plant appear in the last column. By setting a higher value for the serological threshold and a lower value to the bacteriological threshold, the government increases the incentive of adopting costly control actions at the slaughter plant.

When the bacteriological threshold is set to four, the optimal control package for the slaughter plant is always x_1 for all the states, no matter how the rest of the parameters will be changed. When the bacteriological threshold is set to three and the serological threshold is set to one, two or three, the optimal control package is kept on x_1 for all the states. However, as long as the serological threshold is changed to four, the optimal control package will become to x_2. When the bacteriological threshold is set by two and one, this change is even more obvious. Under the bacteriological threshold is two and the serological threshold is four, the optimal control package for state S_0 and S_1 is x_3, and for state S_2 x_2. When the bacteriological threshold is one and the serological threshold four, the optimal control package is x_3 for all states.

Setting a severe serological threshold for instance, t_{sero}=1 to the farms makes the government to increase it policy to aim for the adoption of the intensive control actions at the farm-level (see table 4.4), reduces the expected bacteriological prevalence of carcasses in the slaughter house and lowers the incentives to adopt the costly control packages to the slaughter plant.

Setting a severe bacteriological threshold for instance, t_{bac}=1to the slaughter pant

makes the government to increase the probability to test positive (see the algorithm of matrix D of figure 3.3), and thus impels the slaughter plant to invest in a more intensive control package to reduce the probability of getting the penalty.

Besides, when parameters minimum testing probability parameter α_2 is zero, increasing the value of parameter α_0 and reducing the value of parameter α_1, the slaughter plant may receive an increased probability of being tested and getting the penalty, thus, he is stressed to improve the outcome of control by adopting the more costly control package to avoid getting the penalty. When minimum inspecting probability parameter β_2 is zero, increasing the value of parameter β_0 and reducing the value of parameter β_1, the probability of inspection is enlarged, especially in the lower states. Here, the slaughter plant faces on increased expected inspecting costs if he fails the test and consequently drops down to the lowest state. Therefore, adopting the more costly control packages to enlarge the probability of passing the test becomes necessary for the slaughter plant to avoid the enlarged expected inspection costs in the future.

5.4 Impact of the governmental intervention on the expected prevalence level in the long-run transitions

The expected prevalence levels in the short-term transitions are increased with the value of serological threshold. The more the serological threshold to the farms is relaxed, the higher the bacteriological prevalence the slaughter plant is expected. When a relaxed serological threshold is set to the farms and the most severe bacteriological threshold is set to the slaughter plant, the slaughter plant is stressed to adopt the costly control packages. Because of the a relaxed serological threshold is set to the farms, farmers looses the insensitive of adopting the costly serological control packages. This results in a high serological prevalence in the delivered herds. The bacteriological threshold is restrict make the adoption of the costly bacteriological control packages more necessary to the slaughter plant to avoid the failure in bacteriological tests. If the intensity of meat inspections is reduced it will not influence the efficiency in Salmonella prevalence control if the government passes incentives the slaughter plant on testing intensities, penalties and the allowable bacteriological threshold.

6. CHANGES BASED ON THE EXISTING MODEL

Compared with the existing dynamic principal model that developed by King et al., (2007), the model developed in this study has made some improvement:
First, the incentive system study from the slaughter plant to the farm level was extended to an incentive system from the governmental to the slaughter plant level.

Second, the optimal control package was analyzed when the intensities of meat inspections is reduced, which was not included in the former model.

Third, more incentive parameters were added, such as the inspecting parameters β_0 β_1 and β_2, and bacteriological threshold parameter t_{bac}

Fourth, the algorithm of the expected bacteriological prevalence in carcasses on the slaughter plant-level was developed and added.
Fifth, the design of the transition matrix was changed.
Sixth, the least influential parameter, price premium was removed from the model.

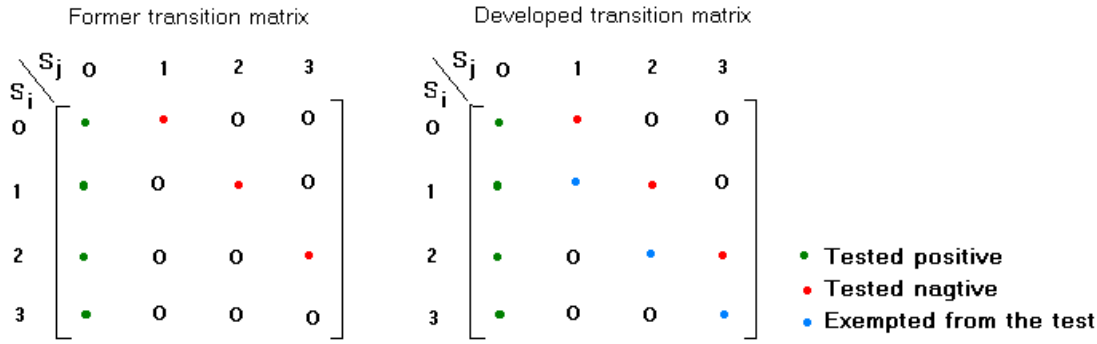


Figure 6.1 Changes in tansition maxtrixes

As illustrated in figure 6.1, the former transition matrix assumes only two positions: carcasses are tested positive (represented by the green dots) and carcasses are tested negative (represented by the red dots). By this definition, the slaughter plant is impossible to stay in the original states in the transition. In the developed transition matrix, the blue dots denotes the situation of carcasses are exempted form the test, and therefore, the changing the rules of state transitions as well as the calculations of transition probability.

Seventh, the objective function was changed from profit maximization to costs minimization.

7. CONCLUSIONS

This research focused on understanding the effect of governmental intervention on the slaughter hose mangers in choosing the optimal control strategies. The focus was specifically on the intensity of public inspection, the intensity of testing, the penalties and the allowable threshold of prevalence levels. the conceptual framework of the market was based on interviews with three experts in supervision of control and one quality manager in a slaughter house integration in the Netherlands.

The analysis based on in this model demonstrated the value of considering performance history when producers make repeated deliveries and the impact of the reduction in public inspections on the consequence of salmonella control in meat production. This study shows how the government inherences the production actives of the slaughter plant through passing incentives to the relevant influential factors.

The most influential factor that may change the choice of the food business operators is the allowable threshold set by the government. When the farm-level threshold is relaxed and the slaughter plant-level threshold is strict, the slaughter plant managers are induced to apply more stringent slaughter plant Salmonella control measures and the expected Salmonella prevalence in meat will be reduced. Reduction in public inspections does not have an effect on the quality of the product. Conversely, it may increase the incentives of slaughter plants in adopting more costly control packages to award the reputed production history and reduce the inspecting costs. However, the testing parameters have less effect on the decisions made by the slaughter plant. The control costs are quite sensitive and robust to the final result. It implicates that the changes in control costs are extremely influential to the slaughter plant's decision makings. Shortening the price differences between bacteriological control package x_2 and x_3 with 0.20 Euros, the optimal control packages of the slaughter plant becomes x_3 for all the state when the bacteriological threshold is two and the serological threshold is four.

8. DISCUSSION

The model is solved with Matlab routines; the inspecting probability written by in Matlab language did not completely present the design of state transitions in this research. In state s_2, the slaughter plant is impossible to move to state s_3, and therefore, the minimum inspecting probability should be e^{-s_2}, whereas, with Matlap routines, the minimum inspecting probability is automatically calculated as e^{-s_3}.

The model analyzed the controlled Markov chain with an infinite time horizon; it assumes the state transitions of the slaughter plant are stationary over time. However this is not completely consistent with the reality. In stead, one can also analyze the slaughter plant's problem as the controlled Markov chain with a finite time horizon.

The result obtained in this research is consistent with the answers got in the interviews with three experts in supervision of control. The quality of product influences a slaughter plant's reputation and brand name. It determines the sustainable profitability of the company in the future. Therefore, with or without public inspections will not change the attitudes of slaughter plants in reducing Salmonella prevalence and improving the product quality.

Visual meat inspections promote the information integration between the farms and the slaughter plant. Information sharing systems may improve the efficiency of Salmonella control but may also bring uncertainties in moral hazards. Therefore, to analyze the risks of Salmonella control in a integrated chain could be the topic in the future research.

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