Epidemiological and economic effects of Salmonella control in the pork production chain

Van der Gaag, M.A.[1,2], G.B.C. Backus [3], R.B.M. Huirne [2]

1Research Institute for Pig Husbandry, P.O. Box 83, 5240 AB Rosmalen, The Netherlands
2Department of Economics and Management, Wageningen Agricultural University, The Netherlands
3Agricultural Economics Research Institute, The Hague, The Netherlands

Abstract

In this paper a salmonella simulation model for the pork production chain is presented to evaluate the epidemiological and economic effects of hygiene measures and price differentiation on *Salmonella*. Results indicate that the farm stages in the chain are the most important stages to achieve reduction of *Salmonella* in pork. To reach an acceptable overall level of *Salmonella* however, every stage has to contribute. With a new system of price differentiation between infected and *Salmonella* free piglets and pork, the stages can be motivated to take measures for reduction and control of *Salmonella*.

Introduction

The issue of food safety is becoming more prominent because of the increasing emphasis on food safety by consumers and the large societal costs associated with food-borne diseases (7). To control food-borne risks in meat, it is essential to include the whole production chain from breeder to consumer (4,6). In agriculture there is an increasing interest for developing production chains, which also involves several types of vertical integration and co-ordination. The objective of such activities is not only to assure food safety, but also to achieve higher levels of service and quality, substantial savings in costs and improved market position (12).

The genus *Salmonella* is ubiquitous in nature and is also rampant in pigs. *Salmonella* food poisoning in humans remains one of the major causes of gastro-enteritis in the developed world (5). In Western Europe the most prevalent type in pork is the *S. typhimurium* (8,9). The estimated average incidence of human salmonellosis in the Netherlands is about 100,000 cases a year. Of the identified cases of human salmonellosis on average 15% are types of *S.* spp. that are associated with pigs and pork and about 50% of all *S. typhimurium* infections in humans have been with the pig-associated types (4). In general, regulations with respect to salmonella become more strict. In the Dutch regulations for instance, the acceptance level of the presence of *Salmonella* in minced meat and meat for raw consumption tends to zero.

Salmonella can survive and proliferate outside their hosts and the salmonella problem is basically a continuous faecal-oral cycle and thus also a hygiene problem. Although *Sal. typhimurium* apparently does not have much effect on the performance figures of pigs as such, it is worthwhile to make a cost-benefit analysis for reduction and control of *Salmonella* in the pork chain. Currently the 'house-flora' is the most important risk for infection on farms (4). The already settled *Salmonella* often have an ecological advantage to 'newly introduced' *Salmonella*. The number of different *Salmonella* that can be isolated from animals or farms is in less then ten percent more than two.

The *Salmonella* isolated from piglets at breeding farms differed in the majority of cases from those found in the same animals at the finishing farms. Nevertheless, it is essential to involve the entire production chain, because if the hygiene-status improves the importance of transmission from stage to stage increases. Research results suggest that vertical transmission is an important factor in the salmonella problem (11).

The purpose of this paper is to describe and discuss a simulation model to evaluate spread and economic consequences of *Salmonella* in the Dutch pork production chain. It first explains the materials and methods used. Then the results are outlined, with an emphasis on epidemiological and economical findings. Finally, the paper is concluded with a discussion and some ideas for further research.

A major difficulty in conducting this type of research is the lack of qualitative data about transmission and about the effects of taken preventive measures. In an exploratory research that we carried out before the simulation study, we questioned some participants of each stage in a structured interview about chains and salmonella occurrence in pigs and pork. The results made clear that in practice the knowledge of control of *Salmonella* is limited. From an epidemiological point of view it is complicated to compare and combine results and to interpret calculated odds ratios from different research projects. Therefore the data used in this paper and the results obtained should be treated carefully.

Materials and Methods

2.1 Dutch Pork Production chain

The Dutch pork sector consists of different stages: breeding, multiplying, transportation, fattening, transportation, slaughtering, processing and sales. The primary stages are mostly family farms, specialised in multiplying or fattening. Most pig-farms are concentrated in two regions in the Netherlands on the sandy soils in the Southern and Eastern of the country. On the multiplying farm the piglets are weaned at 4 weeks and at the weight of 23 to 25 kg (app. 11 weeks old) they are sold to the fattening farm. In about 16 weeks the pigs are fattened to 110 kg live weight. Private transporters mostly arrange transport to the slaughterhouse. At the slaughterhouse the pigs stay in the lairage for a few hours, before being slaughtered, processed and transported to the retailer.

The main economic parameters (table 1) used in this paper are based on the Dutch averages of 1997-1998 (2). The gross returns minus the variable costs are called the gross margin. The gross margin is needed, among others to cover the fixed costs such as labour and housing. We assume the technical results of infected pigs do not differ from salmonella free pigs.

As can be seen in table 1, the typical gross margin for a multiplying farm is $ 430 per sow per year and $24 for a fattening farm per pig sold. All input parameters can be modified to suit other countries and chain conditions.

Table 1. Major technical and economic result of the typical Dutch sow and fattening farm

Technical & economic results (in $) multipying farm*		*Technical & economic results (in$) fattening farm*	
Piglets raised/year/sow	21.5	Daily gain (in gram)	735
Feed costs/sow/yr	$ 223	Feedcosts/pig	$ 52
Feed costs 25 kg piglets/sow	$ 187	Price pork/kg	$ 1.5
Price per piglet of 25 kg	$ 48	Transportation costs/pig	$ 1.5
Miscellaneous costs**/sow/yr	$ 123	Miscellaneous costs**/pig	$ 5
		Rounds/yr	3
Gross margin/sow/yr	$ 430	Gross margin/pig	$ 24

Exchange rate: 1 US dollar ≅ 2 Dutch guilders

** Miscellaneous costs: veterinary costs + insurance + electricity + insemination + water + heating

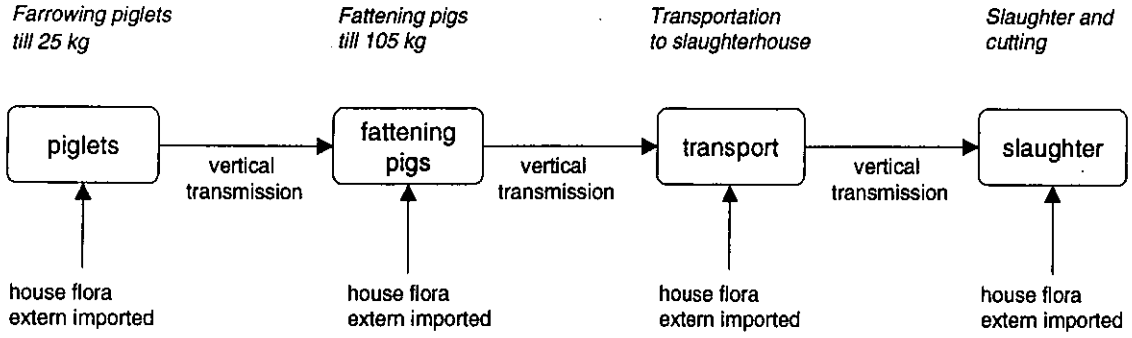

Figure 1. Pork production chain and the salmonella transmission routes

2.2 Description of the model

Because the several farm and firm stages of the chain are linked, they influence each other's technical and economic performance. Usually the optimisation of investments in each individual stage results in sub-optimal overall chain results (6). We developed a model to evaluate the financial and epidemiological consequences of decisions in the chain. In this design the decisions are focused on hygiene strategies for prevention and control of Salmonella. Because of the importance of risk and uncertainty (fluctuation over time, lack of knowledge) involved and the complexity of the problem, we have chosen for a stochastic simulation model. The model is written in Powersim Constructor version 2.5d.

The costs for testing are not a part of the model. Furthermore, these costs depend on the type of test and its specificity and sensitivity. In practice there is nowadays no difference in selling price between infected and free piglets and pork. To motivate stages to take measures for salmonella reduction, there should be a difference. Our model is meant to get an idea of the influence of taken measures in the chain and of price differentiation between infected and non-infected animals.

The version presented is a first design and mainly based on information of *Salmonella typhimurium*. In the model different stages of the pork chain are distinguished: multiply-farm (sows and piglets until 25 kg), fattening stage, transportation and slaughter (figure 1). Within a stage there is no differentiation between farms or firms.

In the model every week a constant number of piglets enter the chain. Because of mortality not every pig reaches the next stage. The mortality rates in the Netherlands for respectively piglets, pigs and transportation are 11.4%, 2.4%, 0.01% (1). We used these rates in our model.

2.3 Salmonella in the pork production chain

In every stage Salmonella can already exist (houseflora), can be introduced by external sources and can be introduced by vertical transmission (figure 1). Hygiene measures, non-contaminated feed and management can reduce the first two. The so-called houseflora's seem to be the most important factor. Vertical transmission is dependent on the prevalence level in the former stage although its role is not completely clear yet (4,11). In our model the prevalences of Salmonella and the effect of management strategies are needed.

The epidemiological basis for our model is primarily based on research of Berends (4). The prevalences are quoted, recalculated or estimated. The number of excreting pigs before (X) and after (Y) transport is sufficiently described by the function $Y=(1.72 \pm 0.18)X$ and the percentage of positive pigs before slaughter (N) and the percentage of positive carcasses just before cooling (M) is described by the function $M=(0.63 \pm 0.14)N$ (4). In table 2 the prevalence numbers in each stage are shown. In other studies different prevalences are presented (11). These will be examined and applied in further research. In some publications it was not clear what was meant with the 'prevalence on farm level': the percentage of excreting pigs or the percentage of infected pigs (e.g. 4).

In each stage three hygiene-strategies are distinguished: 'standard', Good Manufacturing Practice (GMP) and 'Specific Pathogen Free (SPF)/extra' (table 2). Compared with the current standard situation, GMP means additional housing and management measures are taken. The extra measures on farm level are based on the SPF concept. In the 'SPF/extra' concept related to transport no mixing of animals of different pens is allowed and measures for stress reduction and extra hygiene are taken. At the slaughterhouse 'SPF/extra' is about careful evisceration, extra hygiene and reducing cross contamination. The lairage is included in the slaughter-stage. We assume in our calculations that the chain participants completely adhere to the GMP- or SPF- concept. With the most strict strategy (SPF/extra) the chance of salmonella infections are less likely. Because the failed attempts to raise completely salmonella free pigs (e.g. 4), we hypothesise these prevalence levels at 1%.

We present here the economic effects on the gross returns of *Salmonella* on the farm stages. Working according GMP or SPF concept has some side effects like better technical performance, higher investment costs and it is more labour-intensive. These effects are no part of the model yet.

Table 2. Prevalence fractions of Salmonella used in the different stages of the porkchain simulation model

Hygiene-strategy → Stage in the chain ↓	'standard'	GMP	SPF / extra
Multiplying (piglets)	0.10	0.05	0.01
Fattening pigs	0.15	0.08	0.01
Transportation	0.22	0.10	0.01

Preliminary Results

3.1 Epidemiology of Salmonella in the pork chain

Figure 2 shows the different prevalence levels per stage for 5 scenarios: 'standard' (current situation), 'GMP' (every stage works according the GMP-standards), 'SPF/ extra' (every stage takes extra measures), 'end GMP' (the farrowing and fattening stage are standard and the other stages work according GMP) and 'start GMP' (the first two stages work according GMP and the other stages standard).

In figure 2 the prevalence levels are described as a continuous flow in the chain, this is not corresponding with reality. Nevertheless, because of the purpose of this figure (comparing hygiene strategies in each stage) it is a useful way of presenting. The prevalences in each stage are written exactly above the name of the stage at the x-axis.

As can be seen in figure 2, taking prevention measures at farm level (i.e. PGL and PG) is the most effective way to reduce the occurrence of salmonella. If farm level works according GMP, the number of pigs infected in the next stages are decreased considerably (compare in figure 2 'end GMP' and 'start GMP'). To lower the risks for human salmonellosis by pork effectively, the tolerance level should tend towards zero and therefore it is necessary to include every stage in the chain.

3.1 Economic effects of Salmonella in the pork chain

The differentiation in price-settings, the type of housing and management determine largely the gross margin of a farm as mentioned before. The gross margin is defined as revenues minus variable costs. In figure 3 the effect on the gross margin (in percent) is shown for some combinations of price differentiation. As the price difference between infected and free piglets increases, the loss of margin lowers linearly. More prevention measures reduce the loss of margin. Investing in prevention measures is economically worthwhile if it will not exceed that percentage.

Under standard conditions the effect of a price difference is higher because of the higher prevalence. For example: a current multiplying farm with 200 sows with a yearly gross margin of $ 80,000 may invest $960 (i.e. 1.2%) annually to work according GMP if he receives a 10% lower price for its piglets with (provable) *Salmonella*. A 25% discount for infected piglets stands for $2320 per year (i.e. 2.9% of $80.000).

Comparable calculations have been made for the fattening stage. An important factor is the moment and type of testing the animals. The most regular test is measuring antibodies, but this does not exclude recent infections: the presence of antibodies is only measurable after 7 to 14 days after infection. So if the animals are tested at the slaughterline, the infections during transport and lairage cannot be measured. The current Salmonella status of the animals can be tested by a sample. Because the moment of testing is determinative for the prevalence, it can influence the payment to the farmer. In figure 4 we calculated the influence if the pigs are tested before transportation, because infection during transport depends also on the management of the transporter (see also figure 2). All piglets have the same purchase price. When the farmer buys only guaranteed *Salmonella* free piglets there is no vertical transmission, but in the current situation the farmer cannot be sure.

An average Dutch fattening farm of 2000 pigs has a gross margin of $144.000 and GMP hygiene strategy. With a price reduction of 10% for pork price of infected pork this means a loss in margin of $6048 (i.e. 4.2%). If the pigs are tested after transportation the percentages in figure 4 are higher, but depend also on the management of the transporter. In this paper we focus on the farm stages.

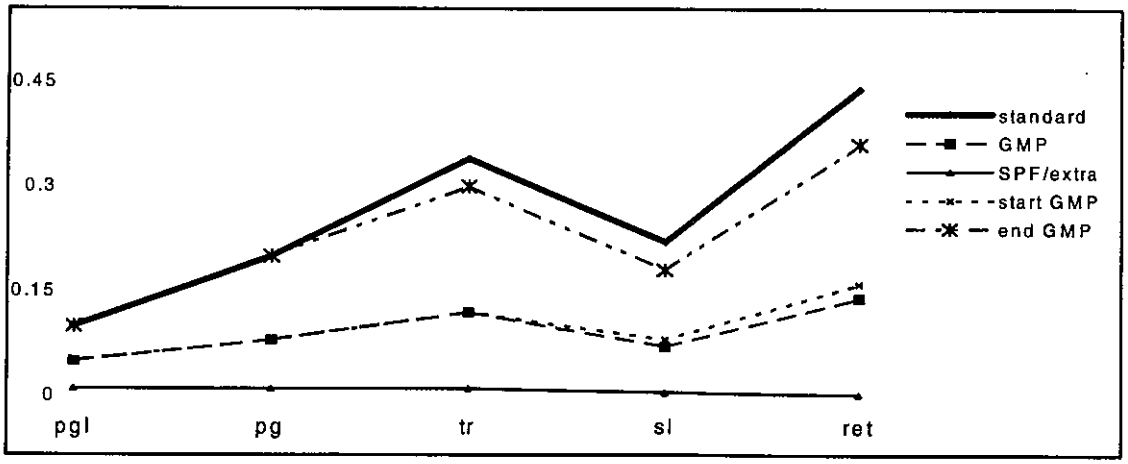

Figure 2. Prevalence levels per stage in the porkchain (PGL = piglets on multiplying farm, PG = fattening stage, TR = transportation, SL = slaughter, RET = retail).

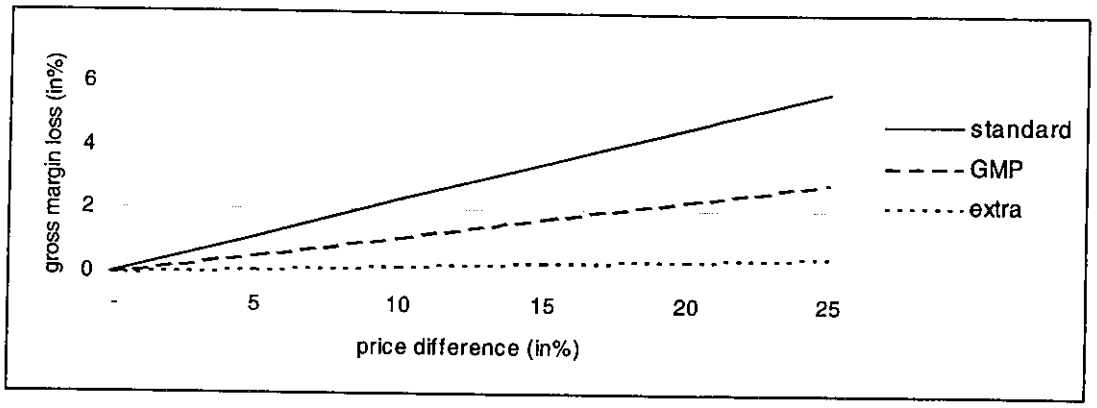

Figure 3. Loss of gross margin (in %) with difference in price piglets and different hygiene strategies

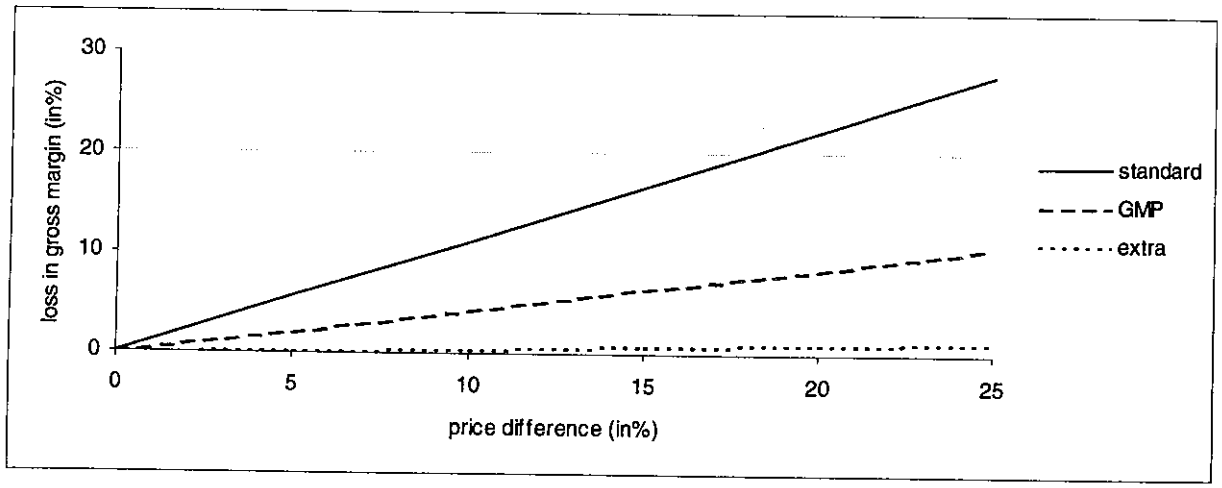

Figure 4. Loss of gross margin (in %) with difference in price pork and different hygiene strategies

Discussion and Outlook

The model presented is a first design for simulation and calculation of the economic and epidemiological effects of different hygiene strategies. During the search for input parameters it became clear that the available data about vertical transmission, the effect of (hygiene) measures and the prevalence levels in the stages are limited. The data used are plausible in our opinion, as of course the output, is dependent on the input. Therefore the results have to be treated carefully. This research does not promise exact amounts of considered investment, but shows the influence of decision making in a stage of a production chain to the other stages. It is important because it affects competitive advantage in a local and global market. The results indicate that information exchange between stages is necessary to guarantee quality to the retailer and the consumer.

The economical effects of hygiene measures and price differentiation are in this paper entirely attributed to Salmonella. In practice this is not realistic, because with certain hygiene measures the occurrence of other bacteria will also be reduced. The total bacteriological quality of pork generally increases and on-farm level it might increase the technical performance as well. This can come down to better economical performance (higher gross margin) and the calculated considered investment costs increase. On the other hand, the fixed costs have to be taken in account, because the depreciation, interest, maintenance and labour are important factors for a farmer in his decision making process.

Because of the used methodology and the difference in prevalence the effect of a discount on the price of piglets exert less influence on the gross margin compared to the same discount on pork. It would be more exact if the farmer who buys the piglets pays less for the infected animals. The model is not yet finished and this is one of the next items to be dealt with.

In the production of agriproducts, like pork, natural fluctuation and uncertainty is inevitable. But with a better knowledge of the processes and a good information flow up- and downstream, uncertainty can be reduced and/or controlled. Simulation models are a tool to understand the problem, to determine critical elements, to evaluate proposed solutions and to synthesise new alternatives (3). A sector can choose between three generic strategies: cost leadership and differentiation on a broad target and focus on cost or differentiation (10). The salmonella problem in pork is actually a differentiation strategy. The next case in this research will be the logistic tuning in the pork chain. If the supply and demand fit better by information exchange, it will reduce costs in the production chain, which will strengthen the position in the market. The combination of these two approaches might be essential for the pig industry in the Netherlands.

References

1. Anonymous 1997 SIVA Agri Software. *Farm Comparison.* (in Dutch) Wageningen, The Netherlands

2. Anonymous 1998. Quantitative Information Livestock (in Dutch), Lelystad The Netherlands

3. Banks J. 1998 Handbook of Simulation, Principles, Methodology, Advances, Applications and Practice. Engineering & Management Press

4. Berends B.R. 1998. A risk assessment approach to the modernization of meat safety assurance. Thesis, Utrecht University, The Netherlands

5. Dargatz D.A., S.J. Wells, P.J. Fedorka-Cray and J. Akkina. 1998. The veterinarian's Role in Diagnosis, Treatment and Prevention of Multidrug Resistant *Salmonella typhimurium DT104* in the Bovine Practitioner, May 1998

6. Den Ouden, M. , A.A. Dijkhuizen, R.B.M. Huirne and P.J.P. Zuurbier (1996) *Vertical cooperation in Agricultural Production-Marketing Chains, with special reference to product differentiation in pork.* In: Agribusiness: an International Journal 12 –3

7. Mora C. (1997) *Quality in Fruit and Vegetables Chain: A case study.* In: G. Schiefer and Helbig, Quality Management and Process Improvement for Competitive advantage in Agriculture and Food. Proceedings of the 49th Seminar of the European Association of Agricultural Economists (EAAE), Bonn Germany.

8. Pelt van, P., W.J. van Leeuwen and Y.T.H.P. van Duynhoven. 1998. A design for early warning of *Salmonella* infections. RIVM Infection diseases Bulletin Vol. 9, nr 4.

9. Pohl, P., H. Imberechts, A. Stockmans, I. D'Hooghe and M. Marin. 1998. Serovars of Belgian *Salmonella* isolates serotyped during the period 1992 - 1997. Ministry of Middle Class and Agriculture, Veterinary and Agrochemical Research Center, Brussels Belgium

10. Porter M.E. (1985) Competitive Advantage, The Free Press New York

11. Schie van, F.W. 1987. Some Epidemiological and Nutritional Aspects of Asymptomatic *Salmonella* Infection in Pigs. Thesis, Utrecht University, The Netherlands

12. Ziggers, G.W. (1997) *Integrated Quality Assurance in the Pork Supply Chain: The challenge of Vertical Cooperation.* In: G. Schiefer and R. Helbig, Quality Management and Process Improvement for Competitive Advantage in Agriculture and Food. Proceedings of the 49th Seminar of the European Association of Agricultural Economists (EAAE), Bonn Germany

Acknowledgement

This research is co-financed by Agro Chain Competence in Rosmalen, The Netherlands.