Individual decision making of Dutch dairy farmers for vaccination against bluetongue virus serotype 8

based on rational decision making with complete information

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Preface

This research report is the result of my minor thesis at the department of the Business Economics Group of Wageningen University in the Netherlands. I'm a master Animal Science student with the specialization Animal Health Management, but by following some courses given by the department business economics, my interest in economics grew and I decided to focus more on economic research. My area of interest is animals, economics and health and at the start of my thesis period there was a nice topic available which fits to all my interest, so everything was easily arranged. The subject is an economic research of bluetongue vaccination and it is especially nice that this is a combination of both animal science and economic knowledge.

In this thesis I have tried to estimate the percentage Dutch dairy farmers that decide to vaccinate for BTV-8 for the years 2008, 2009, 2010 and 2011. I've worked on it from January 2010 till July 2010. I'm content with the result and worked with pleasure on it.

I would like to thank everybody who helped me with my report. Especially my supervisor Dr. Ir. A.G.J. Velthuis for her support and good remarks during the whole thesis period. I also want thank Dr. Ir. A. R.W. Elbers for providing expert information about the epidemiological aspects.

Wageningen, July 2010,
Carlijn Kappert

Summary

Bluetongue (BT) is an infectious, viral and vector borne disease of a broad spectrum of domestic and wild ruminants. Animals which are infected with the BT virus can develop severe clinical symptoms. From origin is BT an African disease, but the virus has spread throughout large parts of the world during the twentieth century. In 2006, the first case of BT infection was confirmed in Western Europe, including the Netherlands. Vaccination was assumed as the most practical and effective control measure to combat BT. Several inactivated BTV-8 vaccines became commercially available in 2008. From the Dutch dairy farmers decide more than 80% to vaccinate his herd in 2008. Willingness of Dutch farmer to vaccinate his herd in 2009 was significantly lower, namely 42% in sheep, 58% in cattle, 19% in goat and 49% in hobby farms. Despite of this low vaccination coverage, no new BTV-8 infections were reported that year.

The objective of this study is to estimate the percentage Dutch dairy farmers that decide to vaccinate for BTV-8 for the years 2008, 2009, 2010 and 2011, based on rational decision making with complete information. We want to investigate the individual decision making of dairy farmers on bluetongue vaccination given the variation in farm size and related net costs, and the uncertainties of the BT status of their farms. We used rational decision making in this study, therefore only economic and epidemiological data are used, whereas other decision criteria as net costs and the risk altitude of the farmer are excluded.

A stochastic decision tree is used to estimate the percentage Dutch dairy farmers that decide to vaccinate. The decision tree in this research study is called the BTV-8-tree. The specific objective of the BTV-8-tree is to minimize the net costs of the Dutch dairy farmer. This costs include vaccination costs or costs of disease (which include production losses, treatment costs and diagnostic costs). In the BTV-8-tree there is one decision needed to be made each year: *'Should I vaccinate this year against bluetongue or not?'* This decision must be made four times, i.e. in 2008, 2009, 2010 and 2011. There are three different uncertain events defined (1) whether or not BTV-8 is introduced in the Netherlands (only relevant in 2011), (2) whether or not the farm is infected and (3) whether or not animals become diseased. A farm is infected when BTV-8 invaded and replicated in at least one animal. Animals are diseased when they have averse health effects causing production effects, i.e. when costs are involved. In the BTV-8-tree are two economic consequences involved. This are the costs of vaccination and the costs of disease.

When we analyse the BTV-8-tree, we can predict what the farmer will decide in 2008, 2009, 2010 and 2011. The Dutch government can respond on it and can make a subsequent policy to control BT. The output of the BTV-8-tree show that the economic optimal decision is that farmers only have to vaccinate their herd in 2008 (except for small farms, <20 cows). In the subsequent years it is economic better not to vaccinate. This seems logical, because if we assume that most farmers vaccinate in 2008, the virus circulation in the vectors is relatively low in the coming years (because there are no cases whereof they can get the virus), which result in less infective vectors. With the sensitivity analysis is shown that the number of farmers that decide to vaccinate not much change if we change the infection probabilities. This is because the probabilities of infection are quite low. The costs of vaccination are however sensitive to changes. When the costs of the veterinarian are excluded, much more farmers decide to vaccinate their herd.

In the BTV-8-tree rational decision making is used. If we extent the BTV-8-tree and include the psychological aspects and the risk preference of the farmer, the results may change. Because some farmers want to maximize the animal welfare and/or are risk averse. These farmers want to vaccinate their herd every year and do not worry about the extra costs of vaccination. Other farmers just decide not to vaccinate, because the risk of introduction is quite low and they want to take this risk. This would be a good research in the future.

Contents

1. Introduction

Bluetongue (BT) is an infectious, viral and vector borne disease of a broad spectrum of domestic and wild ruminants (Saegerman *et al.*, 2008). Animals which are infected with bluetongue virus (BTV) can develop severe clinical symptoms as a result of the infection and can ultimately die (Elbers *et al.*, 2008b). However, a severe clinical picture is generally only seen in certain breeds of sheep and some species of deer (Saegerman *et al.*, 2008). In cattle and goat causes BTV mostly sub-clinical infections (Purse & Rogers, 2009). Cattle are proposed to be reservoir hosts of BTV because infected cattle usually have a prolonged viremia and so provide a source of virus that is available for transmission to other ruminant species (Brewer & Maclachlan, 1994). The duration of this infectious period varies between studies from 145 to 222 days (Schwartz-Cornil *et al.*, 2008). The number of animals died (mortality rate), the number of animals diseased (morbidity rate) and the severity of the clinical signs (case fatality rate), depends on various factors, such as breed and age of infected animals as well as the serotype and strain involved (Mellor & Wittmann, 2002).

BTV belongs to the *Orbivirus* genus of the family *Reoviridae* (Saegerman *et al.*, 2008). There are currently 24 serotypes worldwide, with a probable 25th serotype recently identified among goats in Switzerland (Maclachlan *et al.*, 2009). The virus is transmitted by *Culicoides* midges (Elbers *et al.*, 2008a), whereof high populations are observed in epizootic zones (Schwartz-Cornil *et al.*, 2008). Enzootic zones are mainly tropical zones where BTV transmissions occur throughout the year and subclinical infection is common. Clinical diseases usually occurs only when immunologically naïve ruminants are introduced in the zone (Smith & Sherman, 2009).

BT has spread throughout large parts of the world during the twentieth century, covering much of the Americas, Africa, southern Asia, northern Australia and Europe. Mellor & Wittmann (2002) have done a study on the progress of spreading around the world. They found that BTV was reported only from parts of Africa and Cyprus in the beginning of the discovery of the disease. Later on, BTV was detection in the USA (1952), Asia (1961) and Australia (1957). While between 1956 and 1960 in Europe (Spain and Portugal) a major outbreak of BTV-10 was detected and a smaller outbreak of BTV-4 occurred on several Greek islands in 1979. By the late-twentieth century, the distribution of BTV had expanded dramatically and the virus was reported from most regions within a broad band around the world stretching from approximately 358S to 408N (see figure 1). Since 1998, more serotypes (BTV-1, BTV-4, BTV-9 and BTV-16) were detected in parts of south Europe.

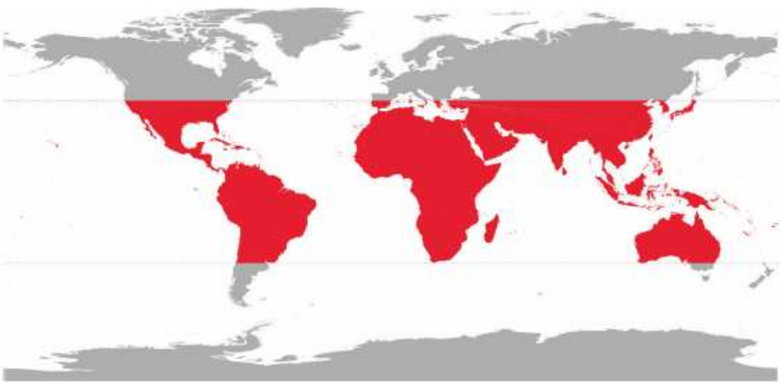

Figure 1: Map of the estimated global range of bluetongue virus prior to 1998 (Wilson & Mellor, 2009)

In August 2006, the first case of BT infection was confirmed in Western Europe. The serotype (BTV-8), which was responsible for this outbreak, has a close similarity to strains of this serotype previously isolated from Africa. During the following months, this outbreak spreads and infect animals on >2000 farms in the Netherlands, Belgium, Germany, France and Luxembourg. The first clinical BT suspicion that was confirmed by laboratory testing occurred in the Netherlands in a sheep flock in the southern province of Limburg on 16 August 2006 (Elbers *et al.*, 2008a). Because of the international press release of the Dutch Ministry of Agriculture, Nature and Food Safety, neighbouring member states as Belgium and Germany came on full alert. Two days later, the first laboratory confirmed BT-outbreak in a cattle herd in Belgium was announced and on 21 August, also Germany announced its first BT-outbreak in a cattle herd. In France, the first laboratory confirmed BT-outbreak in a cattle herd was announced on 31 August. Because typical winter temperatures in Western Europe are considerably lower than the minimum temperature required for BTV transmission, many hoped that the outbreak would be extinguished in the winter of 2006 (Elbers *et al.*, 2009a). However, during 2007, it became evident that BTV-8 had successfully overwintered in the region (Elbers *et al.*, 2009a). The virus spread exponentially within the original affected countries in 2006 and new cases occurring for the first time in Denmark, Switzerland, Czech Republic and the UK. The 2007 outbreak was far more extensive than that of 2006, and by the end of 2007 nearly 60,000 farms had been infected (see table 1). The 2008 outbreak shows a reduction of about half the number of outbreaks compared to 2007. This can have several reasons: due to the effective control strategies which were explored during that year or due to the fact that the vast majority of susceptible animals in these areas has BTV antibodies as a result of natural infection. It can also be a combination of these or another unknown reason, because there is no scientific evidence for the real cause of the reduction.

Table 1: BTV activity in Europe from 2006 to 2008; number (#) of registered farms per country; x =No confirmed instances of local transmission) (Wilson & Mellor, 2009)

	# Farms From July 2006 to July 2007	# Farms From July 2007 to July 2008	#Farms From July 2008 To July 2009			
Country ↓	**BTV-8**	**BTV-8**	**BTV-1**	**BTV-6**	**BTV-8**	**BTV-16**
The Netherlands	460	6442	1	14	58	
Belgium	695	6870		x	27	
Germany	952	23443		x	2487	
France	7	19322		4469	24469	
Luxembourg	8	1315			19	
Denmark		1			15	
Switzerland		7			x	
Spain		12	1918		12	
Czech Republic		2			21	
UK		128	x		x	
Italy		3			x	
Portugal		1	78			
Austria					2	
Greece						43
Sweden					28	
Hungary					1	
Ireland					x	

The major control measures applied during the BTV-8 epidemic include restriction of animal movement, vector control applying insecticides, slaughter of infected animals and vaccination (Bhanuprakash *et al.*, 2009). Prophylactic immunization against BT, which can most easily be achieved by vaccination, was assumed as the most practical and effective control measure to combat BT infection (Bhanuprakash *et al.*, 2009).

Several inactivated BTV-8 vaccines became commercially available in 2008 and vaccination programs were rapidly initiated throughout most of the affected area. Some countries used mandatory vaccination programs (Belgium, Germany, Luxembourg and the

Czech Republic) and others used voluntary vaccination programs (England, Wales and the Netherlands). Within the EU, mandatory vaccination programs are eligible for financial support of the government, which covering 100% of the cost of vaccine purchase and 50% of the cost of delivery (European Commission, 1990). However, such schemes must first be approved by the EU and may carry additional administrative requirements. This, in combination with delay that may result from mandatory government-led vaccination programs, is the reason why not every country choices for a mandatory vaccination program.

The success of vaccination varied considerably from one country to the other. In countries such as Belgium and the Netherlands which were hit hard by BTV-8 in both 2006 and 2007, transmission during the 2008 season was restricted to a handful of cases. However as previous already mentioned, it is difficult to estimate the importance of vaccination in achieving this result as the vast majority of susceptible animals in these areas would be expected to already possess BTV antibodies as a result of natural infection and recovery (Wilson & Mellor, 2009). In Germany, approximately 70% of cattle and 90% of sheep in the infected areas were vaccinated, a fact which the Federal German Ministry of Food, Agriculture and Consumer Protection believed to be responsible for the far fewer cases of BTV-8 seen during 2008 (Bundesministerium für Ernährung, Landwirtschaft und Verbraucherschutz, 2008). In the UK was, despite the voluntary nature of the vaccination program, a coverage of >80% achieved within areas where BTV transmission has been confirmed in 2007. Although coverage in areas where no BTV had been reported was as low as 40% in some areas. To summarize, where uptake was high and vaccine was administered in time for protection to develop before the seasonal peak of transmission, vaccination appears to have been broadly effective in controlling BTV transmission.

Most EU countries used again vaccination as a preventive strategy against BTV-8 in 2009. In the Netherlands, a new voluntary vaccination program was started, although now without subsidizing. Willingness of Dutch farmer to vaccinate was significantly lower, namely 42% in sheep, 58% in cattle, 19% in goat and 49% in hobby farms (Elbers *et al.*, 2009a). Despite of this low vaccination coverage, no new BTV-8 infections were reported in that year (CVI, 2010). Elbers *et al.* (2009a) has find out the motives of dairy farmers to vaccinate or not. The top-5 motives of dairy farmers to have their cattle vaccinated are:

1) To prevent the disease and/or production losses
2) It is recommended by veterinary practitioner
3) For welfare reasons
4) To make a contribution to the eradication campaign
5) Had a good experience with BTV-8 vaccination in the past

And the top-5 motives of dairy farmers against vaccination are:

1) No BT-related clinical problems so far
2) Farmer expects only a low level of disease and/of production losses
3) The costs of vaccination are too high
4) The balance between costs of vaccination against possible losses without vaccination
5) Had a bad experience with vaccination campaigns in the past against other diseases

To find out how many farmers will have to vaccinate in the future, it is essential to know which factors play an essential role in their decision, i.e. what are the motives of farmers to vaccinate or not? With this information, we can get insight in why farmers decided to vaccinate or not. Measures to stimulate vaccination among those that did not want to vaccinate are: subsidized vaccination, possibility to vaccinate their own animals, more information on efficacy/safety of vaccine and why animals had to be vaccinated again, availability of a BT vaccine combined with vaccine(s) against other diseases (Elbers *et al.*, 2009a).

Although vaccination theoretical can control BT, major (economic) constraints may prevent its effectiveness (Schwartz-Cornil *et al.*, 2008). For many diseases, a certain (vaccination) coverage is needed to control the disease. In other words, to achieve eradication of the virus, the number of seropositive animals should be sufficiently high. Therefore, what the farmer decides, vaccinate or not, is important for what will happen to his farm, but also for what will happen in the entire sector. The entire sector is involved because if more farmers decide to vaccinate, more cattle will be immune for the BTV-8. In this case less virus will be replicated, so less *Culicoides* will be infected, which result in a reduced spread of the virus. As a result the herd immunity, which means an indirect immunity of non-protected individuals as a result of reduced transmission in the population, will increase. At least 80% of the susceptible livestock should be seropositive for BTV-8 at the end of 2008 (Europese Commissie, 2007). This means that the herd immunity threshold should be at least 80%, which is based on the evaluation of the rate of spread of the disease measured by the basic reproduction number R_0. R_0 is defined as the average number of secondary infections produced by one infection individual introduced into a fully susceptible population (Anderson & May, 1979). Another constrain is that the vaccine doesn't have a cross seropositive protection, i.e. it protect ruminants only against one serotype, namely BTV-8. Therefore, the vaccinated animals are not protected against other BT serotypes. This can be a problem, because as mentioned before, there are new serotype invasions detected in North-Europe, including the Netherlands. Furthermore, problems arises, because BT is a transboundary animal disease and not every country applies the same regulations: in some EU member states, vaccination is mandatory and in others voluntary. Which may cause problems between countries, e.g. related to export of animals and related products like cheese and dairy products. The previous aspects has consequences for the feasibility of eradication and spread of BT. If this problems or constrains leads to new and large BT outbreaks, this will probably cause economic consequences. Because when cattle and sheep farms are infected, mostly there will be costs involved.

The economic impact of an BT outbreak is relatively large. Worldwide it has been estimated that BTV causes a loss of $3 billion/year (Mellor & Wittmann, 2002). In the Netherlands, the net costs (costs minus benefits) of the BTV-8 epidemic in 2006 is estimated at 32.4 million Euros and in 2007 169 million Euros (Velthuis *et al.*, 2009). The compulsory indoor housing regulation resulted in 55% of total economic impact in 2006, transport restrictions 36%, diagnosis costs 7% and the production losses plus treatment less than 2%. In 2007, 92% of the total economic impact was caused by production losses and treatments and only 6% by transport restrictions (Velthuis *et al.*, 2009). The distribution of the losses over the various components in 2007 differed from 2006.

The cattle sector suffered most damage, namely 88% (in 2006) and 85% (in 2007) of the net costs for BTV-8 (Velthuis *et al.*, 2009). In Scotland, where BT have not been detected yet, is estimated what the total direct costs of a BTV-8 outbreak are compared to the costs of preventing an outbreak using a vaccination control strategy. The estimated direct costs of a BTV-8 outbreak in Scotland are £30 million per year (Scottish Government, 2008). Although the symptoms of disease are expressed more often in sheep than in cattle, the losses to the cattle sector from a BTV-8 incursion into Scotland would exceed those to the sheep sector (Scottish Government, 2008). The cost of a control strategy to vaccinate 80% of cattle and sheep holdings throughout all Scotland is estimated to be £2.3 million (Scottish Government, 2008). So, the findings indicate that the costs of vaccination are justified as protection against the costs of a potential BTV-8 outbreak (Scottish Government, 2008). Although vaccinate costs can then be lower than costs of an outbreak, it is also important to consider the probability of introduction. When the probability of introduction will be low, maybe you don't have to make costs for vaccination.

The objective of this study is to estimate the percentage Dutch dairy farmers that decide to vaccinate for BTV-8 for the years 2008, 2009, 2010 and 2011, based on rational decision making with complete information. This is useful information for decision making by the government, because a lack of this information creates uncertainty about the percentage of seropositive ruminants of BTV-8. This percentage is essential to eradicate BT.

2. Objective and research questions

The objective of this study is to estimate the percentage Dutch dairy farmers that decide to vaccinate for BTV-8 for the years 2008, 2009, 2010 and 2011, based on rational decision making with complete information.
We want to investigate the individual decision making of dairy farmers on bluetongue vaccination given the variation in farm size and related net costs, and the uncertainties of the BT status of their farms. We used rational decision making in this study, therefore only economic and epidemiological data are used, whereas other decision criteria as net costs and the risk altitude of the farmer are excluded.

The questions to achieve the objective are:

1) *Which decisions must be made by the farmer and when?*

Decision making is the most important part of this research. The decision has implications for what will happen next. When you for example decide not to treat an animal against a disease, the chance that your animal becomes diseased increase. But have also the chance that your animal doesn't become diseased and then you will save costs.

2) *What are the uncertainties regarding the decisions?*

Uncertainties are consequences of a certain decision. When you for example decision not to vaccinate, you have an uncertainty to become infected or not. So, when you make decisions, you have to predict the sequent consequences, to know what will happen with the farm.

3) What are the probabilities of the defined uncertainties?

This are the values which indicate the chance of a certain consequence resulting from a decision. This will later on used to determine the costs of a certain decision.

4) What are the economic consequences of the outcomes of the different decision alternatives with the related uncertainties?

This is an economic value describing the net costs of a specific decision. The net costs are the total discounted costs minus the total discounted benefits. During the decision making process, you will get a number of paths, whereof each is related to a certain decision with the subsequent uncertainties. Each path has his own economic value: the net costs that unique situation. These economic impact is needed to decide the optimal decision which the farmer have to made at the beginning of that year.

3. Model description

3.1 General approach

We use a stochastic decision tree to estimate the percentage Dutch dairy farmers that decide to vaccinate in the years 2008, 2009, 2010 and 2011. With a decision tree one can make a decision analysis, which is a prescriptive approach for people who want to think hard and systematically about a decision problem (Clemen & Reilly, 2001). A decision tree is defined as a graphical method of expressing, in chronological order, the alternative actions available to the decision maker and the choices determined by chance (Dijkhuizen & Morris, 1997). So, a decision analysis with a decision tree does not only give a solution, but also insight into the situation, the uncertainty, the objectives and the trade offs (Clemen & Reilly, 2001). A decision tree gives a risk neutral solution.

Figure 2 shows a simple example of a decision tree to explain the general principle. The decision problem in this example is to treat an animal or not against a disease? When you decide not to treat, it costs at least €200 (treatment costs) and you have a probability of 1% that your animal still dies, which results in additional costs of €300. But you have also a probability of 99% that your animal survives. When you decide not to treat, it costs in 20% of the cases nothing, because your animal will survive. But in 80% of the cases, your animal will die, which results in a cost of €300. The decision maker wants to minimize the net costs which is expressed as the Expected Monetary Value (EMV). The EMV is defined as the summation of the possible monetary outcomes multiplied by their probabilities (Dijkhuizen & Morris, 1997), i.e. the probability weighted average value. Figure 2 tells us that the optimal decision is to treat, because then you have the lowest EMV, namely €203 instead of €240 when you decide not to treat.

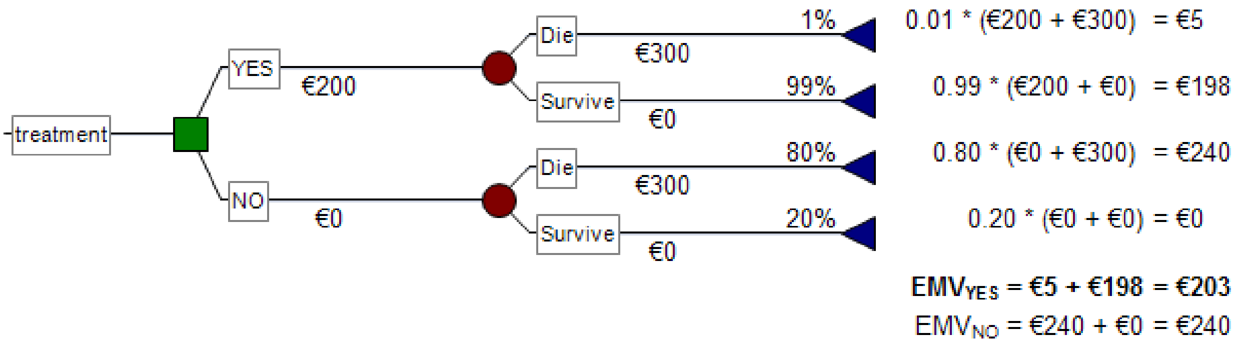

Figure 2: Example of simple decision tree: treatment or not?

There are four steps used to build and analyze the decision tree: determining the structure, gathering the input values, analyzing the decision tree and performing a sensitivity analysis.

Determining the structure

In this step, the decisions, the uncertain events and the pay-off functions are determined. They should be in chronological order.

Decisions

To make a decision tree, the decisions must be determined specifically, and if more subsequent decisions are involved the timing of the decisions is important. There are different kinds of decisions, related to specific decision problems. E.g. treatment of not, choose between red and black, follow route A, route B or route C or to choose between vaccinate or not. Choosing a certain decision has consequences, which are mostly uncertain events.

Uncertain events
Uncertain events in decision making are future events which influence the outcome of present decisions but have not yet occurred and no one can precisely predict what they will be like. There are different kinds of uncertain events, e.g. your animals become diseased or not, you win or you lose, your cow will become pregnant or not. These consequences are expressed in probabilities.

Pay-off functions
A pay-off function is an economic value describing the net costs of a specific decision with the subsequent uncertain events. Each path in the decision tree has his own economic value. When a farmer choose to vaccinate, he has only the vaccination costs and hopefully no costs of disease. When a farmer choose not to vaccinate, he hasn't vaccination costs, but probably he has costs of disease when his farm will be infected with BTV-8.

Gathering the input values
In this step, the input values are collected. For the stochastic variables, we have to get the minimal, maximal and most likely probabilities and for the deterministic variable we have the get the exact probability value. The input values are gathered from literature, an economic model and by asking experts.
The stochastic variables are subject to a probability distribution. When a distribution is involved, the results will shown also the uncertainty about the knowledge of the probability. In this study, there a five stochastic variables: herd size, costs of vaccination, costs of disease, introduction of BTV-8 and infection with BTV-8. Herd size is stochastic because of when a farm is relatively small, the costs of vaccination and the costs of disease are lower. This results in a relative small difference between vaccination or not, which means a smaller benefit if you choice to vaccinate your herd (the opposite is valid for large farms). So, herd size may influence the decision of the farmer to vaccinate or not. Herd size is included in the costs of vaccination and the costs of disease, so these are indirectly also stochastic. Introduction of BTV-8 and infection with BTV-8 are stochastic because one can never predict this variables by one value, because this is influenced by a number of factors.
The deterministic variables are fixed and thus expressed by one number. In this study, only the probability of disease is a deterministic variable.

Analyzing the decision tree
In this step, the decision tree is created and solved, whereof figure 3 gives a schematic overview. The decision tree have to build up in chronological order, from left to right. You start always with a action node, i.e. a particular decision. This decision has a number of uncertain events which are include the event nodes. All the uncertain events of one decision must be add up to one. When for example the probability of becoming disease will be 0.6, than the probability of not becoming diseased will automatically 0.4. Each path in the decision tree ends up with a outcome node, which reflect the EMV of a specific decision with the related uncertain events. When the whole decision tree is created, one can start with analyzing. This is always done in reverse direction, for right to left. At this way, you start analyzing with the most recent decision.

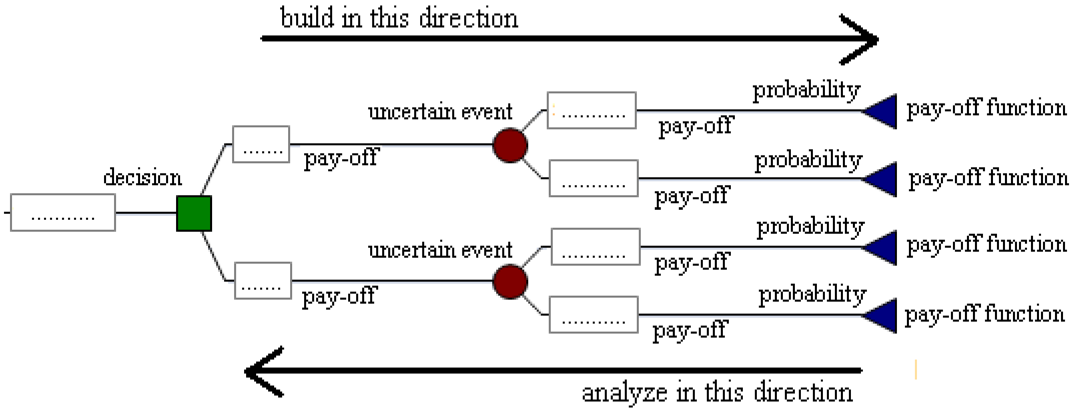

Figure 3: The construction of a decision tree

The program which we use to construct and analyze the decision-tree is precision tree that also includes @RISK. With this program you can make a stochastic decision tree. By adding @RISK to the decision tree, all stochastic variables can be defined with a distribution function. When simulation is running using @RISK, a sample will be drawn from each distribution function during each iteration of the simulation.

Performing a sensitivity analysis

In this step, the decision tree was tested on sensitivity of the used parameters, i.e. what will happened to the optimal solution if we change parameters?

3.2 Decision tree for BTV-8 vaccination

General structure

The decision tree in our research study is called the BTV-8-tree. The specific objective of the BTV-8-tree is to minimize the net costs of the Dutch dairy farmer. This means that de farms on the end of the year the lowest net costs has have during that specific year. This costs include vaccination costs or treatment costs. The BTV-8-tree includes a time period of four years, from May 2008 to May 2012. This is illustrated in figure 4, starting in 2008 where the first vaccination program started.

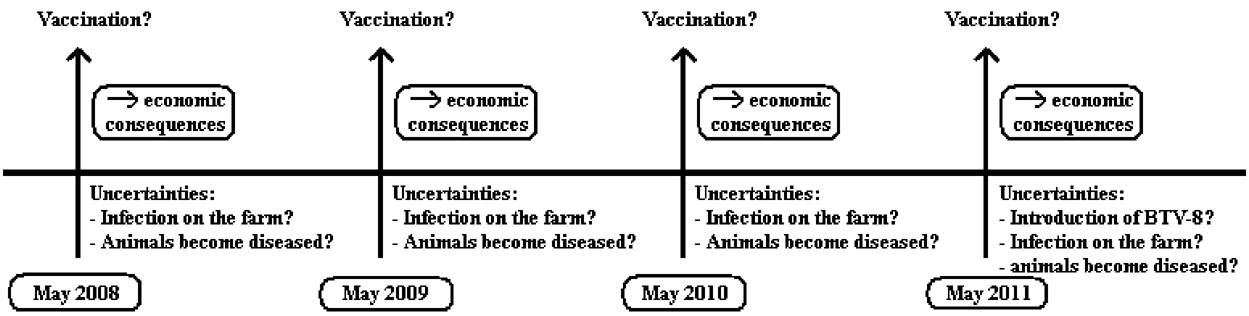

Figure 4: General structure and time period of the BTV-8-tree

The general structure of the BTV-8-tree for one year is simplified shown in figure 5. This structure comes back every year, with some specific modifications for that particular year.

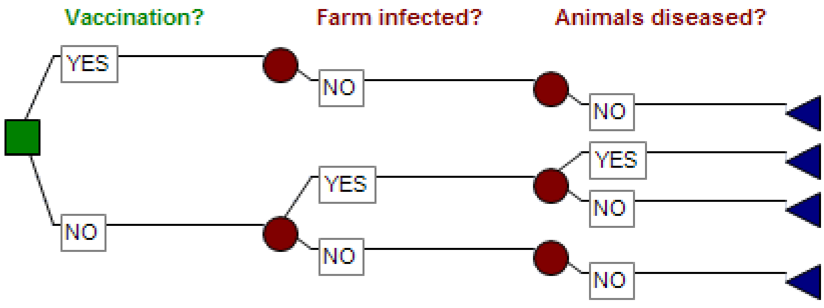

Figure 5: General structure of the BTV-8-tree for one year

Decisions

In the BTV-8-tree four decisions are included.

'Should I vaccinate against bluetongue or not for respectively the years 2008, 2009, 2010 and 2011?'

The moment of the decisions is before June, since 1 June is regarded as the beginning of the BT season (ministry of LNV, 2010).

Uncertain events

After the decision to vaccinate or not, there are three different uncertainties:

- Whether or not there is an introduction of BTV-8 in the Netherlands. This uncertain events is only relevant in 2011 and is defined as P (T) and P (NT). This is done upward of 2011, because of if we assume that the replacement of dairy cattle is about 33%, after three years the whole herd is replaced and all the animals are sensitive for BTV-8 again.
- Whether or not there is an infection on the farm, which is defined as P (I) and P (NI). A farm is infected when BTV-8 invaded and replicated in at least one animal. This uncertain event is relevant, because the probability that an animal becomes diseased dependents on the status of infection on the farm.
- Whether or not that the animals become diseased, which is defined as P (D) and P (ND). Animals are diseased when they have averse health effects which causing production effects, i.e. when costs are involved. This uncertain event is relevant, because this include pay-off costs which are relevant for the decision and the outcomes.

Pay-off functions

The pay-off functions of the BTV-8-tree include the costs of vaccination and/or the costs of disease. Other costs, like control costs are excluded since a farmer doesn´t have to finance them.

The costs of vaccination

The costs of vaccination when the farmer decide to vaccinate his herd, are calculated as:

$$Costs\ V = 2 * (C + HR * D + HS_{distribution} * (V + M + R)).$$

Where C represents the call out fee of the veterinarian, HR the hourly rate of the veterinarian, D the duration of the herd vaccination, HS the herd size (number of animals) which is calculated with a RiskPert distribution (see later), V the costs of the vaccine, M the costs of dispense material and R the costs of registration. The costs are multiplied by two, because all animals should be vaccinated twice to get enough protection against BTV-8. The input values for the various items are obtained by an expert (A.G.J. Velthuis). In 2008, the government covering 100% of the cost of vaccine purchase and 50% of the cost of delivery by subsidizing. So, in that year are the costs significantly lower:

$$Costs\ V2008 = ½ * 2 * (C + HR * D + HS * (M + R)).$$

Upward of 2009, there is no subsidizing and the costs for the consecutive years are calculated by using discounting.

The costs of disease

The costs of disease, which the farmer has if the animals become diseased, are calculated as:

$$Costs\ D = P + T + D$$

Where P represents the total production loss, T the treatment costs and D the diagnostic costs.

The total production losses are calculated as:

$$P = MO + EC + MP + NC + AB + NG + WL + LC + SC$$

Where MO represents the losses due to mortality, EC the costs due to early culling, MP the loss revenue due to reduced milk production, NC the losses associated with increased number of cycles before gestation, AB the losses associated with abortion, NG the financial consequences due to no gestation, WL the losses due to weight loss, LC the losses due to the lower birth weight of calves and SC the losses due to stillborn calves. These separate production losses are calculated as:

$$MO = MTR_{distribution}/100 * PR * HS_{distribution} * (SV + PV + DC)$$

Where MTR represents the mortality rate (per 100 animal months) which is calculated with a RiskPert distribution, PR the period at risk, SV the slaughter value, PV the production value and DC the cost incurred to send an animal for rendering (disposal costs).

$$EC = PO_1 * MBR_{distribution}/100 * PR * HS_{distribution} * PV * HS$$

Where PO_1 represents the percentage of BTV-8-infected cows culled earlier (percentage of occurrence) and MBR the morbidity rate (animals per 100 animal months) which is calculated with a RiskPert distribution.

$$MP = MBR_{distribution} /100 * PR * HS_{distribution} * AM * RM * 0.5 * DD * VM$$

Where AM represents the average milk production, RM the relative reduction in milk production, DD the number of days that the animal is diseased (it is assumed that the milk production is reduced during the first half of this period, i.e. 0.5) and VM the value of the milk that is not produced.

$$NC = PO_{2\ ;\ distribution} * HS_{distribution} * (EI_1 + LC * CI_1)$$

Where PO_2 represents the proportion of cows with an increased number of cycles before gestation (percentage of occurrence) which is calculated with a RiskPert distribution, EI_1 the costs of one extra insemination, LC_1 the length of one cycle and CI the loss of a calving interval per day.

$$AB = HS_{distribution} * PO_{3\,;\,distribution} * (EI_1 + EI_2 + CI_6)$$

Where PO_3 represents the proportion of cows that aborts due to a BTV-8 infection (percentage of occurrence). We hereby assume that cows will not be culled due to abortions and that two inseminations are needed for the subsequent gestation.

$$NG = HS_{distribution} * PO_4 * (PV + VC – FH – \Delta SV)$$

Where PO_4 represents the proportion of animals without a calf (percentage of occurrence), VC the loss value of the calf, FH the costs of feed and housing that are not made and ΔSV the increased slaughter value in relation to the average cow.

$$WL = HS_{distribution} * PO_5 * (EF – FR)$$

Where PO_5 represents the proportion of animals who exhibit weight loss (percentage of occurrence), EF the costs of the extra feed that is required for compensatory growth and FR the drop in feed intake during the first days of disease.

$$LC = HS_{distribution} * PO_6 * (EF – \Delta VC)$$

Where PO_6 represents the proportion of calves with a lower body weight due to BTV-8 (percentage of occurrence) and ΔVC the reduced price paid for the calf.

$$SC = HS_{distribution} * PO_7 * (VC – FC)$$

Where PO_7 represents the proportion of reproductive animals that have a stillbirth due to BTV-8 (percentage of occurrence) and FC the costs incurred before sale of a young calf, i.e. the feed costs.

The treatment costs are calculated as:

$$T = MBR_{distribution} * HS_{distribution} * (CD * 0.85 + A_1 * 0.425 + A_2 * 0.425)$$

Where CD represents the costs of the Non-Steroidal Anti-Inflammatory Drugs (85% of the animals), A_1 the costs of antibiotic 1 (42.5 % of the animals) and A_2 the costs of antibiotic 2 (42.5% of the animals)
The diagnostic costs are calculated as:

$$D = C + HR * 0.5$$

It is assumed that the veterinarian needs half an hours to diagnose.

The costs for the consecutive years are calculated by using discounting.

Assumptions
The following general assumptions are made in the BTV-8-tree:

- Each year is only influenced by the previous year and not by the year therefore.
- When a herd is vaccinated, the probability of infection is zero. It will be assumed that the vaccine is 100% effective.
- When a farm doesn't become infected, the probability that your animals become diseased is zero. When there is no virus on the farm, i.e. the farm will not become infected, than your animals haven't become diseased. This because the animals can't come in contact with the pathogen.
- When a farm is infected and you haven't vaccinate this year and you haven't vaccinate previous year, the probability of disease is one. This is assumed because in this situation is it unlikely that the animals has antibodies against BTV-8.
- When a farm is infected and you have vaccinate previous year but this year you don't vaccinate, the probability of disease is zero (so theoretical a farmer do never vaccinate when he has vaccinate previous year). This is assumed because the most animals has antibodies against BTV-8. So the virus has almost no ability to survive on the farm.
- When there is no introduction of the bluetongue virus in the Netherlands, the probability on infection is zero. This is logic, because when there is no introduction, there are no pathogens, so the chance of infection is zero.

3.2.1 Structure of the BTV-8-tree for 2008

Decision
In this year, there is only one decision needed to be made:

'Should I vaccinate in June 2008 against bluetongue or not?'

This decision has to be made by the farmer. A particular decision has a number of uncertain events who are explained in the next section. This year is the first time with the ability to vaccinate the animals in the Netherlands, so it isn't needed to take vaccination effect of the previous year into account. The general structure of the BTV-8-tree for 2008 is shown in figure 6.

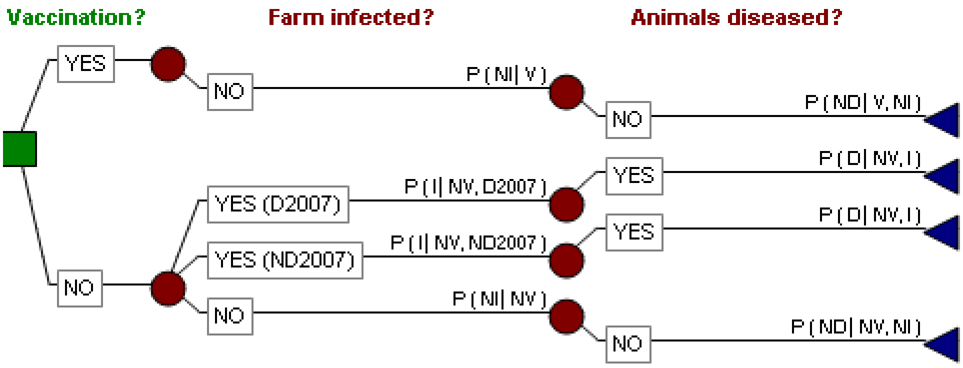

Figure 6: The structure of the BTV-8-tree for 2008

Uncertain events
In this year, there are seven different uncertain outcomes involved. P (NI | V) is the probability that your farm will not be infected with BTV-8 in 2008 under the condition that you did vaccinate in 2008. P (I | NV, D2007) is the probability that your farm will be infected with BTV-8 in 2008 under the condition that you did not vaccinate in 2008 and that your animals did became diseased in 2007. P (I | NV, ND2007) is the probability that your farm will be infected with BTV-8 in 2008 under the condition that you did not vaccinate in 2008 and that your animals did not became diseased in 2007. P (NI | NV) is the probability that your farm will not be infected with BTV-8 in 2008 under the condition that you did not vaccinate in 2008. P (ND | V, NI) is the probability that your animals did not become diseased in 2008 under the condition that you did vaccinate in 2008 and that your farm will not be infected with BTV-8 in 2008. P (D | NV, I) is the probability that your animals did become diseased in 2008 under the condition that you did not vaccinate in 2008 and that your farm will be infected with BTV-8 in 2008. P (ND | NV, NI) is the probability that your animals did not become diseased in 2008 under the condition that you did not vaccinate in 2008 and that your farm will not be infected with BTV-8 in 2008.

Pay-off functions
The pay off functions depend on the decision and the outcomes of the uncertain events. When a farmer decides to vaccinate, vaccination cost have to be paid. When a farmer decides not to vaccinate, they have perhaps costs of disease, but this dependents on the infection probability of the farm. It is also possible that the farm will not become infected, so the animals did not become diseased.

3.2.2. Structure of the BTV-8-tree for 2009

Decision
In this year, there is only one decision needed to be made:

'Should I vaccinate in June 2009 against bluetongue or not?'

This decision has to be made by the farmer. A particular decision has a number of uncertain events who are explained in the next section. The effect of vaccination and disease of the previous year (2008) are taken into account. When we include this, it creates a more realistic situation. Due to the effect of the previous year, there are three different basic models instead of one. The three different basic models are (see figure 7):
- Situation 2008: V + ND → Model 2009A
- Situation 2008: NV + ND → Model 2009B
- Situation 2008: NV + D → Model 2009C

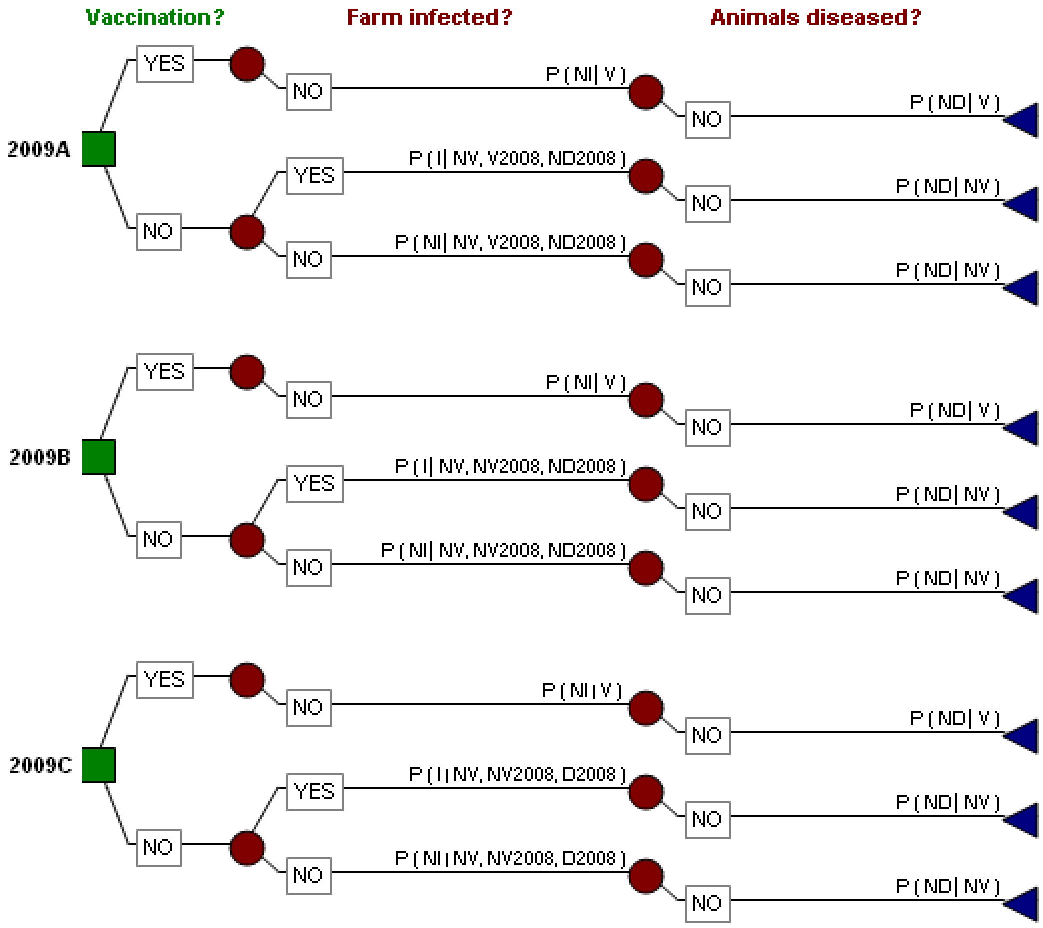

Figure 7: The structure of the three basic models (2009A, 2009B, 2009C) of the BTV-8-tree for 2009

Uncertain events

In 2009, no virus introduction was observed (CVI, 2010), so all animals did not become infected and diseased in this year. This is thus independent of the decision to vaccinate or not. The three basic models of 2009 involved together nine different uncertain outcomes. P (NI | V) is the probability that your farm will not be infected with BTV-8 in 2009 under the condition that you did vaccinate in 2009. P (I | NV, V2008, ND2008) is the probability that your farm will be infected with BTV-8 in 2009 under the condition that you did not vaccinate in 2009, that you did vaccinate in 2008 and that your animals did not became diseased in 2008. P (NI | NV, V2008, ND2008) is the probability that your farm will not be infected with BTV-8 in 2009 under the condition that you did not vaccinate in 2009, that you did vaccinate in 2008 and that your animals did not became diseased in 2008. P (I | NV, NV2008, ND2008) is the probability that your farm will be infected with BTV-8 in 2009 under the condition that you did not vaccinate in 2009, that you did not vaccinate in 2008 and that your animals did not become diseased in 2008. P (NI | NV, NV2008, ND2008) is the probability that your farm will not be infected with BTV-8 in 2009 under the condition that you did not vaccinate in 2009, that you did not vaccinate in 2008 and that your animals did not became diseased in 2008. P (I | NV, NV2008, D2008) is the probability that your farm will be infected with BTV-8 in 2009 under the condition that you did not vaccinate in 2009, that you did not vaccinate in 2008 and that your animals did became diseased in 2008. P (NI | NV, NV2008, D2008) is the probability that your farm will not be infected with BTV-8 in 2009 under the condition that you did not vaccinate in 2009, that you did not vaccinate in 2008 and that your animals did become diseased in 2008.

P (ND | V) is the probability that your animals did not become diseased in 2009 under the condition that you did vaccinate in 2009. P (ND | NV) is the probability that your animals did not become diseased in 2009 under the condition that you did not vaccinate in 2009.

Pay off functions
The pay off functions are dependent of the decision. In this year there no virus circulation was observed in the Netherlands, so no farm did became infected which result in no disease cost. When a farmer decides to vaccinate, then they have only the vaccination cost. When a farmer decides not to vaccinate, they have no costs.

3.2.3 Structure of the BTV-8-tree for 2010

Decision
In this year, there is only one decision needed to be made:

'Should I vaccinate in June 2010 against bluetongue or not?'

This decision has to be made by the farmer. A particular decision has a number of uncertain events who are explained in the next section. The effect of vaccination and disease of the previous year (2009) are taken into account. Because of there was in 2009 no virus introduction and therefore no disease, there are in 2010 only two different basic models (see figure 8):
- Situation 2009: V + ND → Model 2010A
- Situation 2009: NV + ND → Model 2010B

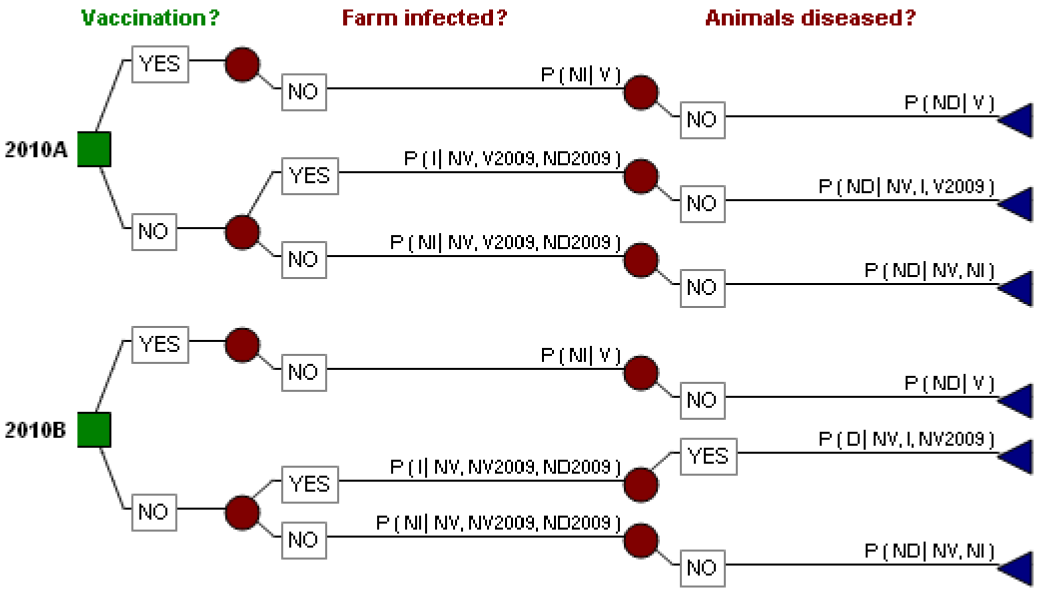

Figure 8: The structure of the two basic models (2010A, 2010B) of the BTV-8-tree for 2010

Uncertain events
The two basic models include together nine different uncertain outcomes. P (NI | V) is the probability that your farm will not be infected with BTV-8 in 2010 under the condition that you did vaccinate in 2010. P (I | NV, V2009, ND2009) is the probability that your farm will be infected with BTV-8 in 2010 under the condition that you did not vaccinate in 2010, that you did vaccinate in 2009 and that your animals did not became diseased in 2009. P (NI | NV, V2009, ND2009) is the probability that your farm will not be infected with BTV-8 in 2010 under the condition that you did not vaccinate in 2010, that you did vaccinate in 2009

and that your animals did not became diseased in 2009. P (I | NV, NV2009, ND2009) is the probability that your farm will be infected with BTV-8 in 2010 under the condition that you did not vaccinate in 2010, that you did not vaccinate in 2009 and that your animals did not became diseased in 2009. P (NI | NV, NV2009, ND2009) is the probability that your farm will not be infected with BTV-8 in 2010 under the condition that you did not vaccinate in 2010, that you did not vaccinate in 2009 and that your animals did not became diseased in 2009.
P (ND | V) is the probability that your animals did not become diseased in 2010 under the condition that you did vaccinate in 2010. P (ND | NV, I , V2009) is the probability that your animals did not become diseased in 2010 under the condition that you did not vaccinate in 2010, that your farm will be infected in 2010 and that you did vaccinate in 2009. P (D | NV, I , NV2009) is the probability that your animals did become diseased in 2010 under the condition that you did not vaccinate in 2010, that your farm will not be infected in 2010 and that you did not vaccinate in 2009. P (ND | NV, NI) is the probability that your animals did not become diseased in 2010 under the condition that you did not vaccinate in 2010 and that your farm will not be infected in 2010.

Pay off functions
The pay off functions are dependent of the decision. When a farmer decide to vaccinate, they have only the vaccination cost. When a farmer decides not to vaccinate, they have perhaps costs of disease. This depends on the infection probability of the farm, which is also influenced by the previous year. In the previous year (2009) no farmer has vaccinate his herd, because there was no virus circulation. This will result in a higher amount of susceptive animals, which may influence the decision of the farmer to vaccinate or not. It is also possible that the farm will not be infected, so the animals did not become diseased.

3.2.4 Structure of the BTV-8-tree for 2011

Decision
In this year, there is only one decision needed to be made:

‘Should I vaccinate in June 2011 against bluetongue or not?’

This decision has to be made by the farmer. A particular decision has a number of uncertain events who are explained in the next section. In this year also the effect of vaccination and disease of the previous year (2010) are taken into account. Furthermore, in this year there will be also a probability of introduction of the BTV-8 virus inserted. Due to the consequences of the previous year, there are three different basic models in 2011 (see figure 9):
- Situation 2010: V + ND → Model 2011A
- Situation 2010: NV + ND → Model 2011B
- Situation 2010: NV + D → Model 2011C

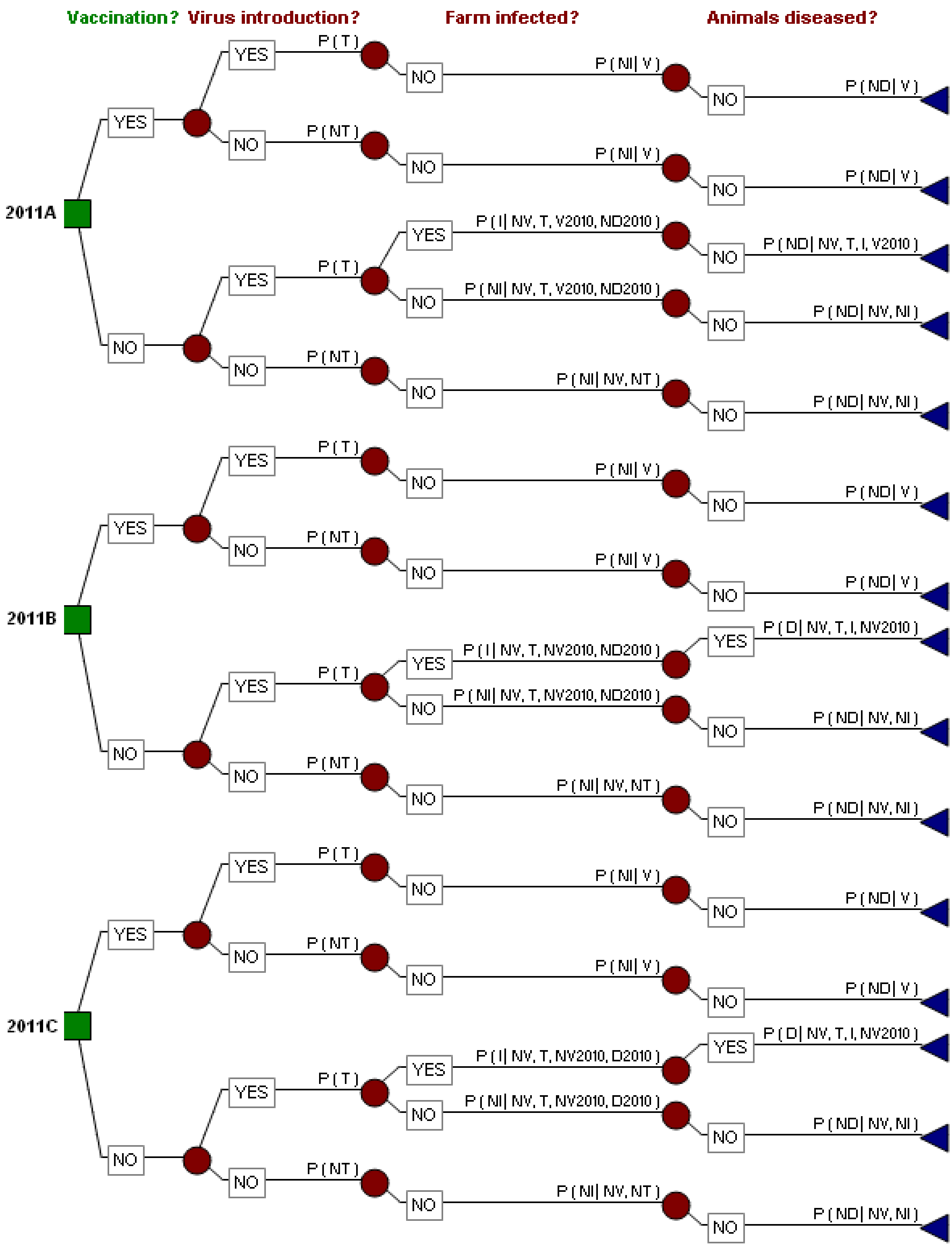

Figure 9: The structure of the three basic models (2011A, 2011B, 2011C) of the BTV-8-tree for 2011

Uncertain events
The three basic models included together 14 different uncertain outcomes. P (T) is the probability of BTV-8 introduction in the Netherlands. P (NT) = 1 - P (T) is the probability of no BTV-8 introduction in the Netherlands.
P (NI | V) is the probability that your farm will not be infected with BTV-8 in 2011 under the condition that you did vaccinate in 2011. P (I | NV, T, V2010, ND2010) is the probability that your farm will be infected with BTV-8 in 2011 under the condition that there is BTV-8 introduction in the Netherlands in 2011, that you did not vaccinate in 2011, that you did vaccinate in 2010 and that your animals did not became diseased in 2010. P (NI | NV, T, V2010, ND2010) is the probability that your farm will not be infected with BTV-8 in 2011 under the condition that the there is BTV-8 introduction in the Netherlands in 2011, that you did not vaccinate in 2011, that you did vaccinate in 2010 and that your animals did not became diseased in 2010. P (I | NV, T, NV2010, ND2010) is the probability that your farm will be infected with BTV-8 in 2011 under the condition that there is BTV-8 introduction in the Netherlands in 2010, that you did not vaccinate in 2011, that you did not vaccinate in 2010 and that your animals did not became diseased in 2010. P (NI | NV, T, NV2010, ND2010) is the probability that your farm will not be infected with BTV-8 in 2011 under the condition that there is BTV-8 introduction in the Netherlands in 2011, that you did not vaccinate in 2011, that you did not vaccinate in 2010 and that your animals did not became diseased in 2010. P (I | NV, T, NV2010, D2010) is the probability that your farm will be infected with BTV-8 in 2011 under the condition that there is BTV-8 introduction in the Netherlands in 2011, that you did not vaccinate in 2011, that you did not vaccinate in 2010 and that your animals did became diseased in 2010. P (NI | NV, T, NV2010, D2010) is the probability that your farm will not be infected with BTV-8 in 2011 under the condition that there is BTV-8 introduction in the Netherlands in 2011, that you did not vaccinate in 2011, that you did not vaccinate in 2010 and that your animals did became diseased in 2010. P (NI | NV, NT) is the probability that your farm will not be infected with BTV-8 in 2011 under the condition that there is no BTV-8 introduction in the Netherlands in 2011.
P (ND | V) is the probability that your animals did not become diseased in 2011 under the condition that you did vaccinate in 2011. P (ND | NV, T, I, V2010) is the probability that your animals did not become diseased in 2011 under de condition that you did not vaccinate in 2011, that there is BTV-8 introduction in the Netherlands in 2011, that you farm will be infected and that you did vaccinate in 2010. P (D | NV, T, I, NV2010) is the probability that your animals did become diseased in 2011 under de condition that you did not vaccinate in 2011, that there is BTV-8 introduction in the Netherlands in 2011, that you farm will be infected and that you did not vaccinate in 2010. P (ND | NV, NI) is the probability that your animals did not become diseased in 2011 under de condition that you did not vaccinate in 2011 and that you farm will not be infected in 2011.

Pay off functions
The pay off functions are dependent of the decision. When a farmer decide to vaccinate, they have only the vaccination cost. When a farmer decides not to vaccinate, they have perhaps costs of disease, but this dependents on the introduction of BTV-8 and the infection probability of the farm. It is also possible that the farm will not be infected, so the animals did not become diseased.

3.3 Gathering the input values

The input values for the various items are obtained by experts (A.G.J. Velthuis and A.R.W. Elbers) and by literature (Velthuis *et al.*, 2009 and Elbers *et al.*, 2009b).

Herd size input

Figure 10 gives an overview of the herd size, i.e. the number of dairy cows on a farm after 1000 iterations. It is a RiskPert distribution with include a minimal value, a most likely value and a maximal value. The distribution is based on the data of LEI/CBS. The median is set on 72 dairy cows, but this is the average number of dairy cows on a farm in the Netherlands.

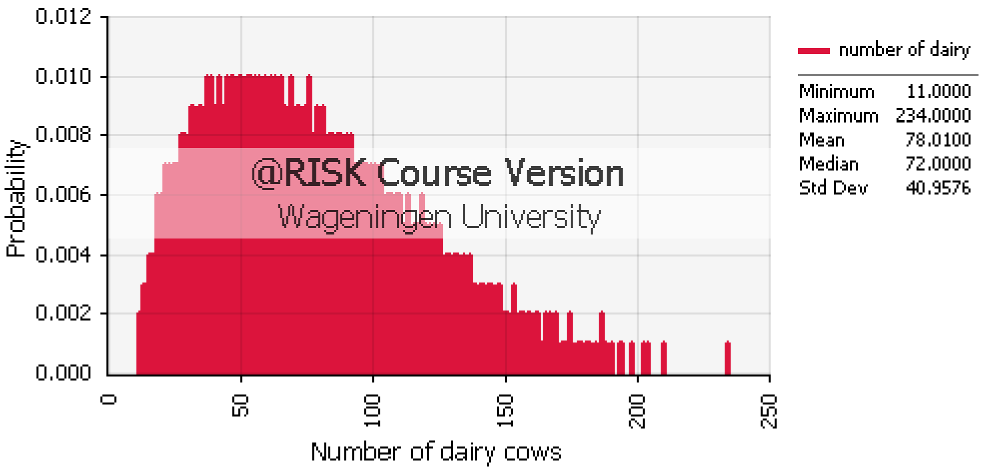

Figure 10: Number of dairy cows on a farm after 1000 iterations

Financial input

In table 2, you can see the epidemiological input values for the cost calculation of vaccination and disease. Some input values are a value while others are a distribution.

Table 2: Epidemiological input values for the cost calculation of vaccination and disease

Variable	Description	Value	Distribution	Min.	ml.	Max.	Unit
C	call out fee of the veterinarian	20.85					€ / visit
HR	hourly rate of the veterinarian	116.17					€ / hours
D	duration of the herd vaccination	1					hours
HS	herd size		RiskPert(min;ml;max)	11	72	234	# / farm
V	costs of the vaccine	0.40					€ / doses
M	costs of dispense material	0.02					€ / animal
R	costs of registration	0.05					€ / animal
MTR	mortality rate		RiskPert(min;ml;max)	0,00	0,00	4,80	animals / 100 animal months
PR	period at risk	6					months
SV	slaughter value	525					€ / animal
PV	production value	785					€ / animal
DC	disposal costs	26.02					€ / animal
PO_1	BTV-8-infected cows culled earlier	0.03					proportion animals / year
MBR	morbidity rate		RiskPert(min;ml;max)	0.00	0.30	11.00	animals / 100 animal months
AM	average milk production	26.90					kg milk / animal / day
RM	relative reduction in milk production	20					kg milk / animal
DD	# days that animal is diseased	9					days
VM	value of milk that is not produced	0.06					€ / kg milk
PO_2	cows with an increased number of cycles before gestation		RiskPert(min;ml;max)	0.00	0.40	0.67	proportion animals / year
EI_1	costs of the first extra insemination	23.75					€ / animal
LC_1	length of one cycle	30					Days / cycle
CI_1	loss of a calving interval per day	9					€ / animal
PO_3	cows that aborts due to an BTV-8 infection		RiskPert(min;ml;max)	0.00	0.00	0.12	proportion animals / year
EI_2	costs of the second extra insemination	13.85					€ / animal
CI_6	length of six cycles	101.9					€ / animal
PO_4	animals without calf	0.05					proportion animals / year
VC	loss value of calf	163.06					€ / animal
FH	costs of feed and housing that are not made	3.57					€ / animal
ΔSV	increased slaughter value in relation to average cow	45.80					€ / animal
PO_5	animals who exhibit weight loss	0.07					proportion animals / year
EF	costs of extra feed that is required for compensatory growth	5.60					€ / animal
FR	drop in feed intake during the first days of disease	2.00					€ / animal
PO_6	calves with lower body weight due to BTV-8	0.03					proportion animals / year
ΔVC	reduced price paid for calf	24.46					€ / animal
PO_7	reproductive animals that have a stillbirth due to BTV-8	0.004					proportion animals / year
FC	costs incurred before sale of young calf, i.e. the feed costs	3.57					€ / animal
CD	costs of Non-Steroidal Anti-Inflammatory Drugs	15.00					€ / animal
A_1	costs of antibiotic 1	25.00					€ / animal
A_2	costs of antibiotic 2	75.00					€ / animal

Figure 11 gives an overview of the simulated costs of vaccination per year after 1000 iterations. It is a RiskPert distribution with include a minimal value, a most likely value and a maximal value. In 2008, the costs of vaccination are considerably lower, this is because the government subsidized a part of the costs in that year. Upwards of 2009, there is no subsidizing, The costs of the consecutive years are each year somewhat higher due to the discounting effect. The variation in the costs is due to the variation in herd size of the farms. In 2008, the variation is less than in other years, because in that year the costs of the vaccine are fully subsidized and these costs are direct related to the herd size, so they ensure the greatest variation.

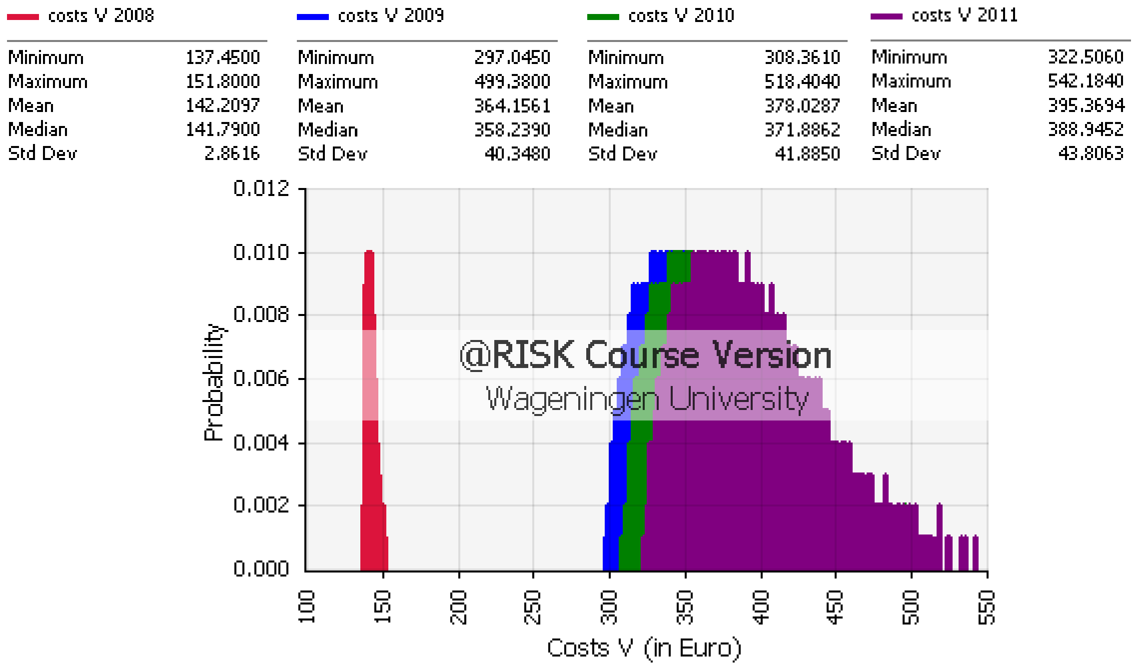

Figure 11: Simulated costs of vaccination per year after 1000 iterations

Figure 12 gives an overview of the simulated costs of disease per year after 1000 iterations. It is a RiskPert distribution with include a minimal value, a most likely value and a maximal value. Each year are the costs somewhat higher due to the discounting effect. De variation in the costs of disease is due to the variation in herd size of the farms.

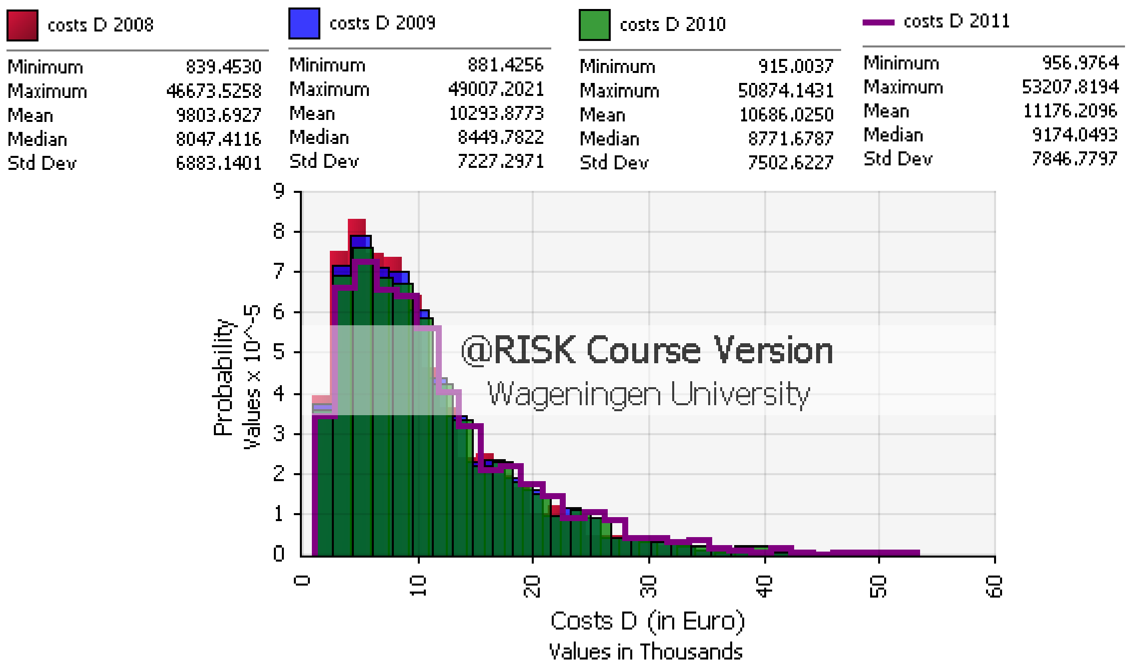

Figure 12: Simulated costs of disease per year after 1000 iterations

Probability input for the uncertain events

The probability input consist of probability of farm infection (P (I)), probability of animals diseased (P (D)) and probability of introduction (P (T)), which are the uncertain events. Table 3, 4, 5 and 6 gives the probability input for each year resp. 2008, 2009, 2010 and 2011. An expert was ask to get these values (A. Elbers).

Table 3: Probability input for 2008

Probability	Value	Distribution	min.	ml.	max.
P (NI | V)	1,00				
P (I | NV, D2007)		RiskPert(min;ml;max)	0,000	0,070	0,100
P (I | NV, ND2007)		RiskPert(min;ml;max)	0,000	0,020	0,050
P (NI, NV)		1 - P (I | NV, D2007) - P (I | NV, ND2007)			
P (ND | V)	1,00				
P (D | NV, I)	1,00				
P (ND | NV, NI)	1,00				

Table 4: Probability input for 2009

Probability	Value
P (NI | V)	1,00
P (NI | NV, V2008, ND2008) (=2009A)	1,00
P (NI | NV, NV2008, ND2008) (=2009B)	1,00
P (NI | NV, NV2008, D2008) (=2009C)	1,00
P (ND | V)	1,00
P (ND | NV)	1,00

Table 5: Probability input for 2010

Probability	Value	Distribution	min.	ml.	max.
P (NI | V) = 1 - P (I | V)	1,00				
P (I | NV, V2009, ND2009) (=2010A)		RiskPert(min;ml;max)	0,000	0,003	0,010
P (NI | NV, V2009, ND2009) (=2010A)		1 - P (I | NV, V2009, ND2009)			
P (I | NV, NV2009 ,ND2009) (=2010B)		RiskPert(min;ml;max)	0,000	0,005	0,010
P (NI | NV, NV2009, ND2009) (=2010B)		1 - P (I | NV, NV2009, ND2009)			
P (ND | V) = 1 - P (D | V)	1,00				
P (ND | NV, I, V2009)	1,00				
P (D | NV, I, NV2009)	1,00				
P (ND | NV, NI)	1,00				

Table 6: Probability input for 2011

Probability	Value	Distribution	min.	ml.	max.
P (T)		RiskPert(min;ml;max)	0,000	0,100	0,200
P (NT)		1 - P (T)			
P (NI | V)	1,00				
P (I | NV, T, V2010, ND2010) (=2011A)		RiskPert(min;ml;max)	0,000	0,010	0,020
P (NI | NV, T, V2010, ND2010) (=2011A)		1 - P (I | NV, T, V2010, ND2010)			
P (I | NV, T, NV2010, ND2010) (=2011B)		RiskPert(min;ml;max)	0,000	0,015	0,030
P (NI | NV, T, NV2010, ND2010) (=2011B)		1 - P (I | NV, T, NV2010, ND2010)			
P (I | NV, T, NV2010, D2010) (=2011C)		RiskPert(min;ml;max)	0,000	0,026	0,050
P (NI | NV, T, NV2010, D2010) (=2011C)		1 - P (I | NV, T, NV2010, D2010)			
P (NI | NT)	1,00				
P (ND | V)	1,00				
P (ND | NV, T, I, V2010)	1,00				
P (D | NV, T, I, NV2010)	1,00				
P (ND | NV, NI)	1,00				

3.4 Analyzing the decision tree

When we analyse the BTV-8-tree, we can predict what the farmer will decide on whether to vaccinate his herd against BTV-8 or not in 2008, 2009, 2010 and 2011. The Dutch government can respond on it and can make a subsequent policy to control BT. We have run the BTV-8 tree 1000 times, because you need enough repetitions to get a reliable conclusion. Because the tree was large, automatic running was not possible. So, all iterations are performed by hand. Therefore it was not possible to run the BTV-8 tree more often.

When we solve the whole BTV-8-tree for 1000 iterations they give the economic optimal decision to vaccinate 967 times, which is equivalent to 96.7%, in 2008. The 33 farms wherefore it is not economic better to vaccinate in 2008 are all small farms (<20 dairy cows). In 2009, 2010 and 2011 all 1000 iterations suggest not to vaccinate. So, in these years it is economic better to take the low risk that your animals might become diseased.

Figure 13 gives an overview of the net costs in 2008. As you can see, it is economic better to decide to vaccinate, because than the net costs are significantly lower. In the box plot for the decision not to vaccinate (NV2008), there are some outliers which has less net costs than for the decision to vaccinate (V2008), these are the small farmers (<20 dairy cows). But there are also much outliers that result in high net costs, these are most large farmers. So, when you decide not to vaccinate the net costs has much variation, because the costs of disease are dependents highly on the herd size. The cost of vaccination dependents however also on the herd size, but by these costs has the herd size less influence.

Table 7 gives a total overview of the different decisions with the related EMVs. In this table you can see the different net costs which you have if you decide to vaccinate or not, with taking into account the situation in the previous year. The net costs are split up in minimal value, median value, mean value and maximum value. The last column shows the difference between the median EMV between the decision not to vaccinate minus the decision to vaccinate. In 2008 this difference has a negative value, i.e. in that year the economic optimal decision is to vaccinate your herd. Furthermore, through the insertion of the situation of the previous years, you can see what the effect is. When you decide not to vaccinate in all years and you got double trouble because your animals become diseased, then the net costs are very high (with a median of approximately 17,000 euro). This is the result of two times disease (in 2008 and 2010, in 2009 there was no virus circulation). This corresponds to figure 7, because there you can see that the median of the costs of disease is approximately 8,500 euro. When you are lucky and you decide not to vaccinate and you animals did not become diseased, your net costs are quite low.

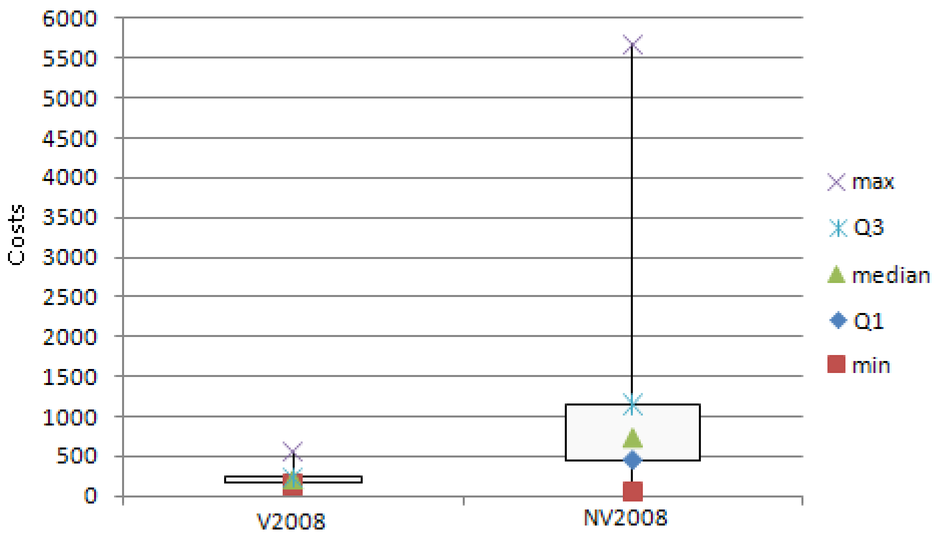

Figure 13: Net costs in 2008

Table 7: Total overview of the different decisions with the related EMVs: result of 1000 iterations

Decision year	Decision V	Situation previous year(s)			EMV (net) costs				Median V_{yes}-V_{no}
		2008	2009	2010	Min	Median	Mean	Max	
2008	Yes				141	197	212	553	
	No				53	732	920	5672	- 535
2009	Yes	V			436	516	522	698	
	No	V			141	197	212	553	319
	Yes	NV+D			1215	8360	10216	58531	
	No	NV+D			921	8016	9906	58322	344
	Yes	NV+ND			299	374	380	548	
	No	NV+ND			4	55	70	407	319
2010	Yes	V	V		745	872	883	1149	
	No	V	V		436	516	522	698	356
	Yes	V	NV+ND		447	514	520	659	
	No	V	NV+ND		141	197	212	553	317
	Yes	NV+D	V		1522	8703	10577	58975	
	No	NV+D	V		1215	8360	10216	58531	343
	Yes	NV+D	NV+ND		1224	8349	10213	58526	
	No	NV+D	NV+ND		921	8016	9905	58322	333
	Yes	NV+ND	V		607	730	741	998	
	No	NV+ND	V		299	374	380	548	356
	Yes	NV+ND	NV+ND		309	372	377	508	
	No	NV+ND	NV+ND		4	55	70	407	317
2011	Yes	V	V	V	1069	1261	1278	1680	
	No	V	V	V	745	872	883	1149	389
	Yes	V	V	NV+ND	759	889	901	1172	
	No	V	V	NV+ND	436	516	522	698	373
	Yes	V	NV+ND	V	770	903	914	1191	
	No	V	NV+ND	V	447	514	520	659	389
	Yes	V	NV+ND	NV+D	1459	9226	11258	63921	
	No	V	NV+ND	NV+D	1136	8854	10893	63535	372
	Yes	V	NV+ND	NV+ND	461	531	537	683	
	No	V	NV+ND	NV+ND	138	155	159	257	376
	Yes	NV+D	V	V	1846	9097	10972	59462	
	No	NV+D	V	V	1522	8703	10577	58975	394
	Yes	NV+D	V	NV+ND	1537	8719	10594	58996	
	No	NV+D	V	NV+ND	1215	8360	10216	58531	359
	Yes	NV+D	NV+ND	V	1548	8733	10608	59013	
	No	NV+D	NV+ND	V	1224	8349	10213	58526	384
	Yes	NV+D	NV+ND	NV+D	2236	17069	20952	121832	
	No	NV+D	NV+ND	NV+D	1913	16678	20586	121447	391
	Yes	NV+D	NV+ND	NV+ND	1239	8366	10231	58547	
	No	NV+D	NV+ND	NV+ND	917	7985	9853	58082	381
	Yes	NV+ND	V	V	931	1119	1136	1529	
	No	NV+ND	V	V	607	730	741	998	389
	Yes	NV+ND	V	NV+ND	622	747	758	1021	
	No	NV+ND	V	NV+ND	299	374	380	548	373
	Yes	NV+ND	NV+ND	V	633	761	772	1040	
	No	NV+ND	NV+ND	V	309	372	377	508	389
	Yes	NV+ND	NV+ND	NV+D	1321	9085	11116	63773	
	No	NV+ND	NV+ND	NV+D	998	8710	10750	63387	375
	Yes	NV+ND	NV+ND	NV+ND	324	389	395	531	
	No	NV+ND	NV+ND	NV+ND	0	13	17	113	376

3.5 Performing a sensitivity analysis

We have performed a sensitivity analysis for the probability of infection and the vaccination costs. For the probability of infection is the question: what will happen if the chance on infection will increase? The infection probability is only increased in this sensitivity analysis, because these probabilities are quite low. This sensitivity analysis is only possible by increasing all the infection probabilities with the same multiplication in all years. There are two different scenarios created. For scenario 1, all infection probabilities are multiplied two times and for scenario 2 are all infection probabilities multiplied three times. These results of this analysis, which are shown in table 8, are a logical consequence when the infection probabilities are increased. In the default situation nearly all farmers vaccinate in 2008. When we increase the probability of infection, more farmers will decide this. In 2009, all farmers don't vaccinate, because in that year there wasn't any virus introduction. In 2010 some of the large farmers will vaccinate because of the higher chance of infection. In 2011, none of the farmers vaccinate.

For the vaccination costs is the question: what will happen if the farm can vaccinate his animals by himself, i.e. the farmer has only the costs of the vaccine. There is one scenario created, called scenario 3. For scenario 3, the farmer's costs of vaccination for the farmer are: 2 * HS * (V + M + R). The results of this analysis, which are shown in table 8, are a logical consequence when we omit the veterinary costs. More farmers decide to vaccinate, because of the vaccination costs are quite low compared with the risk of disease and the subsequent costs.

Table 8: Percentage of Dutch dairy farms that decide to vaccinate in a specific year with different scenarios. Scenario 1 = infection probabilities multiplied two times; scenario 2 = infection probabilities multiplied three times; Scenario 3 = omission the veterinary costs

	% Dutch dairy farmers															
	Default				Scenario 1				Scenario 2				Scenario 3			
Year :	**08**	**09**	**10**	**11**	**08**	**09**	**10**	**11**	**08**	**09**	**10**	**11**	**08**	**09**	**10**	**11**
Farm size ↓																
<50	0	0	0	0	100	0	0	0	100	0	0	0	100	0	9	1
50-100	97	0	0	0	100	0	0	0	100	0	0	0	100	0	10	1
>100	97	0	0	0	100	0	3	0	100	0	8	0	100	0	10	1

4. Conclusion and discussion

The output of the BTV-8-tree shows that the economic optimal decision regarding to vaccination is that farmers should vaccinate their herd in 2008. In the subsequent years it is economic better not to vaccinate. This seems logical, because if we assume that most farmers vaccinate in 2008, the virus circulation in the vectors is relatively low in the coming years (because there are no cases whereof they can get the virus), which result in less infective vectors.

In 2008 the vaccination campaign was partly subsidized by the EU, so the costs of vaccination in that year where considerably lower than the subsequent years without subsidizing. In addition, the farmers (and the government) were warned by the outbreak with the large impact in the previous year. These are two motivations to vaccinate in 2008 and not in another year. In 2009, there was no virus circulation in the Netherlands, probably due to the fact that the vast majority of susceptible animals would have already BTV-8 antibodies through the outbreaks in previous years and the vaccination in 2008. So vaccination wasn't needed in 2009. The BTV-8-tree suggests that the dairy herd in 2010 and 2011 is sufficiently protected against BTV-8, so vaccination isn't needed. The low probability of introduction and infection plays hereby also a role, because if a herd will become diseased, the costs would be high. The vaccination costs are significantly lower than the costs of disease. So, if you decide not to vaccinate, you have to be almost sure that your animals doesn't become diseased (otherwise you have high costs). When almost all farmers participate in one vaccination campaign (2008) then is the risk of an outbreak in the coming year(s) much less likely. Because the virus circulation is very low and the most animals have antibodies against BTV-8. Seeing the probability of infection is very low, it is economic not optimal to vaccinate, because the probability that your animals become diseased is almost zero.

The introduction and infection probabilities are hard to estimate. We have asked an expert to get a good estimating of this probabilities. But the future is uncertain and things can happen which we cannot judge in advance. For example, there is also a risk of a major outbreak in another EU country, which will increase the introduction and infection probability in the Netherlands considerably. We have tried as much as possible to take these consequences into account. During the conversation with the expert we discussed a lot of scenarios; hereby we came up with for example the insertion of the introduction probability in 2011. However, with the sensitivity analysis is shown that the number of farmers that decide to vaccinate not much change if we change the infection probabilities. When we multiply the probabilities 3 times (this is 300%), we see not much change with respect to the default situation. This is also because the probabilities of infection are quite low.

We assumed that the reason behind the optimal vaccination decision is located in the area of herd replacement. When a herd is vaccinated in 2008 and a herd replacement of 33% consists, the herd is in three years fully replaced and therefore fully susceptive to BTV-8. If we know this, it is better to enlarge the BTV-8-tree by a few years. In this way, we can investigate when a farmer have to vaccinate his herd again (assuming that the farmer vaccinated his herd in 2008).

The costs of vaccination are sensitive to changes. When the costs of the veterinarian are excluded, much more farmers decide to vaccinate their herd. This is an important outcome, because most farmers are able to vaccinate his herd by themselves. One can develop a course with certification that the farmer entitled to vaccinate his own herd. However, we must consider that this has some constrains. Firstly, this also implies a cost. Secondly, this strategy results in missed costs for the veterinarian. And thirdly, it can harm animal welfare, because the farmer has less experience with applying a vaccination.

The method which is used in the study is a good tool in decision making. A decision tree is easy to understand and you can use parameters distributions, when you are uncertain about the knowledge of the probability. However, the probabilities are estimations, so is it not realistic data. For the economic optimal solution regarding to vaccination, we have run the BTV-8-tree 1000 times. Due to practical reasons we have run the BTV-8-tree not more often. This was because the BTV-8-tree was too large to run them automatically. So all iterations were performed by hand. But 1000 iterations give a good reflection of the situation. Furthermore, the BTV-8 tree has restrictions, for example you cannot take all aspects into account. In the BTV-8-tree we used rational decision making. Therefore only economic and epidemiological data are used, whereas other decision criteria are excluded. If we extent the BTV-8-tree and include the psychological aspects and the risk preference of the farmer, the results may change. Because some farmers want to maximize the animal welfare or are fully risk averse. These farmers want to vaccinate their herd every year and do not worry about the extra costs of vaccination. Other farmers just decide not to vaccinate, because the risk of introduction is quite low and they want to take this risk. This would be a good research in the future.

The BTV-8-tree and especially the costs of vaccination and disease depends on the herd size. When a individual farmer use the BTV-8-tree, he can fill in his own herd size instead of the distribution of the average herd size in the Netherlands. In this way, he gets an farm specific solution, so the BTV-8-tree is usable for individual decision making of a Dutch farmer.

This study can be helpful for researchers who want to do a similar study for sheeps or for another disease. They can use the method and maybe some input values of this study. Also, the Dutch government can respond on this study and can make a subsequent policy to control BT. During policy making the government can use the results of this study. At the moment, the Dutch policy stimulates every year to vaccinate against BT, but in this study is shown that you don't have to vaccinate your herd every year. It is more effective that all farmers vaccinate their herd in the same year, because this result in less infective vectors, because they cannot take the virus from the environment. In this way, BT has no chance to survive. When the government one year encourage the farmers to vaccinate and the next year they do not, more farmers will decide to vaccinate because they save the costs of vaccination for one year. Thus, with this strategy we control BT in an more efficient way compared to the situation that every year a part of the farmers vaccinate and the vector get the opportunity to spread BT among the ruminants which are not vaccinated.

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