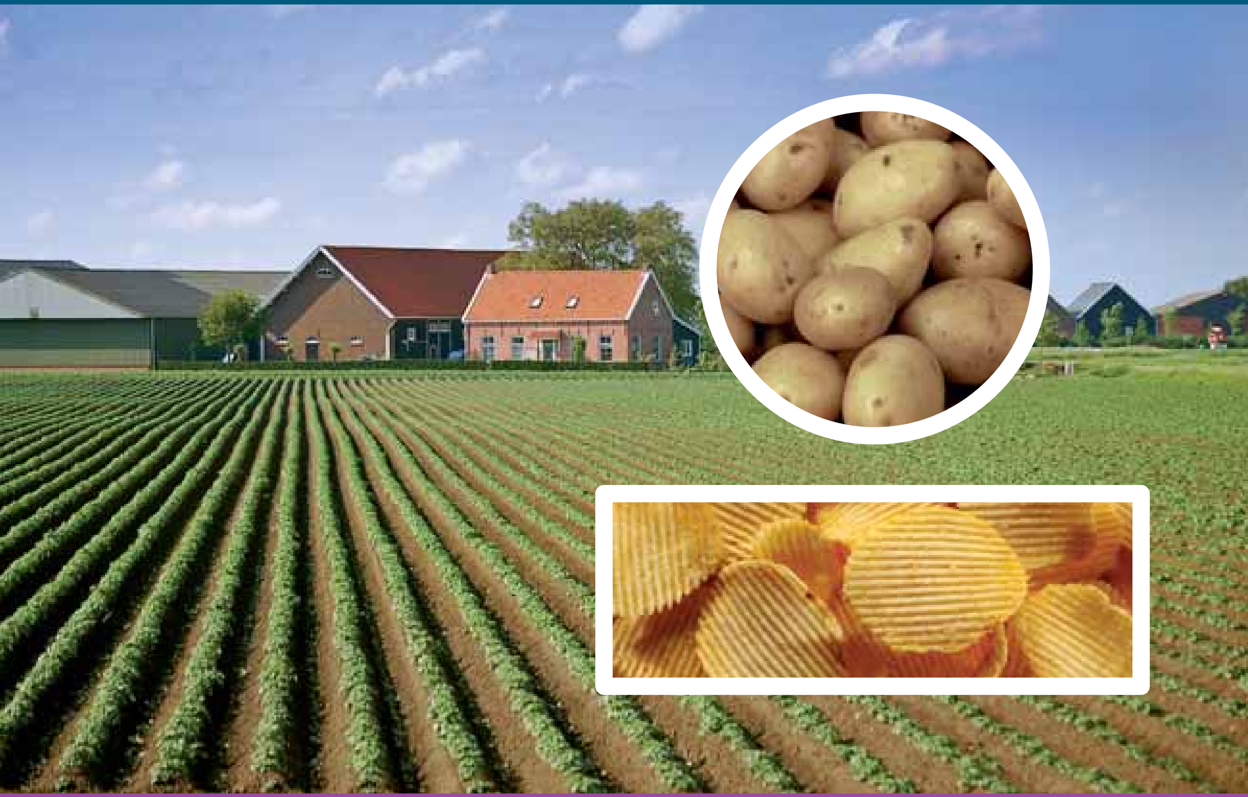
Chain Risk Model for quantifying cost effectiveness of phytosanitary measures



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Chain Risk Model for quantifying cost effectiveness of phytosanitary measures

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A Chain Risk Model (CRM) was developed for a cost effective assessment of phytosanitary measures. The CRM model can be applied to phytosanitary assessments of all agricultural product chains. In CRM, stages are connected by product volume flows with which pest infections can be spread from one stage to another. The arrangement of these stages can be varied. Experience with CRM was acquired through two cases: Clavibacter in Tomatoes and PSTVd (Potato Spindle Tuber Viroid) in potatoes. Employees from the Dutch Plant Protection Service (PD) will initially test CRM.

Ten behoeve van een onderbouwde kosten effectieve afweging tussen fytosanitaire maatregelen is een Keten Risico Model ontwikkeld. Het KRM model is toepasbaar voor alle agrarische productketens. In het model zijn ketenschakels verbonden door product volume stromen, waarmee infecties kunnen worden verspreid. De rangschikking van de keten schakels kan door de gebruiker van het model worden gevarieerd. Met het model is ervaring opgedaan aan de hand van een tweetal cases: Clavibacter in tomaat en Potato Spindle Tuber Viroid (PSTVd) in aardappel. In eerste plaats wordt beoogd medewerkers van de PD te laten werken met KRM.

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Contents

Preface

As international trade increases, phytosanitary problems are becoming more and more important. On the other hand, there is a tendency to shift phytosanitary tasks and responsibilities from government to business. For this reason, there is need for a model which enables the user to assess different phytosanitary measurements or combinations of measurements. Furthermore, there is an increasing tendency to follow a product chain approach in the phytosanitary area. This was the incentive for the development of a Chain Risk Model (CRM) by LEI Wageningen UR and the Dutch Plant Protection service (PD).

Developing the CRM involved intensive collaboration between LEI Wageningen UR and PD. A sounding board consisting of I. Koomen J. Heres, P. Jellema (all PD) and the authors of this report worked intensively together, following the principle of improving knowledge and anticipating the wishes of future users of CRM. In addition, participants from business were also consulted to check the usefulness of CRM for them and receive feedback. Those consulted were S. Poot and J. den Dekker (Plantum), A. Toussaint and H. van der Haar (both NAK-Agro), M. de Graaf (KCB) and J.H. Hoogenboom (HZPC).

Besides the sounding board, a scientific guidance committee consisting of Professor O. van Kooten, Dr W. v.d. Werf and Dr J.H. Trienekens guided this project. We would like to thank them all for their valuable input.

Professor R.B.M. Huirne
Director General LEI Wageningen UR

Summary

Problems with pest infection for agricultural products are becoming more and more common in the EU due to increasing trade between countries and changing climate. Diseases may have a major economic impact. For this reason, phytosanitary measures are taken to prevent the introduction, spread and establishment of pests. This problem directly or indirectly affects agricultural product supply chains as a whole, where different stakeholders are involved with inherent interests regarding phytosanitary problems.

Optimally distributing limited financial and human resources for phytosanitary measures over the chain stages is a complex problem. In order to take the right decisions, the financial results of different measurement scenarios must be compared. A chain risk model (CRM) was developed to calculate the costs and the financial impact of various alternative measures against pests for product chains as a whole and for individual chain stages.

Outline of CRM

The model is a generic template for a static and deterministic economic model which makes it possible to develop individual agricultural chain models for different agricultural products where pests and pathogens are of phytosanitary concern. A chain in the model is arranged according to an existing agricultural chain. A stream of products goes through the chain; each stage involves inflow from previous stages (import), processing activities and outflow to successive stages (export). The entities in the model are: volumes of products, the number and size of lots, and the number of infected objects in each lot.

In CRM, each stage in the chain has the same structure, only the values of the stage objects differ. Processing activities in each stage are characterised by the type of stage involved. Activities may be growing, production, multiplication, processing, transport, storage or selling. Inflow and activities contribute to the level of infection, as do infection from outside and spread. Phytosanitary measures can be taken in one or more chain stages to reduce the risk of infection and spread in that stage and to reduce crop and export damage due to infection. Types of measures distinguished in CRM are: import inspection, preventive measures, curative measures and stage inspection. Measures result in cost effectiveness of these measures, not only for the stage concerned but also for the chain as a whole. In each stage, a different combination of measures can be applied and for each measure it is possible to assign the intensity

of application, the effect on the infection or spread and labour or other costs. For inspection, information about the sample and quality of the test is required. Other aspects like risk of infection from outside or spread are entered, independent of the measures to be taken. Calculations result in costs for the stakeholders involved, cost effectiveness of measures to be taken, (avoided) damage, volumes and infection levels.

In each stage, the infected lots and farms are calculated. A lot is infected if one or more objects in this lot are infected. This infection may increase, spread or fade away and may infect other lots on the same farm or on other farms. CRM calculates the distribution of infected objects among lots and the distribution of infected lots among farms.

The model calculates the number of lots in each of the four infection categories, e.g. the category 'Severely infected'. Since pests are not distributed randomly and are found in aggregated spatial patterns, the Negative Binomial Distribution is applied in CRM to calculate the number of infected lots in each chain stage.

Possibilities of using the model

CRM can be used for following purposes:

- Choice between different combined measures against different pests;
- Allocation problems: it concerns different intensities of measures or application in different stages combined with variation of intensity;
- Consequences of shifting responsibilities between stakeholders; When responsibility for implementing phytosanitary measures shifts from government to business, for example, the impact can be calculated with CRM;
- Dealing with uncertainty: CRM can be used to make sensitivity calculations.

Two case studies of actual problems

The use of the model is illustrated with two case studies, Clavibacter Michicanensis in tomatoes and Potato Spindle Tuber Viroid (PSTVd) in potatoes. The aim of case studies is to validate CRM, to make employees of the Dutch Plant Protection Service (PD) familiar with the model, to ensure that the model output is realistic and to promote and provide a guideline for the best way of working. The development of cases was an iterative process resulting in a number of improvements of CRM. Data collection is very important for these case studies and for using of CRM in future. Different scenarios were used for the calculations, based on the current situation as reference. This produced some interesting results, for example regarding to zero tolerance of export; minimising the population of the pest is an important goal of the phytosanitary measures. The zero population level can only be reached when the measures are implemented more intensively, especially import inspection and chain stage inspection in an early stage. However, it will be difficult or impossible to reach zero infection. Regarding the PSTVd case in potatoes, the model illustrates that import inspection alone is not sufficient and that additional chain stage inspection is required (most cost effective).

Discussion

The impact of phytosanitary measures often extends beyond the period in which products pass through a chain. In CRM, the factor time is handled in a static way, which is a simplification of the reality. Some aspects are discussed to make CRM more dynamic.

There is a tension between the generic and aggregated approach of CRM and the detailed approach that might be required. However, for the kind of assessment problems and economic scale (sector) for which CRM is intended, an aggregated approach is desired. A more detailed approach would require more data collection and a more complex model.

Infection from outside in the way it plays a role in CRM is a collection of infection from different pathways. If data are not available in a short time, this infection is assumed to be at a certain level. However, if data are available, it should be collected proactively before the actual problem is expressed. For the intended use of CRM, data collection should be properly organised, data sources should be known and the product chains of the main agricultural export products defined beforehand.

The use of the Negative Binomial Distribution is discussed, especially the way in which the clustering parameter is estimated. For the future, this will need further attention and improvement.

Every simulation model is an imitation of reality. The results of calculations with CRM will always deviate from reality to some extent as well. Calculations based on logic and relevant data result in more reliable estimates than estimates based on intuition.

CRM is intended to be used before phytosanitary measures are taken. The extent to which model output differ from real outcomes afterwards depends on the quality of the data. Furthermore, great uncertainty is to be expected due to the estimate of the risk of infection from outside, the risk of infection via import and the rate of clustering. This is why CRM is most suitable for carrying out sensitivity calculations. CRM requires a lot of experience to use. Phytosanitary problems need a proactive approach with little time to carry out calculations. A proactive use of CRM requires the availability of different constructed product chains filled with data. In this way, calculations can be carried out before a problem becomes reality, which then makes CRM a workable tool.

Samenvatting

Problemen met besmetting van landbouwproducten door plagen komen steeds vaker voor in de EU als gevolg van de toenemende handel tussen landen en het veranderende klimaat. Ziektes kunnen grote economische gevolgen hebben. Daarom worden er fytosanitaire maatregelen genomen om de introductie, verspreiding en vestiging van ziektes te voorkomen. Dit is direct of indirect het probleem van de toeleveringsketens van landbouwproducten als geheel, waar verschillende betrokkenen elk hun eigen belangen hebben als het gaat om fytosanitaire problemen.

Het is behoorlijk ingewikkeld om de beperkte financiële middelen en mankracht die beschikbaar zijn voor fytosanitaire maatregelen optimaal over de verschillende schakels van de keten te verdelen. Om de juiste beslissingen te kunnen nemen, moeten de financiële resultaten van verschillende scenario's met elkaar worden vergeleken. Er wordt een ketenrisicomodel (KRM) ontwikkeld om de kosten en de financiële gevolgen van verschillende alternatieve maatregelen voor productketens als geheel en voor verschillende schakels afzonderlijk te berekenen.

Overzicht van KRM
Het ketenrisicomodel is een generieke sjabloon voor een statisch en deterministisch economisch model die het mogelijk maakt om afzonderlijke landbouwketenmodellen te ontwikkelen voor de verschillende landbouwproducten waarbij plagen en pathogenen een fytosanitair probleem vormen. De ketens in het model zijn gebaseerd op bestaande landbouwketens. Elke keten bestaat uit meerdere schakels en in elke schakel is er een toestroom van importproducten of producten uit eerdere schakels. Deze producten worden dan verwerkt, waarna ze naar de volgende schakel gaan of worden geëxporteerd. Bij het model gaat om de volgende gegevens: de productvolumes, het aantal partijen en de grootte ervan, en het aantal besmette producten per partij.

In KRM heeft elke schakel van de keten dezelfde structuur en verschillen alleen de waarden voor de producten per schakel. De verwerkingsactiviteiten in elke schakel worden gekenmerkt door het type schakel. De activiteiten kunnen zijn teelt, productie, vermeerdering, verwerking, transport, opslag of verkoop. De toestroom en de activiteiten dragen bij aan het besmettingsniveau, de besmetting van buitenaf en de verspreiding. Om de kans op besmetting en verspreiding in een bepaalde schakel te reduceren en om de schade aan gewassen

en exportproducten als gevolg van besmetting te verminderen, kunnen er in een of meerdere schakels van de keten fytosanitaire maatregelen worden getroffen. Binnen KRM worden er verschillende soorten maatregelen onderscheiden: importcontrole, preventieve maatregelen, curatieve maatregelen en schakelcontrole. De resultaten tonen aan hoe kosteneffectief deze maatregelen zijn, niet alleen voor de betreffende schakel, maar ook voor de keten als geheel. In elke schakel kunnen de maatregelen in een andere samenstelling worden toegepast waarbij er voor elke maatregel kan worden bepaald hoe intensief deze moet worden toegepast, wat het effect moet zijn op de besmetting of verspreiding en hoeveel werk en andere kosten hiervoor moeten worden uitgetrokken. Voor de controle maatregelen zijn er gegevens over het monster en de kwaliteit van de test nodig. Er wordt ook rekening gehouden met andere aspecten, zoals de kans op besmetting van buitenaf en de verspreiding, ongeacht welke maatregelen er moeten worden genomen. De uitkomst is een schatting van de kosten voor betrokken belanghebbenden, de kosteneffectiviteit, de (vermeden) schade, de volumes en de besmettingsniveaus.

In elke schakel wordt er berekend hoeveel besmette partijen en bedrijven er zijn. Een partij is besmet als een of meer producten in deze partij besmet zijn. Deze besmetting kan uitbreiden, zich verspreiden of geleidelijk verdwijnen en er kunnen andere partijen bij hetzelfde bedrijf of bij andere bedrijven besmet worden. KRM berekent de verspreiding van besmette producten binnen partijen en de verspreiding van besmette producten binnen bedrijven.

Het model berekent hoeveel partijen er in elk van de vier besmettingscategorieën vallen, bijvoorbeeld de categorie 'ernstig besmet'. Aangezien plagen zich niet willekeurig verspreiden maar geaggregeerde ruimtelijke patronen volgen, wordt in het KRM de negatief binomiale verdeling toegepast om het aantal partijen in elke categorie te berekenen.

Toepassingsmogelijkheden van dit model

KRM kan worden gebruikt voor:

- het kiezen tussen verschillende combinaties van maatregelen tegen verschillende plagen;
- het signaleren van toewijzingsproblemen. Dit heeft te maken met maatregelen die elk met een andere intensiteit worden toegepast of die in verschillende schakels steeds met een andere intensiteit worden toegepast;
- het bepalen van de gevolgen wanneer er een verschuiving van de verantwoordelijkheden plaatsvindt. Als de verantwoordelijkheid voor het uitvoeren van fytosanitaire maatregelen bijvoorbeeld verschuift van de overheid naar

het bedrijfsleven, dan heeft dit bepaalde gevolgen die kunnen worden berekend met KRM;
- het omgaan met variabelen. KRM is geschikt voor het doen van gevoeligheidsbepalingen.

Twee casestudies van problemen uit de praktijk

De toepassing van dit model wordt geïllustreerd aan de hand van twee casestudies: aardappelspindelknolviroïde (PSTVd) bij aardappelen en ringrot bij tomaten. Aan de hand van deze casestudies willen we KRM illustreren zodat medewerkers van de Plantenziektenkundige Dienst (PD) vertrouwd kunnen raken met het model en ervoor zorgen dat de output van het model realistisch is. Op basis hiervan kan worden bepaald wat de beste manier van werken is. De ontwikkeling van de cases was een iteratief proces dat bovendien tot een aantal verbeteringen in KRM heeft geleid. Het verzamelen van gegevens is uiterst belangrijk voor deze casestudies en voor de toepassing van KRM in de toekomst. De berekeningen worden gebaseerd op verschillende scenario's en de huidige situatie wordt ter referentie gebruikt. Dit leidde tot enkele interessante resultaten. Gezien de nultolerantie voor export is het bijvoorbeeld belangrijk dat de Clavibacter-populatie met behulp van fytosanitaire maatregelen zo klein mogelijk wordt gehouden. Er kan alleen een nulniveau van de populatie worden bereikt als de maatregelen intensiever worden uitgevoerd. Het gaat dan met name om vroegtijdige import- en schakelcontrole. Het zal echter zeer moeilijk of zelfs onmogelijk zijn om het niveau van infectievrij te bereiken. Bij de casestudy met betrekking tot PSTVd bij aardappelen toont het model aan dat alleen importcontrole niet voldoende is en dat er meer controle nodig is in de verschillende schakels van de keten (meest kosteneffectief).

Discussie

De gevolgen van de fytosanitaire maatregelen werken vaak langer door dan de doorlooptijd van een product is. In KRM wordt de tijdfactor statisch behandeld. Het is een vereenvoudiging van de werkelijkheid. Er wordt een aantal aspecten besproken om KRM dynamischer te maken.

De generieke en geaggregeerde benadering van KRM is niet zo gedetailleerd als misschien nodig zou zijn. Maar gezien het soort beoordelingsproblemen en de economische schaal (sector) waar het model voor bedoeld is, is een geaggregeerde benadering gewenst. Voor een gedetailleerdere aanpak zouden er meer gegevens moeten worden verzameld en is er een complexer model nodig.

De besmetting van buitenaf waar KRM rekening mee houdt, is een verzameling van besmettingen via verschillende wegen. Vanwege het gebrek aan beschikbare gegevens wordt aangenomen dat een dergelijke besmetting een bepaalde omvang heeft. Maar als er wel gegevens beschikbaar zijn, is het beter om deze gegevens proactief te verzamelen voordat de problemen zich daadwerkelijk voordoen. Om KRM te kunnen toepassen, moeten de gegevens op een bepaalde manier worden verzameld, moeten de gegevensbronnen bekend zijn en moeten de productketens van de belangrijkste landbouwproducten voor de export op voorhand worden vastgesteld.

Het gebruik van de negatief binomiale verdeling wordt besproken en vooral de manier waarop de clusterparameter wordt bepaald. In de toekomst moet hier meer aandacht aan worden besteed om dit verder te ontwikkelen.

Elk simulatiemodel is een imitatie van de werkelijkheid. De uitkomsten van KRM zullen daarom ook altijd in meer of mindere mate afwijken van de werkelijkheid. Berekeningen op basis van logica en relevante gegevens leiden tot realistischere uitkomsten dan schattingen op basis van intuïtie.

Het is de bedoeling om KRM in te zetten vóórdat er fytosanitaire maatregelen worden genomen. Afhankelijk van de kwaliteit van de gegevens wijkt de output van het model achteraf in meer of mindere mate af van de daadwerkelijke uitkomst. Daarnaast is de onzekerheid waarschijnlijk groot, omdat er een schatting is gemaakt van de kans op besmetting van buitenaf, de kans op besmetting via import en de mate van clustering. Om die reden is KRM vooral geschikt voor het doen van gevoeligheidsbepalingen. Voor KRM is het erg belangrijk dat men zich op ervaringen kan baseren. Fytosanitaire problemen moeten proactief worden benaderd en er is meestal weinig tijd beschikbaar voor het doen van berekeningen. Om KRM proactief in te kunnen zetten, moeten er gegevens van verschillende soorten productketens beschikbaar zijn. Op deze manier kunnen er berekeningen worden uitgevoerd voordat een probleem werkelijkheid wordt, zodat KRM een werkbaar instrument wordt.

1 Introduction

Infection of agricultural products with harmful organisms (pests) is a growing problem in the EU because of increasing trade between countries and changing climate. Therefore phytosanitary measures are taken by countries not only to protect against the introduction of pests (import constraints), but also to prevent their spread by elimination, containment or keeping the population at an acceptable level (EU, 2000). For a large number of pests, zero tolerance for trade between EU Member States and with third countries is applied. Even the threat of introduction of harmful organisms may have severe economic impacts (Knowler and Barbier, 2000). Despite the fact that phytosanitary problems in plant production chains have a great economic importance, Breukers et al. (2006) remark that this has received little attention. In their opinion, 'the explicit analysis and evaluation of epidemiological and economic consequences of alternative strategies got little attention'.

Phytosanitary problems are directly or indirectly the problem of maintaining quality standards in agricultural product supply chains as a whole. In a nutshell, product supply chains are defined as 'an integrated process in which various business entities work together in the effort to convert raw materials (means) into final products and deliver these final products to retailers' (Beamon, 1998). Supply chains consist of several chain stages and each chain stage delivers its additional value. The different chain stages are connected by a forward flow of materials' (Beamon, 1998). In every chain, particular stakeholders are often concerned with their own interests, regarding phytosanitary problems (Wijnands et al., 2006).

The chain approach has so far been used to a lesser extent in relation to sanitary crises (Vo and Thiel, 2006). The application of chain modelling generally concerns the harmony of supply and demand, efficient handling of chain flows and exchange of information in supply chains (Beamon, 1998). A number of studies are known in which the effect of phytosanitary measures are related to their costs (Breukers, 2007; MacLeod, 2006; Mumford, 2006; Surkov, 2007). However, none of these studies follows a chain approach. In some studies with a food safety background such as Salmonella in pork (Van der Gaag, 2004; Van der Fels-Klerx, 2008) and PCBs (McLachlan, 1997), certain product chains form the structure of the model.

Optimally distributing limited financial and human resources for phytosanitary measures over the chain stages is a complex problem. Uncertainty and the risk of introducing pests play an important role in the assessment. In order to take the well considered decisions in such a complex problem, the financial results of different scenarios of measures to be taken must be compared with the 'do nothing' or base line scenario without measures and also compared to each other. Thus, the development of a chain risk model is the objective of this research.

The chain risk model (CRM) was developed to calculate the costs and the financial impact of different alternative measures for product chains as a whole and for individual chain stages. Section 2 of this paper outlines the CRM in a technical way. The potential of the model is described in section 3 and its use is illustrated with two case studies of actual problems: Potato Spindle Tuber Viroid (PSTVd) in potatoes and Clavibacter Michicanensis in tomatoes (section 4). The contents of CRM and its background, as well as the model's potential are discussed in section 5.

2 Outline of the model

CRM is a template[1] for a static and deterministic economic model which makes it possible to develop specific agricultural chain models for different agricultural products where pests and pathogens are of phytosanitary concern. A stream of product volumes is followed through the chain and product volumes and levels of infection are estimated for each chain stage. In this model, a chain stage is defined as a subsector or a group of farms with comparable (production) activities. Phytosanitary measures can be taken in one or more chain stages to reduce the risk of infection or to detect infections. This results in cost effectiveness of these measures, not only for each stage but also for the whole chain. Cost effectiveness in this research is defined as the avoided damage by the measures to be taken, divided by the costs of the measures.

2.1 Literature review

The literature review is limited to the use of a product chain about phytosanitary problems and the role of cost effectiveness of measures herein.

Beamon (1998) reviews methods applied to supply chain design, predominantly deterministic analytical models, in which the variables are known and specified. For example, *dynamic programming,* which is applied by Williams (1983) within a supply chain network for production scheduling. The following examples of other methods for chain risk models are in the agricultural domain:

- Both Breukers (2007) and Van der Gaag (2004) use a combination of epidemiological and economic components (sub models). In her thesis, Breukers (2007) called this a bio-economic model and developed and used this model to evaluate the cost effectiveness of brown rot control strategies. This was done with two model approaches, a state-variable model for dispersal and an individual-based model considering the trading units of a production chain as individuals. Although more complex, the latter approach provides a detailed and realistic representation and 'can be effectively used for the analysis, evaluation and design of cost-effective disease management

[1] This model is developed in Excel with functions and procedures programmed in Visual Basic for Applications.

policies' (Breukers et al., 2006; Breukers, 2007). This model is event-driven (stochastic) and comparable to discrete-event simulation.

- For a food supply chain, Van der Vorst et al. (2000) applied the method of discrete-event simulation based on *Petri-nets* and argued that systems modelled in this way are more realistic than those modelled with mathematical approaches. In discrete-event simulation, the operation of the system is represented as a chronological sequence of events. Each event occurs at an instant in time and marks a change of state in the system.
- Van der Fels-Klerx et al. (2008) developed an analytical model based on the *Markov chain* principle to describe the transmission of Salmonella through the broiler supply chain. The model gives insight into stages at which interventions are needed and most effective and they suggest incorporation of the costs of the measures. A *statistical model* (regression) is used by Van der Fels-Klerx et al. (2008a) to estimate the occurrences of emerging mycotoxins in the different stages of the supply chain.
- Bai et al. (2007) uses Markov chains and a Poisson process in a model for a food production chain.
- In the context of the spread of contagious disease, Rahmandad (2004) compared and combined *agent-based* and *differential equation models* and demonstrated that these approaches lead to different conclusions.
- A *system dynamics* model is characterised by depended variables and feedback loops to capture system behaviour and performance over time (Vo and Thiel, 2006). According to these authors, system dynamics is widely applied in modelling and analysing supply chain behaviour, but there are only a few applications in food supply chain in the context of sanitary crises. They applied this method in a simulation model for the chicken meat supply chain in a bird flu crisis and studied the stability of the chain under different environmental uncertainties.

Like the chain risk model of Van der Fels-Klerx et al. (2008a), in the CRM the occurrence of an infection also depends on the occurrence in previous stages. They indicate the problem for calculation that originates when units vary per stage and mixing and splitting of lots throughout the supply chain. Different from other chain models, CRM combines the chain approach with the assessment of measures against phytosanitary risks.

2.2 Structure of the supply chain

The product chain is the core of the model and represents the actual stream of product objects in a particular existing agricultural chain, e.g. the potato chain. The volume stream consists of a number of lots. For the definition of a lot, an adapted definition of the potato lot by Breukers (2007) is used. A lot is defined as a group of product objects of the same variety and quality class, which are processed or grown together on the same area or location and treated as one unit. For example, one lot of potatoes is 15 tonnes and each tonne contains 12,000 objects.

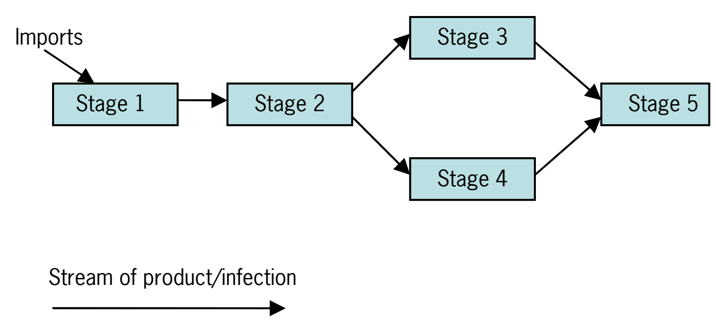
A product chain in the model is defined according to an existing agricultural chain. The first step in the use of CRM is the formulation of the underlying problem. The degree of detail must be chosen by the user of the model, in relation to that problem. This is the second step in the process of using the model, for example the potato chain can be defined according to the Dutch seed potato selection system or by putting seed potato growing in one stage. The number of distinguished chain stages corresponds with the degree of detail.

The figure below illustrates a chain of a hypothetical agricultural product. This simple example starts with the import (e.g. seeds) in the first stage. After process activities have taken place in this stage, the product goes to one or more successive stages. During its path though a product chain, the following aspects are essential:

- *volumes of products* (expressed in units, e.g. tonnes, and in objects per unit) between chain stages;
- *the number (and size) of lots*, each is classified based on the infection level: 'Having no infection', 'Slightly infected', 'Fairly infected' and 'Severely infected';
- *number of infected objects* of each lot and in total.

The stages are connected by volumes from one to another.

Figure 2.1 **Structure of a hypothetical chain**



A chain stage is not seen as a separate farm but as a set of farms with the same chain stage activities but the number of farms per stage plays a role and is distinguished. If it is necessary to make a subdivision, the structure of the chain model can be extended with subsets (e.g. the parallel stream 'Stage 3a' and 'Stage 3b' in figure 2.1). In practice, chain integration, or a farm covering two or more chain stages, may occur. It is possible to model this. Volumes and other relevant parameters of a stage should account for this.

A product remains in a stage for a period of time before moving to the next stage, e.g. for one year. If part of the product remains in the stage (or on a farm) for breeding, this can be modelled by using multiple cycles. The outflow of a stage is used as inflow for the next stage.

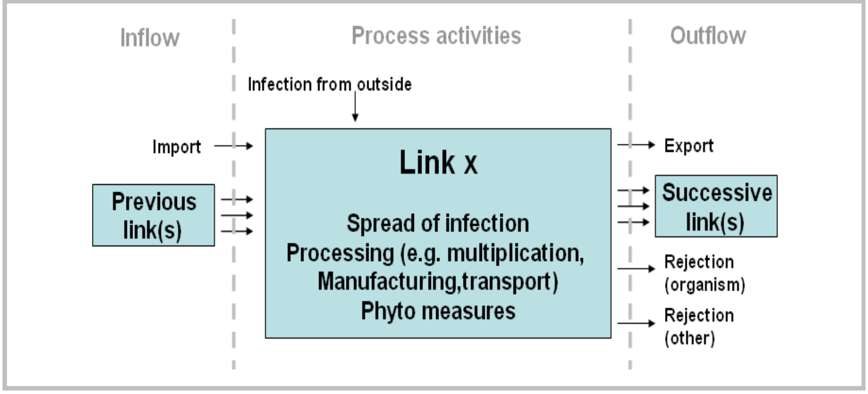
2.3 Structure of the generic stage object

In CRM every stage in the chain has the same structure, only the values of the stage parameters differ. In fact, the stage is characterised by these values. A stage is characterised by the following keynotes:

1. inputs from previous stage(s) including import;
2. process activities;
3. output to other stage(s) or export.

Figure 2.2 illustrates the structure of a stage.

Figure 2.2 **Structure of the chain stage object**



2.3.1 Inflow

The input or inflow in a stage consists of streams (1) from previous stages and, if relevant for this stage, (2) from import (from countries from inside or outside EU). In a stream, a volume of products as well as corresponding infected objects enter the stage and can be followed throughout the chain. So, from previous stages the infected objects are known. Regarding import, the number of entered infected objects is estimated after the inspection of lots in the consignments from distinguishing countries, regions or pathways (low risk versus high risk). Lots are divided into four lot categories with different number of infected objects (e.g. the category 'Severely infected' lots).

It is obvious that the inflow of the first stage in the chain is not based on previous stages (e.g. 'Stage 1' in figure 2.1). A declared fixed volume is used as first input in the first stage. The volume of this is calculated in a way that the volume that leaves the first stage has the right quantity. In agricultural chains, the first stage is often the breeding stage.

2.3.2 Process activities

In a stage, one or more process activities can take place; these characterise the type of stage. Activities that take place in a stage can be one or more of the following:

- growing (e.g. plants from seeds);
- production (e.g. plant out cuttings);
- multiplication (e.g. seed potatoes);
- processing (e.g. potato starch)
- transport;
- store;
- selling.

The product that leaves the stage (outflow) might be different from the kind of product that entered with the inflow. Even if the product remains unaltered, e.g. with transport or store, the size of lots can be changed and might result in a different number of expected infected objects in a lot.

Multiplication of the product in a stage is very important regarding the multiplication of infected objects. For example, when one object is infected and multiplied to seven objects, there are generally also seven infected objects instead of one, depending on the kind of organism.

2.3.3 Infection from outside

Like the Markov chain model of Van der Fels-Klerx et al. (2008), CRM distinguishes contamination from inside the chain (dependent) and from outside the chain (independent). Contaminations may occur at various points in the chain. The product volume in a stage may be infected not only from infected inflow, but also from outside. Probable sources are a primary infection in another product chain (e.g. other host plants, trash heap, transport, visitors) or directly over the country border. Only one parameter represents the repository of possible sources of infection from outside. This parameter, the risk of infection from outside, is assessed by the user of the model.

2.3.4 Spread of pests

In a stage, the number of infected objects can decrease or increase. The rate of increase of an infection depends on the multiplying characteristics of the organism concerned. In CRM, this aspect is brought into the model via the so-called 'spread factor'. This factor is independent of the multiplying factor of the product, which generally also contributes to the multiplication of the organism concerned.

2.3.5 Infected lots and infected firms in a stage

A lot is infected if one or more objects in this lot are infected. This infection can increase, spread or fade away. An infected lot can infect other lots on the same farm or on other farms. CRM estimates the distribution of infected objects among lots and the distribution of infected lots among farms.

Infected lots
The model calculates the number of lots in each of the four distinguished infection categories, e.g. the category 'Severely infected'. Since pests are not distributed randomly and are found in aggregated spatial patterns (Binns et al., 2000), the Negative Binomial Distribution is applied to calculate the number of infected lots in each category.

The negative binomial distribution is described by the following recursive formula:

$$P(0) = \left(\frac{k}{k+\mu}\right)^k$$

$$P(x) = \frac{k+x-1}{x}\frac{\mu}{k+\mu}P(x-1)$$

Where:
P(x) = the probability of finding x infected objects
P(0) = the probability of finding none infected objects
k = the dispersion parameter
μ = the mean for this distribution

The number of infected objects in a lot is used for the value of the mean μ and the user supplies information to obtain the value for the clustering parameter *k*. Strong clustering is associated with a low value for *k*.

Bliss and Fisher (1953) compared this distribution with other distributions for over dispersion and suggest that the negative binomial is the most widely adaptable and generally useful. In these situations, the assumption of complete randomness and independence of the locations of infected objects is not correct, so the use of distributions such as the Poisson distribution is not correct either. According to Binns et al. (2000), 'The probability distribution that is most often used in describing sampling distributions of pests is the negative binomial probability distribution'. In CRM, the negative binomial distribution is used to calculate the number of infected lots and infected farms. In fact, a calculation run by CRM is the result of a moment shot of a chain.

Regarding the negative binominal distribution, it is normal practice to estimate the k-value from existing data, e.g. with the principle of maximum likelihood. For various damaging organisms, Bliss and Fisher (1953) used an extension of the maximum likelihood procedure as an efficient estimate for the k-value of the negative binomial distribution. Mean-variance relationships are used for the calculation of k. However, when k exceeds the average, the difference with a Poisson distribution is small (Wilson et al., 1984). Counting with the characteristics of the organism concerned and the exchange of lots, the shape parameter k of the negative binomial distribution expresses the degree of clustering. Low values for k indicate high levels of clustering. Suitable data for estimating the k-value are not available for CRM. Therefore the k-value is estimated indirectly. The following aspects play a role in estimating the k-value.

- The extent of difference in lot size in the concerning stage;
- The number of supplying farms;
- To what extent the organism concerned can spread (nature spread);
- The effect of farm hygiene on the spread of the organism.

In CRM, different types of lots, with various degrees of infection, account for the fact that some lots or consignments are free from organisms, while others are infected to a varying extent. According to Surkov et al. (2006), a more realistic model should take this into account[1].

Infected farms

The negative binomial distribution is also applied to estimate the number infected farms. The user supplies the model with the total number of farms in a stage. The average number of infected lots per farm is calculated and used for the value of the mean μ. In addition to this, the clustering of lots in a farm depends on the clustering of infected objects in the lots.

[1] The drawback of the subjective estimation, while the k value should be estimated from sample unit and density (Taylor, 1984), has special attention for the further development of the model.

2.3.6 Damage by pests

Pests can cause damage in the short and long term. The damage can be distinguished in two categories:

- Export damage;
- Crop damage (product).

The amount of potential damage must be estimated and entered into CRM by the user. The time horizon is important for that.

2.3.7 Phytosanitary measures

Phytosanitary measures aim to reduce the potential damage of pests. In CRM, a linear relationship between the amount of damage and the extent of infection is assumed.

The number of infected objects normally expands due to spread (population development). When no phytosanitary measures are taken, the level of infection increases not only in one stage but also in the successive stages of the chain. CRM was primarily developed to calculate the cost effectiveness of different measures. The costs of these measures will often depend on the reduction of the level of infection (effect) by these measures. The costs of measures are defined as the *extra* costs which have to be made for a particular organism regarding the normal costs (zero level).

Different types of measures against infection that can be taken:

- Import inspection, with number of inspected lots, sample size and quality of the inspection (effectiveness) as parameters for the different pathways (explained below);
- Preventive measures, which reduce the risk of infection from outside the stage or reduce the spread of infection. Parameters are the effectiveness of measures and the reduction in yield (due to certain pests);
- Curative measures, which reduce the amount of infected objects in a stage after infection is detected;
- Stage inspection, to detect infected lots and reduce the risk of infection at export and in successive stages, by rejection of detected lots. This may lead to the destruction of products. Parameters for stage inspection are comparable to import inspection.

For all types of measures, inherent parameters are available, e.g. for the effectiveness[1].

Import inspection
Regarding import inspection, the user of CRM enters in the model the division of lots between categories of pathways and the fraction of infected objects in each category. Inspection results between categories differ due to this fraction. An inspection method can be defined by the parameters for sensitivity of the test method and sample size. Intercepted lots are replenished or not. This can be chosen by the user. The calculations for import inspection are based on binomial distribution, corrected for relative large sample sizes (Snedecor and Cochran, 1983). The costs of rejection are charged to the exporting company or importing company (choice by user).

Stage inspection
The calculations for the inspection of lots in the chain stage are equal to import inspection. The result of detection by inspection depends amongst others on the number of infected objects in a lot. Lots that are severely infected have more chance of being detected than other lots. So, from the foregoing it is clear that a high clustering of infected objects in lots results in a higher number of detected infected objects found. The result of stage inspection can be rejection of lots or a part of a lot (choice by user).

2.3.8 Cost effectiveness of phytosanitary measures

The model distinguishes five different stakeholders:
- infected farms in this stage;
- non-infected farms in this stage;
- organised private farms;
- government;
- other sectors outside this stage (e.g. recreation).

For each of these stakeholders, costs are calculated. Required labour to carry out the measures and parameters for miscellaneous (non-labour) costs are used to calculate the economic effects and cost effectiveness of measures.

[1] Van der Gaag (2004) distinguishes preventive and corrective measures to prevent introduction and spread of Salmonella in a comparable way.

In the model, the result of 'Doing nothing' (i.e. the calculations without measures) are compared with the results of 'Taking measures'.

According to Breukers (2007), a cost-effective policy requires quantitative knowledge of the effect of control strategies on incidents and economic consequences. Performance indicators are important elements in supply chain models (Beamon, 1998). For CRM, performance indicators are the cost effectiveness and the level of infection. Van der Gaag (2004) calculated cost effectiveness by dividing the reduction in prevalence by the change in net costs. This corresponds with the definition of cost effectiveness in CRM. Conclusions about cost effectiveness of measures depend on the period regarded by a model (Breukers, 2007).

2.3.9 Stage outflow

Infected objects that do not manifest or have not been detected are propagated to successive stages of the chain or leave the chain by export. The product volume with remaining infected objects is divided into lots and then flow to successive stages and, if relevant for this stage, to other countries (export). If the stage has more than one period or cycle, a part of the outflow is used as inflow.

Lots can be rejected partially or completely. The volume rejected consists of two sources of rejection:

- Rejected volume as a result of phytosanitary inspection measures in a chain stage;
- Rejection due to other reasons than phytosanitary (e.g. quality, selection, overproduction).

Rejected volume is destroyed or finds a destination at a lower price further on the chain (e.g. the arrow from 'Stage 2' to 'Stage 4' in figure 2.1).

3 Use of the model

The Chain Risk Model (CRM) is designed as a tool to support the assessment of measures against the entry of pests in the Netherlands and the allocation of restricted means in a more or less optimal way. This will generally be achieved by trial and error. This chapter describes how the model can be used for different kinds of phytosanitary problems.

3.1 Choice between different phytosanitary measures

CRM can activate four types of phytosanitary measures in each stage (chapter 2). Different types of measures can be applied in combination, e.g. import inspections and chain stage inspections. In a separate module, the costs of measures must be brought in per chain stage, distinguished for different stakeholders. The effect of a measure on the population of the organism is calculated by CRM for the two types of inspection. Parameters must be estimated and entered in the model. The effect on the population of an organism can be different for different chain lots.

The following aspects for phytosanitary measures or sets of measures are relevant:

- The chain stage in which they are applied;
- The intensity of application;
- The effect on the infection or spread, per chain stage;
- The costs per cost carrier.

For import inspection as well as stage inspection, information about the sample (number of objects) and quality of the test (percentage detection) must be brought in the model. Other aspects like risk of infection from outside are brought in, independent of the measures which have to be taken. The quantity of the volume stream is calculated by the model. The stream from one stage to another, export and waste have to be put in CRM as percentages.

The model output contains the following relevant figures:

- Cost effectiveness for the whole chain;
- Cost effectiveness per chain stage;
- Number of infected objects in exported products per chain stage;
- Number of infected exported lots per chain stage;

- Development of number of infected objects, lots and farms in the chain;
- Total costs and costs per stakeholder.

This illustrates that discussions are not just taken because of differences in cost effectiveness, although it is an important figure in policy assessment.

3.2 The allocation problem

The intensity of application of phytosanitary measures affect the population of established pests and impacts on the costs of the measures. An example of this is the size of the sample or an alternative detection technique in the case of import inspection. CRM is a simulation model which is suitable for making several calculations with different points of departure.

Phytosanitary measures can be taken in different chain stages. CRM is not currently able to optimise the effort of financial and human resources, but by carrying out different model runs the user gets an overview of the consequences of different alternatives and a basis for policy (trial and error). A practical approach for handling allocation is the one where the aim of measures is fixed and the way to achieve this is calculated as efficiently as possible with the aid of the model (Van der Fels-Klerx, 2008), under the limitation of financial means. CRM contains no optimisation module, so this has to be carried out by way of simulation.

3.3 Combined measures against different pests

Especially when pests are related to each other, opportunities to combine measures should be utilised e.g. for different kinds of nematodes. The financial and population dynamic consequences of this entrance to achieve efficiency become apparent when CRM is used. However, using CRM for combined measures for two pests is more complex than using it for one organism, because of difficulties estimating the risk of infection via import or from outside as a combined risk. To compare measures for single pests with combined measures for different pests, at least three model runs must be made to make clear what the benefits are (two separate and one combined run).

3.4 Consequences of shifting responsibilities between stakeholders

Depending on how detailed a supply chain is defined, different stakeholders are distinguished. In many agricultural chains we distinguish plant breeders, plant multipliers, production firms and trading companies (inclusive exporting companies). Difference between government and collective business is an important aspect and can be made visual within a stage in CRM.

Responsibilities and therefore also costs tend to shift from government to collective business. CRM can calculate possible consequences of this shift.

Wijnands et al. (2006) signalled the often contradictory interests between separate chain participants. The CRM model can contribute to transparency; for supply chains and networks transparency is the extent to which stakeholders have a shared understanding and access to information (Hofstede et al., 2004). Breukers (2007) argues that, by enabling an objective communication between stakeholders on the costs and benefits, a model can play an active role in achieving support from the sector. Use of CRM in practice is required to find out if it can also play such role and contribute to transparency.

3.5 Dealing with uncertainty

Uncertainty plays an important role concerning the risk of introducing pests. This is the case for the important pathways, imports and infection from outside. The risk of an introduction of pests can be estimated from discoveries in the past. However there is the danger of underestimation because of objects which have left the product chain without being detected. The user of the model can handle this uncertainty to make more calculation runs with the model with different risks of infection (sensitivity analysis). An alternative approach is to take as starting point one infected object per year (or other time span) and then increase this rate of infection and look at the consequences (model output).

Expected damage to exports is one of the main motives for phytosanitary measures with a potentially great impact on series of agricultural products. Export restrictions can lead to a smaller exported quantity and this may lead to lower prices. With CRM more scenarios can be calculated and compared. Regarding the estimate of export damage, a linear dependence is built in, in relation to the percentage of infected lots. In future this might be other kinds of dependencies.

Product prices are always uncertain. To make clear what this sensitivity is, more model runs with variable prices can be made. Fluctuations in prices can be estimated by using price information over at least eight years. Effects on prices can also be estimated by price elasticities.

Another unsure development is the imported quantity from certain countries. By mean of trend analyses, imports can be estimated, but there always will be uncertainties. The import quantity is connected with the chance of introduction of pests (Mumford, 2006).

4 Case studies

The aim of case studies is to illustrate CRM, to make employees of the Dutch Plant Protection Service familiar with the model, to validate the model and to promote and provide a guideline for the best way of working. The development of cases was an iterative process resulting in a number of improvements of CRM.

4.1 *Clavibacter* in the tomato chain

Clavibacter is a disease caused by the bacterium *Clavibacter michiganensis spp. michiganensis*, with disastrous consequences for tomato crops. This organism is listed in Annex IAII of Council Directive 2000/29/EC. When it is found in lots of tomato plants for planting (including seeds) at import in the Netherlands, the lot is rejected. When it is found in crops, growers must eliminate the infected plants and the plants in a surrounding area, according to the elimination protocol (Ministry of Agriculture, Nature and Food Quality, 2008).

The primary question for this case is: 'What is the cost effectiveness of different alternative measures, applied separately and in combination' in a situation where Clavibacter is found on firms in the production stage (stage 3). The requirement is zero tolerance for export of tomatoes and tomato seed.

The following step is to define the product chain and its stages. This is illustrated in figure 4.1.

The tomato chain is an example of a rather simple supply chain. However, the unit of the objects differs per chain stage and that makes it more complex. This is illustrated in table 4.1.

Figure 4.1 The Dutch tomato chain

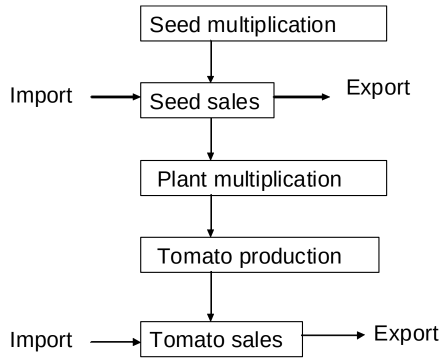


Table 4.1 Entities per chain stage in the tomato chain

Chain stage	Input unit	Output unit
Seed production	Seed	Seed
Seed selling	Seed	Seed
Plant production	Seed	Plants
Tomato production	Plants	Fruit
Tomato selling	Fruit	Fruit

The definition of a unit, the number of objects in a unit and the number of units per lot directly influence the spread of the organism when an infection has taken place. In every chain stage, the user must bring in the unit definition and the number of units per lot of the outgoing volume stream. The essential transition takes place via the so-called 'multiplying factor' e.g. the unit plant to the unit fruit. In the case of the tomato chain, one plant produces 45 kg tomatoes and one kg contains twelve tomatoes, which means the multiplying factor is 540.

Data collection
After the chain is defined, data must be collected. Roughly it concerns the following data:

- Volumes from one stage to another. Data is collected from existing databases from the Dutch product board. Lacking data particularly from the first stage, i.e. seed production, is estimated by way of the known data, areas and number of farms;
- Volumes of import. Data is collected from the Dutch product board and EUROSTAT;

- Risk of infection via import (per pathway). Estimated the Dutch Plant Protection Service (PD);
- Risk of infection from outside. Estimated by the Dutch Plant Protection Service (PD).

Potential sources of infection are the pathways: imports and the infection from outside. In the tomato chain, import only takes place in the chain stages seed selling and tomato selling (3 and 6) (table 4.2). For one tomato plant, two seeds are needed because tomato plants are grafted.

Table 4.2 Volumes, units and multiplication factors in the tomato chain

Chain stage	Volume from preceding chain stage (units)	Import volume (units)	Volume leaving stage (units)	Export (units)	Unit	Multiplication factor
1			1,500		10,000 seeds	6,000
2	1,500	13,700	7,500	7,562	10,000 seeds	1
3	7,500		37,500	378	1,000 plants	0.5
4	37,500		728,500		Tonnes tomato	236.4
5	728,500	200,000	247,000	642,000	Tonnes tomato	1

Illustration of multiplication factor stage 4:

- one m^2 greenhouse produces 49.2 kg per year;
- one m^2 greenhouse contains 2.5 plants;
- the production per plant is thus 19.7 kg;
- one kg contains twelve fruits, so 19.7 kg correspond with 236.4 fruits.

Measures and their effects

The policy question for the case Clavibacter in tomatoes is to make clear which measure or combination of measures is most cost effective for the whole supply chain. That means that the costs and the effect on the population of measures against Clavibacter must be put in the model. It concerns the following measures:

1. Import inspection; the effect is calculated by the model; when Clavibacter is found, lots are sent back which means lower incoming infection pressure. This is the present situation before extra measures are taken.
2. Chain stage inspection by the Dutch Plant Protection Service (PD) in stage 1, 2 and 3. Infected lots are destroyed as well as the plants of the production farm where infection was found, located in the same water giving area. Extra costs of disinfection must be incurred by farms.
3. Investigation of the seed producing firms (8) to find the source of infection by the PD. The effect will be a lower risk of multiplying infection to the following stages. This measure will take place after the first infection in the following stage is reported.
4. Development of a quality safety system for the seed producing, seed selling firms (the same companies) and plant producing firms. This will reduce the risk of bringing the infection to the following chain stages (spread of infection).

Infected objects and infected lots

The chances of infection of pathways with high risk in table 4.3 are traced back to the seed production of one plant or multiple of one plant. The variation of infection in import volumes per pathway are illustrated in table 4.3 for chain stage 2.

Table 4.3 Input data of infection by imports for stage 2 a) b)

Specification of imported lots		**Pathways with high risk of infected objects**	**Pathways with medium risk of infected objects**	**Pathways with low risk of infected objects**
Lightly infected	Percentage Volume	0.5	0.1	0.1
	Chance of infection	$18x10^{-5}$	$1x10^{-5}$	$1x10^{-7}$
Medium infected	Percentage Volume	0.5	-	-
	Chance of infection	$32x10^{-5}$	-	-
Medium infected	Percentage Volume	0.5	-	-
	Chance of infection	$64x10^{-5}$	-	-

a) The infection chances are estimated by experts and were compared with real figures from the past; b) 99.3% is healthy.

The risks in the other two pathways are less than the seed production of one plant. The percentages of import volumes are based on import check data from the Dutch Plant Protection Service (PD). The risk of infection from outside and the spread factor per stage are represented in table 4.4.

Table 4.4	**Infection from outside, unit and lot per chain stage**	
Chain stage	**Risk of infection from outside**	**Factor spread organism in stage**
1. Seed production	0	5
2. Seed selling	0	5
3. Plant production	0	5
4. Tomato production	0	10
5. Tomato selling	0	2
N.B. The risk of infection from outside is estimated by experts and is based on the sources of findings in the past.		

The possible measures are reproduced in table 4.5, with their allocation, costs and estimated effect. Measure 1; import inspection is already applied in today's practice. Although cost effectiveness is the important figure, measures should have a minimum effectiveness (reduction of the infected objects).

From the separate measures, combinations are formed (scenarios):

- Scenario A: Import inspection in stage 2; In fact this is the basic scenario;
- Scenario B: Import inspection in stage 2 and Chain stage inspection in stage 1, 2 and 3;
- Scenario C: Import inspection, 2. Chain stage inspection and 3. Intensive check seed firms (stage 2);

Scenario D: Import inspection, 2. Chain stage inspection and 3. Intensive check seed firms; 4. Development and maintain quality care system in stage 2, 3 and 4.

Table 4.5	Effects and costs of measures which may be taken			
Measure	**Applied in Chain Stage**	**Responsible Stakeholder**	**Costs**	**Estimated effect**
1. Import inspection	3 and 5	Dutch Plant Protection service	€290 per inspected lot	Inspected sample is 12,500 seeds and 200 fruits ; effect is calculated by CRM
2. Chain stage inspection	1, 3 and 4	Dutch Plant Protection service+ growers	€95 per inspected lot	Inspected sample is 200 fruits; effect is calculated by CRM
3. Intensive check seed firms	1	Dutch Plant Protection service+ collective growers organisation (NAK)	Total amount €800,000 per year	Reduction infection from outside with 90% (chain stage 2)
4. Development and maintain quality care system	1	Seed firms	Total amount €1,200,000 Per year	Reduction infection from outside with 60% (chain stage 2) and reduction infection by imports

Clustering of infected individual organisms over lots has an impact on the spread of the population in a chain. For the tomato chain, the k-coefficients in table 4.6 are the starting point for the extent of clustering. The same indication is applied for the clustering of firms with infected lots.

Table 4.6	Starting point for clustering	
Chain stage	**Indication**	**K-coefficient**
1. Seed production	Strong lot directed	10^{-6}
2. Seed selling	Strong lot directed	10^{-6}
3. Plant production	Lot directed	10^{-5}
4. Tomato production	Lot directed	10^{-5}
5. Tomato selling	Neutral	10^{-3}

Potential damage

Potential damage due to an organism is not usually the damage in the time span of a chain cycle, but it becomes important in the longer term. Potential damage is defined as the sum of damage which may occur in future when no measures are taken. The chosen time horizon taken into consideration is important in this context. The potential damage consists of crop damage, direct damage to exported volume and indirect damage to export, e.g. by lower prices. In the case of Clavibacter in tomatoes, the starting point is the potential estimated damage over a period of twenty years (table 4.7). The damage is brought into the model as a mean amount per year, per stage.

Taking measures will reduce damage by pests. In this case, the assumption is made that the reduction of damage is proportional to the reduction of the population of Clavibacter, which is a rather simple approach. The potential crop damage in the case of tomatoes is estimated on the volume of the (Dutch) yield of one year and export damage on Dutch export of five years.

Table 4.7 **Estimated crop and export damage for Clavibacter in tomatoes in the basic scenario (€ x 1.000 per year)**

Chain stage	Crop damage	Export damage
1	1,700	-
2		3,000
3	300	-
4	15,000	-
5	-	500

N.B. The export damage is estimated at five times the yearly export value.

Results of CRM calculations for the Clavibacter case

The calculation based on previous tables produces the following results.

Population development

Regarding zero tolerance of export, minimising the population of Clavibacter is an important goal of the phytosanitary measures.

The infected lots are divided in proportion over the different outgoing volume streams, including the export volume.

Figure 4.2 **Development infected lots per stage.**

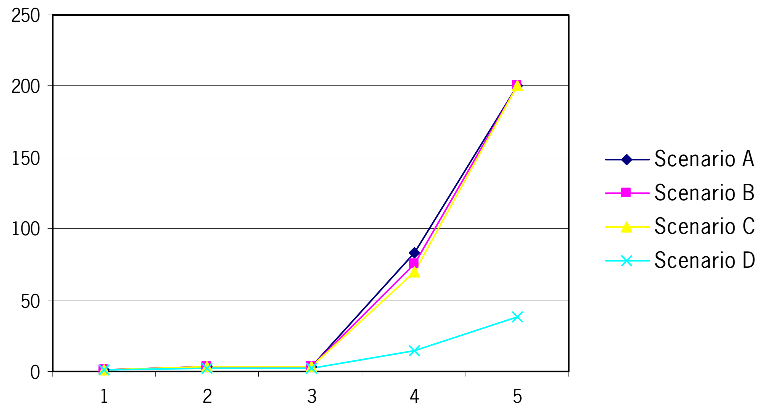


Table 4.8 **Overview of the measures per scenario per chain stage**

	Scenario A	Scenario B	Scenario C	Scenario D
Stage 1		S	S;P	S;P;C
Stage 2	I	I; S	I; S; P	I; S; P; C
Stage 3		S	S; P	S; P; C
Stage 4	No measures			
Stage 5	No measures			

I = import inspection; S = chain stage inspection; P = investigation; C = development quality safety system.

Cost effectiveness

The CRM calculations result in a comparison between the four scenarios and are primarily focused on the main indicator, cost effectiveness (table 4.8). Based on cost effectiveness, it can be concluded that scenario B has the best prospects. However, Clavibacter infection is lowest in scenario D. Scenario A is the one representing the present situation, so extra measures seem to have little added effect on cost effectiveness in this case.

The zero population level can only be achieved when the measures are implemented more intensively, especially import inspection and chain stage inspection in stage 2. However, it will be very difficult or impossible to achieve the absolute zero point.

Table 4.9	Results per scenario of the CRM calculation (€ x 1,000)			
	Scenario A	**Scenario B**	**Scenario C**	**Scenario D**
Avoided crop damage	16,500	17,000	17,000	16,500
Avoided export damage	107,000	108,000	108,000	107,000
Damage rejected lots	0	1	1	0
Costs measures	110	700	1,900	2,600
Cost effectiveness (1)	123,000	123,000	123,000	121,000
Cost effectiveness (2)	16,000	16,000	15,000	14,000
(2) excluding export damage.				

This example illustrates that a slight infection in the first stages can easily have major consequences in later stages.

Working with CRM

Collecting data about product values in the tomato chain was quite easy for the Dutch situation regarding the production and sales of tomatoes (chain stages 4 and 5). Values of seed and plant production were first estimated backwards from stage 4 with the help of the known multiplication factors. Information about lot value per stage and number of objects per unit was collected. Supplementary information was collected directly from seed firms. The data collection was led by the chain structure.

A clear definition of the basic problem and the distinguished measure scenarios appeared to be important. This clear definition is only possible when the user of CRM is an expert in phytosanitary risk management.

If the user of CRM wishes to know the definition of certain parameters in the model, information from glossary can be retrieved.

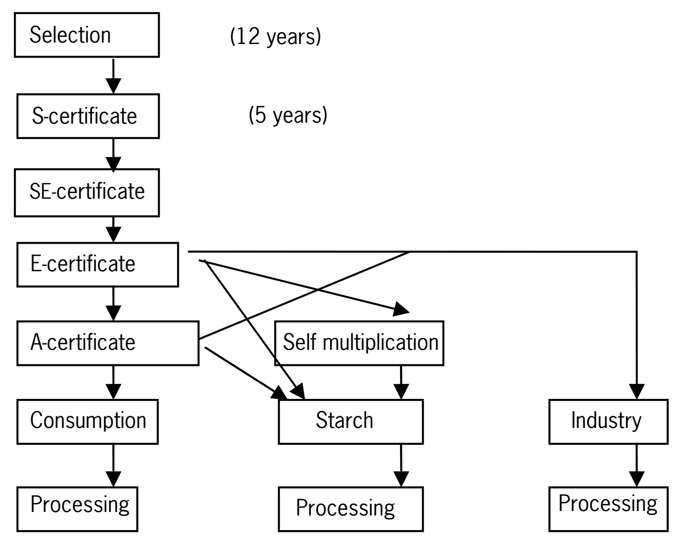
4.2 PSTVd in potato chain

The Potato Spindle Tuber Viroid (PSTVd) is listed in Annex IAI of Council Directive 2000/29/EC because of its potential damage to potato plants (dwarf growth). It is currently absent in the EU and introduction and spread by any means is prohibited. Because PSTVd is also a quarantine pest for many third countries, export of potatoes must be free from PSTVd. The export interests of Dutch seed-potatoes, consumption potatoes and potato products are big. The species in the plant genus 'Solanacae' are host plant for PSTVd. The primary policy question is to calculate which scenario of phytosanitary measures is most attractive.

Definition of the potato chain

The potato chain can be defined in an aggregated and more detailed way. Regarding the basic problem, the more detailed potato chain is applied. In this case, the structure of the Dutch selection system for seed potatoes is followed. The stages 'Selection' and the first three years of 'S-certificate' are not taken into consideration.

Figure 4.3 **Potato chain following the cut off system for seed potatoes**



The chain stages, taken into consideration are:

Stage number	**Stage name**
1	Selection
2	Seed potato S-certificate
3	Seed potato SE-certificate
4	Seed potato E-certificate
5	Seed potato A-certificate
6	Seed potato C-certificate and Extra multiplication
7	Production Consumption
8	Production Industry
9	Production starch
10	Processing
11	Processing
12	Processing

Data collection
The consequence of choosing a detailed structure of the potato chain is that more detailed data has to be collected. This is the case for volumes from one stage to another (table 4.10), for example. The figures correspond with the average production and processing of volumes in the time span 2003-2008.

Table 4.10	Volumes per stage in the potato chain (1000 ton) and other essential characteristics					
Chain stage	**Volume from preceding chain stage (units)**	**Imported volume (units)**	**Volume leaving stage (units)**	**Exported volume (units)**	**Number of objects (per Kg)**	**Multiplication factor**
1		-	11	-	12	6
2	11	-	47	29	12	6.8
3	20	-	67	-	12	6.8
4	94	-	257	423	10	6.8
5	142	-	469	261	10	6.8
6	17	-	118	-	10	6.8
7	117	0.2	1,497	-	8	11
8	152	2.2	3,078	-	5	11.1
9	91	0.2	2,230	93	3.8	9.7
10	1,822	279	1,091	1,025	8	1
11	3,078	459	170	1,528	5	0.48
12	2,230	290	4,218	1,541	3,8	0.50

Table 4.11	Change of infection from outside and spread factor per chain stage	
Chain stage	**Change of infection from outside**	**Spread factor**
1	$2*10^{-9}$	1.01
2	$2*10^{-9}$	1.01
3	$2*10^{-9}$	1.01
4	$2*10^{-9}$	1.01
5	$2*10^{-9}$	1.01
6	$2*10^{-9}$	1.01
7	$2*10^{-9}$	1.01
8	$2*10^{-9}$	1.01
9	$2*10^{-9}$	1.01
10	$2*10^{-9}$	1.01
11	0	1.01
12	0	1.01
13	0	1.01

Measurements
Measures against PSTVd will focus on reducing the risk of introduction in the Netherlands. Import is seen as the sum of pathways to the Netherlands.

Table 4.12	**Effects and costs of measures which may be taken**				
Measure	**Applied in Chain stage**	**Responsible Stakeholder**	**Costs**	**Sample size**	**Estimated effect**
1. Import inspection	7, 8 and 9	Dutch Plant Disease Council	€290 per inspected lot	200;	By CRM
2. Chain stage inspection	In stages 1, 2 and 3	Growers	€95 per inspected lot	200	By CRM
3. Chain stage inspection	In stages 1, 2, 3, 4 and 5	Growers	€95 per inspected lot	200	By CRM
4. Check and illumination of PSTVd of the ornamental chain (Plant family deadly nightshade)	Effect in all stages;	Other sector; not direct participating in the potato supply chain.	Total amount €1,400,000 = 0.187 per unit	-	Reduction infection from outside with 25%

From these separate measures, combinations are formed (scenarios):
- Scenario A: Import inspection (present situation);
- Scenario B: Import inspection and Chain stage inspection in stages 1 till 3;
- Scenario C: Import inspection, Chain stage inspection in stage 1 to 5;
- Scenario D: Import inspection, Chain stage inspection, check and illumination of PSTVd of the ornamental chain (Plant family 'Deadly nightshade').

Clustering of firms with infected lots
Clustering of infected individual organisms over lots has an impact on the spread of the population in a chain. For the potato chain, the indicative terms in table 4.13 are the starting point for the extent of clustering. The same indication is applied for the clustering of firms with infected lots.

Table 4.13	**Starting point for clustering infected objects in lots and infected lots in business**			
Chain stage	**Indication clustering in lots**	**K-coefficient**	**Indication clustering in firms**	**K-coefficient**
1	strong lot directed	10^{-6}	very concentrated	10^{-4}
2	strong lot directed	10^{-6}	very concentrated	10^{-4}
3	lot directed	10^{-5}	reasonably concentrated	10^{-3}
4	Neutral	10^{-3}	reasonably concentrated	10^{-3}
5	Neutral	10^{-3}	neutral	10^{-2}
6	reasonably in proportion divided	10^{-2}	low concentration	10^{-1}
7	reasonably in proportion divided	10^{-2}	low concentration	10^{-1}
8	reasonably in proportion divided	10^{-2}	low concentration	10^{-1}
9	Neutral	10^{-3}	very concentrated	10^{-6}
10	Neutral	10^{-3}	very concentrated	10^{-6}
11	Neutral	10^{-3}	very concentrated	10^{-6}

Potential damage

Potential damage due to an organism is not usually the damage in the time span of a chain cycle but becomes important in the longer term. This damage concerns direct crop damage, direct damage to exported volume and indirect damage, e.g. on prices. In the case of PSTVd in potatoes, the starting point is the potential estimated damage over twenty years (table 4.14). This is calculated back to an amount per year (excluding interest effect). The potential damage depends on the population and spread of PSTVd in this case.

Table 4.14	**Estimated crop and export damage for PSTVd in potato (€ x 1,000 per year)**	
Chain stage	**Crop damage**	**Export damage**
1	1,100	
2	1,300	650
3	1,150	
4	8,650	6,175
5	4,925	2,600
6	1,050	-
7	9,500	950
8	12,300	225
9	5,800	-
10	-	-
11	-	-
12	-	-
13	-	-
The total amount of crop damage is the yearly turnover. Export damage is the Dutch export amount in 2006.		

Results of CRM calculations for the PSTVd case
The points of departure of the previous tables lead to the following results.

Population development
Regarding zero tolerance of export, keeping the population of PSTVd as low as possible is an important goal of the phytosanitary measures.

Considering the number of infected lots, it can be concluded that import inspection (scenario 1) had no effect at all. The reason for that is that the risk of infected imported lots is very low and a sample of 200 is too low to find anything. Chain stage inspection and a check in other sectors lead to a reduction of infected lots.

Figure 4.4 **Course of the population in the chain stages per scenario of measurements, measured in terms of the number of infected lots**

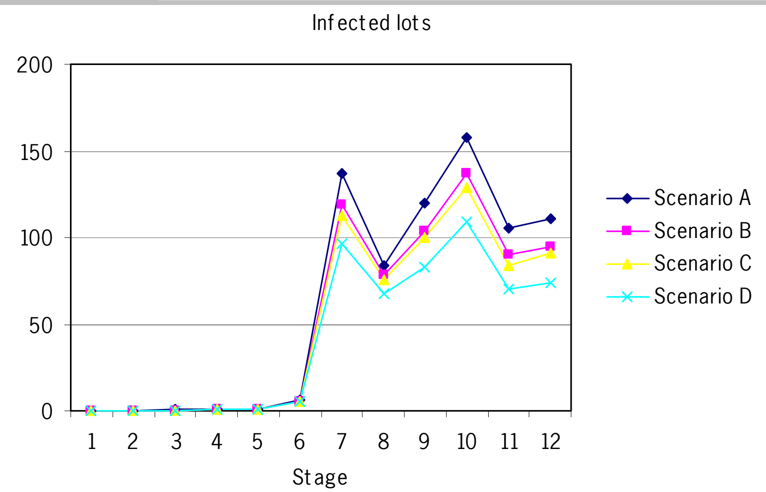


Table 4.15 **Results per scenario of the CRM calculation (€ x 1.000)**

	Scenario A	Scenario B	Scenario C	Scenario D
Avoided crop damage	0	8,000	10,000	18,000
Avoided export damage	1,100	4,000	4,500	7,000
Damage rejected lots	0	6	6	6
Costs measures	10	900	6,000	9,000
Cost effectiveness (1)	1,200	11,000	8,500	16,000
Cost effectiveness (2) a)	-10	7,000	4,000	9,000

a) (2) exclusive export damage.

Based on the cost effectiveness, it can be concluded that scenario A, representing the present situation, is not attractive. Compared with scenario A and scenario B, scenarios C and D also show positive cost effectiveness. However the reduction in the number of infected objects is not high enough to guarantee zero infection.

Because scenario D adds such a big amount to cost effectiveness, the advice would be to take scenario D. With the help of CRM, it is possible to calculate the impact on the risk of infection at which scenario D would have no extra addition on cost effectiveness. This is the case when the reduction of infection from outside is less than 1% against the originally 25%.

Experiences of working with CRM

Data collection

The potato chain in this case was defined rather detailed. That means that the data to be collected were also rather detailed. Some data especially in relation to the 'early chain stages' were hard to get. Volumes of stages 1 to 3 were estimated by the multiplication factor and the volume in stage 4 (backward calculation). CRM is useful for comparing different scenarios of intensity of measures, for instance concerning the sample size in relation to costs and the stage in which inspection is applied. More runs with CRM must be carried out for that purpose.

In CRM, scenarios with measures are compared with the situation with no measures. In reality, the situation with no measures is not realistic. In practice, all kinds of measures are taken, before and independent of actual measures to be chosen. To get a correct reference, the user first has to formulate and calculate a scenario in which present measures come to expression. This basic scenario is the real reference situation.

CRM has a cockpit function in which the user gets an overview of the measures taken per stage. Especially in a case like the potato chain, this function proved to be useful because it gives the needed overview.

The outcome of the CRM calculations supports different kinds of policy questions. The result of model calculations will always be an advice and is never binding.

5 Discussion and recommendations

Static character of CRM

The consequences of phytosanitary measures often extend beyond the period in which products pass through a chain. In CRM, the factor time is handled in a static way. In most cases, each chain stage will last one year or a multiple period of that. In fact, in CRM a product chain represents a moment shot of that product chain. This is a simplification of the reality. In this context, Breukers (2007) argues that the time span has a great effect on the cost effectiveness in relation to the estimated damage caused by a certain organism. A practical solution is to calculate potential damage (crop and export) as a mean value over a defined time span.

The following aspects are considered to make CRM more dynamic:

- Location-bound infection such as for nematodes and fungi. Infection in a stage in one year affects the infection in following years;
- The affect of infection from outside, such as from waste streams, will affect the risk of infection in later years;
- In reality, product chains are dynamic in themselves. Over the years, volume streams and risks of infection will change. A truly dynamic CRM makes it possible to make estimate calculations over twenty years.

Tension between generic, aggregated and detailed approach

For the kind of assessment problems and the economic scale (sector) for which CRM is intended, an aggregated approach is desired. This is despite the fact that each organism and each product has specific characteristics. The possibility to arrange a chain as the CRM user wishes implies that the model is generic for each product. Organism- specific qualities come to expression in stage parameters, such as spread and clustering of infected objects. These types of parameters must be estimated by experts or from historical data. Comparable models, designed to calculate the cost effectiveness of measures against certain organisms, are organism-specific (Van der Fels-Klerkx et al., 2008; Salmonella in relation to food safety, Van der Gaag, 2004; Salmonella in relation to food safety) or measure-specific (Surkov, 2007; import inspection). The generic character of CRM implies that the calculated data used are not as detailed as in the models mentioned above.

In CRM, it is not always necessary to construct transport or store stages between successive stages, but it is possible to distinguish them as individual stages. They may be omitted because there are stage parameters for infection and spread during transport or store. The cases described in chapter 4 are not detailed in a way which distinguishes these types of stages. When transport has to be distinguished as a stage, for example, this can be modelled in a chain.

Infection from outside

Infection from outside in the way it plays a role in CRM is a collection of infections from different pathways. The easiest way to work with this risk of infection is simply to take the total number of objects in a chain stage as the starting point and assume that one or more of these objects are infected per time span. An alternative way of estimating this risk is to assume that in future the chance will be the same as it was in the past. This is only possible when more infections have taken place in a longer period, were attributed to infection from outside and registered as such.

Data collection

Phytosanitary problems often require a quick review of available information. To make calculations with CRM, data is needed about volumes from one stage to another, import volumes per pathway, export volumes, prices per chain stage, cost and effects of measures and chances of infection. This data should preferably be collected in a pro-active way and be available before the actual problem comes to expression. The value of adequate data is also emphasised by Van der Fels-Klerkx et al. (2008). For the intended use of CRM, data collection can be organised in such a way that data sources are and the product chains of the most important agricultural export products defined beforehand. The framework for this is described in Benninga et al. (2008).

Clustering of infected objects

The way infected objects are clustered in lots depends on several circumstances, such as the way in which the organism can spread and the extent to which lots are mixed or divided. In the present version of CRM, the qualifying k-value of the negative binominal distribution must be estimated and can vary per chain stage. This estimate would be improved if the k-value was based on data. An approach where k-value is based on behaviour of groups of organisms and products would mean an enormous step forwards. However, this requires quite a lot of research.

Inspection sampling

Surkov et al. (2007) assume a binomial distribution of infected plants in situations where the sample size is small, compared to the consignment size. In CRM, the sample size can be any value, even equal to consignment size. Therefore in CRM, a statistical correction of the binomial distribution for large sample sizes is used (Snedecor and Cochran, 1980). In the model, the proportion of infestation is always known, unlike the practical situation. So, an assumption of the level of infection below which a consignment is deemed free from quarantine organisms (Surkov et al., 2006) is not needed. According to Taylor (1984), the k-value of the negative binominal distribution can be estimated by historical data. In CRM the user can estimate k-value per stage. The main aspects that influence the k-value are: the natural spread of the pest and the exchange of objects over lots.

Application of CRM

The Dutch Plant Protection Service (PD) is an intended user of CRM and is actively participating in the project. Representatives of the business community have been involved in an early stage of the development of CRM and it is to be expected that collective business will use CRM too.

Cost effectiveness and effectiveness

The zero tolerance for export outside EU for EU-quarantine organisms means that the effectiveness of measures against certain pests is important in addition to cost effectiveness. Therefore CRM makes it possible to follow the development of the population of a pest throughout the chain. In practice, a requirement of tolerance will be connected to the measures to be chosen.

Sense of reality

Every simulation model is an imitation of reality. The results of calculations with CRM will always deviate from reality to some extent too. In general, calculations based on logic and relevant data result in more reliable estimates than estimates based on intuition. CRM is suitable for 'sensitivity analyses' and 'getting feeling' for data is a positive consequence of using it.

CRM is not suitable for use by individual businesses. This is because agrarian businesses never enclose a whole product chain, with some exceptions. The use of CRM for a sub group of product chain businesses is possible but has repercussions for the data needed. When this is modelled in CRM, a calculation for some areas can be performed.

Use of CRM

CRM is intended to be used before phytosanitary measures are taken. The extent to which model output will differ from real outcome afterwards depends on the quality of data. Further, a lot of uncertainty is to be expected due to the estimate of the risk of infection from outside, the risk of infection via import and the rate of clustering. This is why CRM is most suitable for carrying out sensitivity calculations. Using CRM requires a lot of experience. Phytosanitary problems require a proactive approach with little expected available time for carrying out calculations. A proactive use of CRM demands the availability of different constructed product chains filled with data. In this way, calculations can be carried out before a problem becomes reality, which then makes CRM a workable tool.

References

Bai, P., H.T. Banks, S. Dediu, A.Y. Govan, M. Last, A.L. Loyd, H.K. Nguyen, M.S. Olufsen, G. Rempala and B.D. Slenning, *Stochastic and deterministic models for agricultural production networks*. Mathematical Biosciences an engineering Vol. 4, Number 3, July 2007.

Beamon, B. M., 'Supply chain design and analysis models and methods'. In: *International Journal Production Economics* 55 (1998), pp. 281-294.

Benninga, J., W. Hennen and M. van Galen, *Productie en handelsdata voor fytosanitair beleid*. Report 2008-052. LEI Wageningen UR, The Hague 2008.

Binns, M.R., J.P. Nyrop and W. van der Werf, *Sampling and monitoring in crop protection, the theoretical basis for developing practical decision guides*. CABI Publishing, CAB international, 2000.

Breukers, A., M. Mourits, W. van der Werf and A. Oude Lansink, 'Costs and benefits of controlling quarantine diseases: a bio-economic modeling approach'. In: *Agricultural Economics* 38 (2008), pp. 1-13.

Breukers, M.H., *Bio-economic modelling of Brown Rot in the Dutch Potato Production Chain*. PhD thesis. Wageningen University, 2007.

Breukers, A., D.L. Kettenis, M.C.M. Mourits, W. van der Werf, A.G.J.M. Oude Lansink, 'Individual-based models in the analysis of disease transmission in plant production chains: An application to potato brown rot'. In: *Agricultural Systems* 90 (2006) 1-3, pp. 112-131.

EU, *Fytorichtlijn*. Plantenziektenwet, 2000/29/EG.

Fels-Klerx, H.J. van der, M.C. Kandhai and C.J.H. Booij, 'A conceptual model for identification of emerging risks, applied to mycotoxins in wheat-based supply chains'. In: *World Mycotoxin Journal* 1 (2008), pp. 13-22.

Fels-Klerx, H.J. van der, S. Tromp, H. Rijgersberg en E.D. van Asselt, 'Application of a transmission model to estimate performance objectives for Salmonella in the broiler supply chain'. In: *International Journal of Food Microbiology* 128 (2008), pp. 22-27.

Gaag, M.A. van der, *Epidemiological and economic simulation of salmonella control in the pork supply chain*. Wageningen UR Animal Sciences Group, 2004.

Hofstede, G.J., H. Schepers, L. Spaans-Dijkstra, J. Trinekens and A. Beulens, *Hide or confide? The dilemma of transparency. The emerging world of chains and networks*. Reed Business Information, The Hague, The Netherlands, 2004.

Kooten, O. van, *Transparante ketens: een kwestie van vertrouwen! Essay; onderdeel van het programma Glastuinbouw 2020*. Report 02.2.010. The Hague, 2002.

Knowler, D. and E.B. Barber, 'The economics of an invading species: a theoretical model and case study application'. In: Perrings, C., M. Williamson and S. Dalmazzone, *The economics of biological invasions*. Elgar, Cheltenham (2000), pp. 70-93.

McLachlan, M.S., 'A simple model to predict accumulation of PCDD/Fs in an agricultural food chain'. In: *Chemosphere* 34 (1997), Nos. 5-7, pp. 1263-1276.

Macleod, A., 'The benefits and costs of specific phytosanitary campaigns in the UK' (G.J.M. Oude Lansink (red.)). In: *New approaches to the economics of plant health* (2006), pp. 163-177.

Ministry of Agriculture, Nature and Food Quality, *Hand Out Clavibacter*. www.minlnv.nl

Moffitt, L.J., J.K. Stranlund, B.C. Field and C.D. Osteen, 'Robust inspection for invasive species with a limited budget' (Oude Lansink (red.)). In: *New approaches to the economics of plant health* (2006), pp. 7-22.

Mumford, J.D., 'Model frameworks for strategic economic management of invasive species' (Oude Lansink (red.)). In: *New approaches to the economics of plant health* (2006), pp. 181-190.

Oude Lansink, A., 'New approaches to the economics of plant health'. In: *New approaches to the economics of plant health* (2006), pp. 1-3.

Plant Protection Service, *Summary of plant health regulations of the Netherlands*. Plant Protection Service, Ministry of Agriculture, Nature and Food Quality, Wageningen 2004

Rahmandad, H., *Heterogeneity and network structure in the dynamics of contagion comparing agent-based and differential equation models*. System Dynamics Group, MIT School of management, Cambridge, Management Science Vol. 54, No. 5 May 2008, pp. 998-1014.,

Schaik, G. van, *Risk and economics of disease introduction into dairy farms*. Wageningen UR Animal Sciences Group, 2000.

Scedecor, G. and W.G. Cochran, *Statistical methods*. The Iowa State University Press, Ames, Iowa, U.S.A. 1980.

Surkov, I.V., *Optimising Import Phytosanitary Inspection*. Wageningen, 2007.

Surkov I, A. Oude Lansink, W. van der Werf and O. van Kooten, 'Designing optimal phytosanitary inspection policy - a conceptual framework and an application. In: Oude Lansink A. (ed.), *New approaches to the economics of plant health* , Springer pp. 39-54., Dordrecht 2006.

Taylor, L.R., 'Assessing and interpreting the spatial distributions of insect populations'. In: *Annual Review Entomology* 29 (1984), pp. 321-357.

Vo, T.L.H. and D, Thiel, *A System Dynamics Model of the chicken meat supply chain faced with bird Flu*. University of Nantes and E.N.I.T.I.A.A. Nantes, LEM-LARGECIA, France, 2006.

Vorst, G.A.J. van der, A.J.M. Beulens and P. van Beek, 'Modelling and simulating Multi-echelon food systems'. In: *European Journal of Operational Research* 122 (2000), pp. 354-366.

Werf, W. van der, *Patterns, distributions, sampling*. Epidemiology lecture Wageningen UR, Wageningen, 2008.

Wijnands, J.H.M. en C.J.M. Ondersteijn, 'Quantifying the agri-food supply chain: Overview and new research directions'. In: *Quantifying the agri-food supply chain*. *Proceedings of the Frontis workshop on quantifying the agri-food supply chain*. Wageningen, The Netherlands, 22-24 October 2004. - Wageningen UR Frontis Series 15, p. 1-10. Dordrecht: Springer, 2006.

Wikipedia, *Negative binominal distribution*.

Wikipedia, *Hypergeometric distributions*.

Whiting, R.C. and R.L. Buchanan, 'Development of a quantitative risk assessment model for Salmonella enteritis in pasteurized liquid eggs'. In: *International Journal of food Microbiology* 36 (1997), pp. 111-125.

Willson, L.J., J.L. Folks and J.H. Young, 'Multistage Estimation compared with Fixed-Sample-size Estimation of the negative Binominal Parameter'. In: *Biometrics* 40 (1984) 1.

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LEI report 2009-113