



**Analysis of measures to reduce antimicrobial resistant bacteria in
German and Dutch pig and poultry meat supply chains**

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1. Introduction

1.1. Background

Bacteria that are resistant to antimicrobial treatments are gaining increasing importance in Public Health worldwide. For instance, it is estimated that 25,000 patients die in the European Union each year from infections caused by multidrug resistant bacteria (ECDC/EMA, 2009). Moreover, scientists have found that the transfer of these resistant bacteria to humans is partly associated with foodstuffs from animals, especially poultry and pig meat.

Poultry and pig meat are produced in supply chains that consist of inputs from several actors at different stages to provide consumers with the final meat product. The pig and poultry meat supply chains are composed of: farm, transport, slaughterhouse, processing, retail and consumer. However, this study focuses on beyond farm stages until retail. It is important to notice that the prevalence of antimicrobial resistant (AMR) bacteria in every stage of the food supply chain may vary depending on different factors such as management decisions, hygiene practices, etc. (Zbrun *et al.*, 2015). There are measures that are implemented in the meat supply chains routinely which are common hygiene practices in that meat chain. However there are extra measures that can be implemented which can provide an extra bacteria reduction to the meat supply chains. Each actor in the meat supply chain implements measures to reduce the prevalence of bacteria, including those that are resistant to antimicrobial treatments. For example, steam ultrasound treatment and hot-water decontamination at poultry and pig slaughterhouses, respectively (Jensen, Lawson, & Lund, 2015; Goldbach, & Alban, 2006). The decision to implement extra measures or not depends on a range of factors. Current studies consider only the cost-effectiveness of measures to determine their viability (Lawson, & Lund, 2015; Goldbach, & Alban, 2006; Van der Gaag *et al.*, 2004; Jensen). Also, other criteria such as legal aspects, can play a role in their decision making. The decision-making of implementing or not certain measures is driven by stakeholder's criteria such as cost-effectiveness, in which they compare cost and effects, and non-cost-effectiveness criteria where they compare legal aspects, organizational aspects, consumers aspects, and so on.

Multiple Criteria Analysis has been used in several different fields such as sustainable energy, health care, contagious animal diseases, and so on, as a tool to provide a structure and clear framework for the analysis of different types of decisions (Thokala *et al.*, 2016; Wang *et al.*, 2009; Mourits *et al.*, 2006).

A Multiple Criteria Decision Analysis (MCDA) is one type of multi criteria analysis. MCDA is at the same time an approach and a set of techniques that provide a ranking of options, from the most preferred to the least preferred option. It is intended to be an aid to decision making, putting emphasis on the judgement of the decision maker (Dodgson *et al.*, 2009). MCDA was the tool used to determine the

preferences for measures that reduce AMR bacteria in the poultry and pig meat supply chains and to know the level of agreement among stakeholders.

1.2. The problem

The problem is that research emphasis is usually on cost-effectiveness of measures, other aspects such as legal aspects, consumer acceptance, moral hazards, and so on are not taken into account. Conflicts of interest always rise in the chain when defining which measures to implement to reduce the prevalence of bacteria in the final meat product. Hence, preferences regarding these aspects can provide useful insights to design an optimal set of measures to reduce the AMR bacteria problem in the poultry and pig meat supply chains.

1.3. Study objective and research questions

The objective of the study was to analyse the measures that can contribute to reduce the prevalence of AMR bacteria in the pig and poultry meat supply chains in Netherlands and Germany. To achieve this objective four research questions were derived:

Q1. To establish the inventory of measures that can be used in the broiler and pig meat supply chains to reduce the AMR bacteria and criteria per stakeholder.

Q2. To determine performance scores for the measures under each criterion.

Q3. To elicit the non-cost-effectiveness criteria preferences by the stakeholders of the pig and broiler meat chains in Netherlands and Germany.

Q4. With the overall values obtained for each measure by the use of MCDA, provide a ranking of measures to reduce AMR bacteria in poultry and pig meat supply chains.

2. Materials and methods

2.1. Q1. Established the inventory of measures and criteria that can be used in the broiler and pig meat supply chains to reduce the AMR bacteria per stakeholder

2.1.1. Stakeholders' in the pig and poultry meat supply chains

Pig and poultry meat are produced in supply chains that consist of inputs from several stakeholders at different stages to provide consumers with the final meat product. A stakeholder can be defined as people or organizations that are affected by a decision or that to have to implement it (Greco *et al.*, 2010).

The stakeholders of the pig and poultry meat supply chains are: farm, transport, slaughterhouse, processing, retail and consumer. However, farm and consumer were not included in this study. In the Figure 1 and Figure 2 can be observed the different steps inside the slaughterhouse stakeholder.

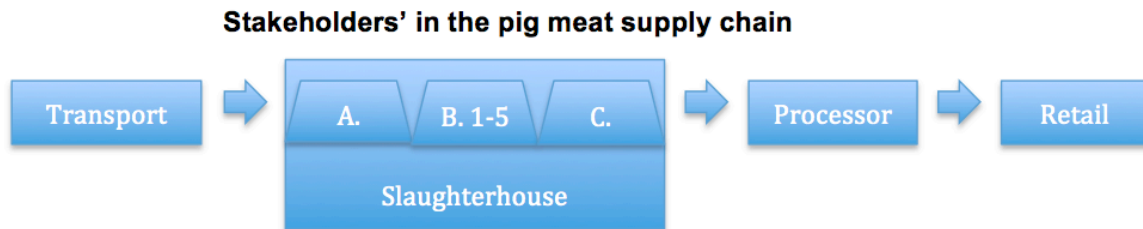


Figure 1. *The four stakeholders in the pig meat supply chain.* Within the slaughterhouse different steps take place, where (A.) is the lairage step, (B.) is the slaughtering step and has 5 sub-divisions that are: (B.1) Scalding, (B.2) Dehairing, (B.3) Singeing, (B.4) Evisceration, (B.5) Carcass splitting, and (C.) is the initial processing step.

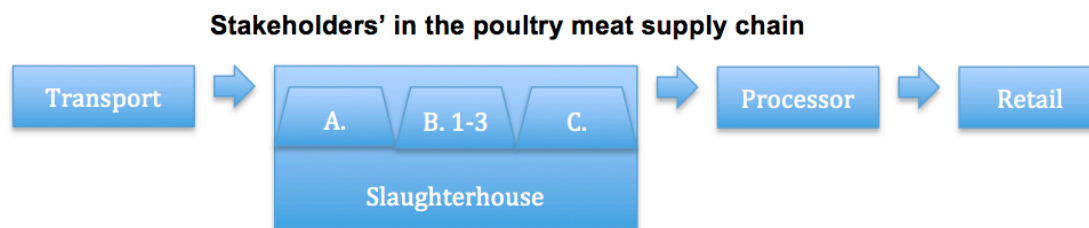


Figure 2. *The four stakeholders in the poultry meat supply chain.* Within the slaughterhouse different steps take place, where (A.) is the lairage step, (B.) is the slaughtering step and has 3 sub-divisions that are: (B.1) Scalding, (B.2) Defeathering, (B.3) Evisceration, and (C.) is the initial processing step.

2.1.2. Selection of measures to consider

The basis for this study was the working paper by Gocsik & Saatkamp, 2015; in their work they provide a comprehensive list of measures to reduce AMR bacteria by stakeholders in the pig and poultry meat supply chains, as well as 6 non-cost effectiveness criteria. As part of their work, they asked 2 experts, 1 expert of the pig meat supply chain and 1 expert of the poultry meat supply chain, to determine the performance of measures on each of the established 6 criteria.

From the vast list of measures from Gocsik & Saatkamp, 2015, only the measures considered to have the capacity to reduce the level of bacterial contamination and that are currently not part of normal processes in the poultry and pig meat supply chains in Europe were considered for this study. Those measures are known as **decontamination measures**:

- For poultry meat supply chains: Irradiation, air chilling, organic acids, chlorine-based treatments, phosphate-based treatments, other chemical treatments, steam ultrasound.
- For pig meat supply chains: Steam, ultraviolet C irradiation, organic acids, and other chemical treatments.

After a review of the listed measures in Gocsik & Saatkamp, 2015; “steam ultrasound” treatment in poultry meat supply chains was included in the analysis by the author of this master thesis. This measure was included because this new technology is an effective decontamination measure for different bacteria pathogens affecting poultry meat, in addition some companies in Europe already started using this technology in poultry meat supply chains (Jensen, Lawson, & Lund, 2015; Musavian *et al.*, 2014; Lawson, Jensen, & Lund, 2009).

2.1.3. The non cost-effectiveness criteria selected

The criteria selected for this study were the ones established in the working paper by Gocsik & Saatkamp, 2015. The criteria are:

- **Complexity of implementation**
- **Complexity of performance monitoring**
- **Costs of implementation and monitoring**
- **Consumer acceptance**
- **Conformity with international trade agreements**
- **Moral hazard**

2.2. Q2. To determine performance scores for the measures under each criterion.

2.2.1. Sources of the measure’s performance scores

Performance scores were established using two sources. The sources were via expert consultation and via literature review. For the expert consultation the performance scores were already available in the working paper by Gocsik & Saatkamp, 2015. In the case of the literature review, the author of this master thesis assigned the performance scores by analysing the literature available in relation to the 6 non-cost effectiveness criteria.

Not enough literature was found for the “other chemical treatments” measure for poultry and pig meat supply chains. Similarly, the “Moral hazard” criterion was not

taken into consideration in the literature review for any of the measures due to scarcity of literature on this topic.

2.3.Q3. To elicit the non-cost-effectiveness criteria preferences by the stakeholders of the pig and broiler meat chains in Netherlands and Germany

2.3.1 Elicit criteria weights

2.3.1.1. Elicitation method

A literature review was conducted to select an elicitation method that would be reliable to determine the criteria preferences among stakeholders. The swing method was selected to be the appropriate weighting method for this study; this method is a subjective weighting method and is part of the rank-order weights method (Wang *et al.*, 2009).

The swing method allows the respondents to state their preferences and how much that preference is important for them, main reason for its use on this study (Dodgson *et al.*, 2009).

The use of this method can be described as follows: first the criteria are described so the respondents can have a clear understanding of each criterion. Immediately, the respondent was asked to select among the 6 criteria, the one criterion that he/she would most prefer and to assign 100 points to this most important criterion. Then the respondent continued to chose the criterion which he/she considers to be the second most preferred and to assign points less than 100 to that criterion. Proceeding in this fashion, the decision maker ranks all criteria and assigns relative importance points to their value ranges. The values range was from 0 to 100 points (Wang *et al.*, 2009; Dodgson *et al.*, 2009).

2.3.1.2. Survey/questionnaire

The purpose of the survey was to elicit the preferences among stakeholders for the criteria being studied using the swing method of criteria elicitation. The survey was conducted by sending a cover letter and an email questionnaire to three industry representatives in the pig and poultry meat supply chains in Netherlands and Germany. They were Dutch poultry meat slaughterhouse+ processing, German pig meat retail, and Dutch pig meat slaughterhouse.

The survey and cover letter that was sent to the stakeholders can be found on the Annex A and Annex B respectively. The questionnaire was anonymous based, only relevant information for the study was asked.

2.3.1.3. Normalizing weights

After the results of the survey were obtained, the points were introduced on a Microsoft Excel worksheet, to be normalized to sum up to 1 to obtain the criteria weights for poultry and pig meat stakeholders (Wang *et al.*, 2009; Dodgson *et al.*, 2009 ; Zopounidis & Pardalos, 2010). This was done for each stakeholder, first a sum of all the criteria points obtained. Then the result of the addition was used to divide by the points of each criterion, obtaining the criteria weights. The mentioned procedure was performed for each of the three stakeholders under the study.

There were different criteria weights depending if the calculation was used to derive the overall value with the expert consultation performance scores. In that case all the criteria were taken into account to calculate the weights. Contrary, the criteria weights used to derive the overall values with the literature review performance scores had a different value because the “moral hazard” criterion was not included to calculate the weights.

2.4. Q4. With the overall values obtained for each measure by the use of MCDA, provide a ranking of measures that can be applied by stakeholders in the poultry and pig meat supply chains in order to successfully diminish AMR bacteria

2.4.1. Calculation of the overall value

Using Microsoft Excel the overall value was calculated by applying the simple linear additive evaluation model. The model consists of multiplying the performance score of a measure under each criterion by the weight of that criterion, that procedure for every criterion. After those values are obtained, the next step was adding all those weighted scores together to obtain the overall value per measure. It is important to bear in mind that two different overall value calculations were executed: one for the performance scores from expert consultation and a second one using performance scores from literature review (Dodgson *et al.*, 2009).

2.4.2. Multiple Criteria Decision Analysis

The measure’s performance scores set by expert consultation and literature review, with the weighting outcomes set by stakeholders can be combined to produce three sets of results: 1) group rankings of the measures, representing and ordered ranking of most preferred to least preferred measures that takes all weighting schemes and measure performance into account; 2) individual rankings for each stakeholder, representing the most preferred to least preferred measures for a particular stakeholder given their specific weighting scheme; and 3) individual performance of measures for every criterion, showing how a measure performs on

every criterion independently of all stakeholders weighting schemes (Aenishaenslin et al., 2013).

Analysis presented in this study includes group rankings of the measures, and individual performance of measure for every criterion. The MCDA results were presented in 7 steps: 1. Establish the decision context, 2. Identify the measures to be appraised, 3. Identify objectives and criteria, 4. Scores, 5. Weights, 6. Calculate overall value, 7. Examine the results (Mourits *et al.*, 2006).

3. Results

3.1. Step 1: Decision context

The objective of this MCDA was to assess decontamination measures that can be applied by stakeholders in the pig and poultry meat supply chains in order to successfully diminish the prevalence of AMR bacteria in Germany and Netherlands.

The stakeholders that participated in this study were industry representatives from the Dutch poultry meat slaughterhouse, Dutch pig meat slaughterhouse + processing, and German pig meat retail.

3.2. Step 2: Identify the measures to be appraised

Decontamination measures not applied on a normal basis through Europe for the pig and poultry meat supply chains were selected from the working paper by Gocsik & Saatkam, 2015; with further literature review by the author of this master thesis steam ultrasound was also included as part of decontamination measures for the poultry meat supply chain. Therefore that measure only had performance scores under the literature review. The decontamination measures and their description were:

- For poultry meat supply chains:
 - **Irradiation:** The use of ionizing radiation either by radionuclides or machines (Arvanitoyannis, 2010).
 - **Air chilling:** Cold air is blown into both the abdominal cavity and the exterior of the thick parts of the carcass (Sansawat *et al.*, 2014).
 - **Organic acids:** Lactic, acetic and citric acids are applied as a rinse to the entire surface of the carcass by either immersion or spraying (Mani-Lopez *et al.*, 2012).

- **Chlorine-based treatments:** Water-soluble chlorine, chlorine dioxide, and acidified sodium chlorite are usually applied as sprays or dips on poultry carcasses (Bunic & Sofos, 2012).
 - **Phosphate-based treatments:** Trisodium phosphate is used as a dip immediately post water chilling or pre-air chilling (Dinçer & Baysal, 2004).
 - **Other chemical treatments:** Peroxides, sulphate-based compounds or sodium peroxide on poultry carcasses and parts (Loretz *et al.*, 2010).
 - **Steam ultrasound:** Combines the effect of hot steam and high frequency ultrasound, which are produced simultaneously by specially designed nozzles (Jensen *et al.*, 2015).
- For pig meat supply chains:
 - **Steam:** At the end of slaughter process, steam vacuum and hand held steam vacuum technology (Lawson L.G. *et al.*, 2009).
 - **Ultraviolet C irradiation:** The use of radiation from UV-C wavelength for microbial intervention on food surfaces (US-FDA, 2000).
 - **Organic acids:** Lactic, acetic and citric acid spraying (Loretz *et al.*, 2011).
 - **Other chemical treatments:** Electrolyzed water, potassium sorbate, sodium hypochlorite and trisodium phosphate (Loretz *et al.*, 2011).

3.2.1. Location of measures in the pig and poultry meat supply chains

The decontamination measures selected for the pig meat are applied in the slaughterhouse, the exact location of the implementation of those measures are:

- Slaughterhouse: Carcass splitting: steam, organic acids, other chemical treatments; C. Initial processing: ultraviolet C irradiation.

The decontamination measures selected for the poultry meat are applied by slaughterhouse and processor, the exact location of the implementation of those measures are:

- Slaughterhouse: Evisceration/ dressing: use of chlorine for whole carcass rinses; Initial processing: irradiation, steam ultrasound, organic acids, chlorine based rinses, phosphate based treatments, and other chemical treatments.

- Processor: Air chilling.

3.3. Step 3: Identification of the evaluation criteria

Definition of the 6 non-cost effectiveness criteria selected for the study:

- **Complexity of implementation:** easiness of applying a measure within the organization.
- **Complexity of performance monitoring:** easiness to monitor the performance of a measure, e.g., is additional personnel required? Do equipment or installations need to be adopted? Etc.
- **Costs of implementation and monitoring:** costs needed to implement and monitor a measure.
- **Consumer acceptance:** likelihood that a consumer will purchase the final product if a certain measure is implemented.
- **Conformity with international trade agreements:** compliance of a measure with international legal frameworks.
- **Moral hazard:** the risk that a supply chain participant does not apply measures at his specific stage of the supply chain, therefore relying on measures applied by other participants.

3.4. Step 4: Scores of measures on each criterion

3.4.1. Scales of measures on each criterion

The scale of the score was from 0 to 2, in Table 1 below are depicted for each criterion (Gocsik & Saatkamp, 2015).

Table 1. Scale for assign scores to the different measures.

Criteria/ Scores	0	1	2
Complexity of implementation	Very complex	Moderate	Not at all complex
Complexity of performance monitoring	Very difficult to monitor	Moderate	Very easy to monitor
Costs of implementation and monitoring	Very high cost	Moderate cost	Very low cost
Consumer acceptance	Very low acceptance	Moderate	Very high acceptance
Conformity with international trade agreements	Not at all	Conform with most EU countries	Worldwide conformity
Moral hazard	Very high likelihood for moral hazard	Moderate	Very low likelihood for moral hazard

3.4.2. Performance scores from expert consultation

The scores from poultry and pig meat supply chains resulted from the external expert consultation from the working paper of Gocsik & Saatkamp, 2015. Decontamination measures performing scores for the poultry meat supply chains were presented in Table 2, and the decontamination measures performing scores for pig meat supply chain presented in Table 3. Note that the initial list of measures did not include steam ultrasound for poultry.

Table 2. Performance scores from the expert consultation in poultry meat supply chains.

Measure	Complexity of implementation	Complexity of performance monitoring	Costs of implementation and monitoring	Consumer acceptance	Conformity with international trade agreements	Moral hazard
Irradiation	0	0	0	0	2	2
Air chilling	1	2	0	2	2	2
Organic acids	1	1	1	0	0	0
Chlorine based treatments	2	2	1	0	1	0
Phosphate based treatments	1	1	1	0	0	0
Other chemical treatments	1	1	1	0	0	0

According to experts consulted poultry meat consumers accept only “air chilling”. It is interesting that “Irradiation” had worldwide “conformity with international trade agreements” and very low likelihood of “Moral hazard”, while “air chilling” was considered to have only one disadvantage and was to be too costly. Among the

chemical measures, only “Chlorine based treatment” conforms to most EU countries and considered not complex to implement.

Table 3. Performance scores from the expert consultation in pig meat supply chains.

Measure	Complexity of implementation	Complexity of performance monitoring	Costs of implementation and monitoring	Consumer acceptance	Conformity with international trade agreements	Moral hazard
Organic acids	2	2	0	1	0	1
Steam	2	2	0	2	2	1
Ultraviolet-C irradiation	2	2	0	0	0	2
Other chemical treatments	2	2	1	0	0	1

It is also striking that according to the experts consulted, pig meat consumers highly accept the use of “steam” and in a moderate extent “organic acids”. Moderate costs of implementation and monitoring were exclusively for “other chemical treatments”. At the same time, all the measures obtained the same scores for “complexity of practical application” and “complexity of performance monitoring”. Moderate levels of “moral hazard” were identified for all the measures except for “ultraviolet-C irradiation” which was regarded with a very low likelihood of it.

3.4.3. Performance scores from the literature review

3.4.3.1. Literature review of decontamination measures on each criterion and performance scores

Table 4 & Table 6 summarize the main findings of the literature review for the decontamination measures for each of the 6 criteria analysed in the study.

For the pig and poultry meat supply chains, the “moral hazard” criterion and “other chemical treatments” measures were not considered for the literature review section of this study. Nevertheless, the measure called “steam ultrasound” was added to the poultry meat decontamination measures.

In order to perform the MCDA, performance scores of the measures were derived using the results of the literature review. Performance scores were assigned to each of the decontamination measures for poultry and for pig meat supply chains on each criterion by using the same scale that the experts used to assign scores (Table 5 & Table 7).

Table 4. *Summary of decontamination measures for poultry meat supply chains.* Where CI= complexity of implementation; CPM=complexity of performance monitoring; CIM= costs of implementing and monitoring; CA= consumer acceptance; CITA= conformity with international trade agreements.

Measure	CI	CPM	CIM	CA	CITA	References
Irradiation	Design, build, and operation of the facilities	Easy to monitor	Relatively inexpensive machines	Poorly accepted, leaves meat unchanged in appearance	Not allowed to be used on meat in the EU	Umaraw <i>et al.</i> , 2015; FAO/IAEA/WHO, 1999; Pacholewicz, 2016; MacRitchie <i>et al.</i> , 2014; Arvanitoyannis, 2010.
Air chilling	It is not easy to adapt from other chilling systems to air chilling	Longer chilling time and lower processing throughput	Reduced water consumption, lower labour cost, reduce waste water management	Better taste and product juiciness, also reports of more frequent visual defects	Traditionally used among European community	Sansawat <i>et al.</i> , 2014; Jeong <i>et al.</i> , 2011;
Organic acids	Acids are added to the scald water or in the chill water, easy to manipulate	Need to check if the acid concentration is correctly settled	They are low cost	Undesirable effect on product quality (negative flavor and colour changes), low acceptability	Not accepted in Europe	Mani-López <i>et al.</i> , 2012; Dinçer & Baysal, 2004; Buncic & Sofos, 2012; EFSA, 2010; Nagel <i>et al.</i> , 2013.
Chlorine based treatments	In water washing and immersion chilling system	Test and verify the appropriate concentration	Low cost	Low acceptability, not perceivable quality changes	In Europe water used in poultry maximum chlorine concentration of 5 ppm.	Buncic & Sofos, 2012; MacRitchie <i>et al.</i> , 2014; Nagel <i>et al.</i> , 2013.
Phosphate based treatments	Investment on the chemical and some equipment	Extra labour, water and energy	It requires capital investments and variable expenses	Not sensory or quality alterations, Low acceptability	Not authorized in Europe	Dinçer & Baysal, 2004; MacRitchie <i>et al.</i> , 2014; Capita <i>et al.</i> , 2002; Jensen <i>et al.</i> , 2015.
Steam ultrasound	Investment to acquire the equipment and arrangements for the installation	Labour remain unaffected	Capital investment, lower water and energy consumption	Highly acceptance among consumers, no changes in quality	Has no restriction for application among Europe	Jensen <i>et al.</i> , 2015; Lawson <i>et al.</i> , 2009; MacRitchie <i>et al.</i> , 2014; Musavian <i>et al.</i> , 2014.

Table 5. Performance scores from the literature review in poultry meat supply chains.

Measure	Complexity of implementation	Complexity of performance monitoring	Costs of implementation and monitoring	Consumer acceptance	Conformity with international trade agreements
Irradiation	0	2	1	0	0
Air chilling	1	1	2	2	2
Organic acids	2	1	2	0	0
Chlorine based treatments	2	1	2	0	0
Phosphate based treatments	1	1	1	0	0
Steam ultrasound	0	2	1	2	2

Table 5 shows that “air chilling” and “steam ultrasound” measures are highly accepted by consumers and comply with trade agreements. The decontamination measures analysed provided from moderate to a very low “costs of implementation and monitoring”, even though most of the decontamination measures analysed are not allowed in Europe. Equally, the “complexity of implementation” and “complexity of performance monitoring” was easy to moderate for all the chemical treatments.

Table 6. Summary of decontamination measures for pig meat supply chains. Where CI= complexity of implementation; CPM= complexity of performance monitoring; CIM= costs of implementing and monitoring; CA= consumer acceptance; CITA= conformity with international trade agreements.

Measure	CI	CPM	CIM	CA	CITA	References
Organic acids	Problems with working environment and corrosion of equipment.	Complexity will depend on the equipment used.	Costs will depend on the equipment used	Low consumer acceptance	Not approved in Europe	EFSA, 2010; Loretz <i>et al.</i> , 2011; Lawson L.G <i>et al.</i> , 2009; Mørkbak <i>et al.</i> , 2011; Rodriguez, 2007.
Steam	Currently used in some European slaughterhouses, can be used as large commercial or small portable systems	Effectiveness relies on the quality of the steam generated by the steam system	Requires installation of steam generators, chilled water and regeneration plant	Can affect the quality of meat such as slight discoloration and deformation of skin	Approved in Europe	Lawson L.G <i>et al.</i> , 2009; Trivedi <i>et al.</i> , 2008; Loretz <i>et al.</i> , 2011; Mørkbak <i>et al.</i> , 2011.
Ultraviolet-C irradiation	Restricted penetration depth, not commercial application on meat	Use of UV sensors, UV lamps must have same age and quality	Not requires chemicals or heat, not expensive	Cause few changes in the quality of food	It is allowed to use in Europe but not in meat	Mukhopadhyay & Ramaswamy, 2012; US-FDA, 2000; Loretz <i>et al.</i> , 2011; Chun <i>et al.</i> , 2009; Cummins & Lyng, 2016.

Table 7. Performance scores from the literature review in pig meat supply chains.

Measure	Complexity of implementation	Complexity of performance monitoring	Costs of implementation and monitoring	Consumer acceptance	Conformity with international trade agreements
Organic acids	1	1	1	0	0
Steam	1	1	1	1	2
Ultraviolet-C irradiation	0	1	2	0	0

The only measure complying with “international trade agreements” as well as for “consumer acceptance” criterion was “steam” for pig meat supply chains. Meanwhile, “organic acids” and “steam” share the same moderate values for the complexity and cost criteria. Interestingly, “Ultraviolet-C irradiation” had the lowest costs but it is the most difficult to implement.

3.5. Step 5: Weighting of criteria

3.5.1. Survey results

The results obtained were from one Dutch pig meat slaughterhouse + processing, one from the Dutch poultry meat slaughterhouse, and one from the German pig meat retail. The results are shown in the Table 8.

Table 8. Ranking of each measure according to German and Dutch stakeholders. Being number 1 the most important criteria and number 6 the least important criteria. In braces the points assigned for each criterion by stakeholders.

Measures/stakeholders	German pig meat retail	Dutch pig meat slaughterhouse + Processing	Dutch poultry meat slaughterhouse
Complexity of implementation	2(85)	4(60)	3(80)
Complexity of performance monitoring	1 (100)	5(50)	4(60)
Costs of implementation and monitoring	4(62)	6(10)	2(95)
Consumer acceptance	3(75)	1(100)	1(100)
Conformity with international trade agreements	5(30)	2(99)	5(30)
Moral hazard	6(10)	3(98)	6(0)

It can be observed that for the Dutch meat chains the most important criteria was consumer acceptance. Whereas for the German pig meat retail complexity of monitoring was the most important and consumer acceptance ranked third.

For the German pig meat retail the least important criteria was moral hazard as well as for Dutch poultry meat, in the latter case zero points were assigned to the

moral hazard criterion. On the other hand cost of implementation and monitoring was the least important criterion for the Dutch pig meat stakeholder.

3.5.2. Normalized criteria weights

The results of normalizing the points obtained in the surveys are the criteria weights. The criteria weights were used to derive the overall value with the expert consultation performance scores can be found on Table 9.

Table 9. *Criteria weights for the expert consultation.*

Measures/stakeholders	German pig meat retail	Dutch pig meat slaughterhouse + Processing	Dutch poultry meat slaughterhouse
Complexity of implementation	0.234	0.143	0.219
Complexity of performance monitoring	0.276	0.119	0.164
Costs of implementation and monitoring	0.171	0.023	0.260
Consumer acceptance	0.207	0.239	0.273
Conformity with international trade agreements	0.082	0.237	0.082
Moral hazard	0.027	0.235	0

Table 9 shows that, the “moral hazard” criterion two of the stakeholders’ value on 0 or close to it, however the Dutch Pig meat stakeholder considered it as it third most important criterion.

In Table 10 the criteria weights to obtain the overall value with the literature review performance scores vary because the “moral hazard” criterion was not taken into account.

Table 10. *Criteria weights used to calculate the overall value for the literature review.*

Measures/stakeholders	German pig meat retail	Dutch pig meat slaughterhouse + Processing	Dutch poultry meat slaughterhouse
Complexity of implementation	0.241	0.188	0.219
Complexity of performance monitoring	0.284	0.156	0.164
Costs of implementation and monitoring	0.176	0.031	0.260
Consumer acceptance	0.213	0.313	0.273
Conformity with international trade agreements	0.085	0.310	0.082

In both tables, it can be observed that the weights are relatively close in value for the three stakeholders in the “consumer acceptance” and “complexity of implementation” criteria. The Dutch stakeholders had very close values for

“complexity of performance monitoring” criterion. Interestingly, the German pig meat retail and the Dutch poultry meat slaughterhouse had the same weight for the “conformity with international trade agreements” criterion.

In table 10 the values for Dutch poultry meat slaughterhouse were the same for all criteria as for Table 9. It is important to consider the adjustment in the calculation from one table to the other in order to cope with the lack of “moral hazard” criterion. Bearing this in mind, the range of values keeps its consistency and only shows slightly differences between Tables 9 & 10.

3.6. Step 6: calculate overall value

The expert consultation performance scores and the criteria weight results obtained for the Dutch poultry meat supply chain provide the overall value; in the same manner the overall value was calculated for the performance scores results of the literature review and the criteria weights adapted for this condition.

The fact that there is no “steam ultrasound” value for the expert consultation was because it was not part of the list of measures in the paper of Gocsik & Saatkamp, 2015. It can be noticed as well that no value was generated for the “other chemical treatments” measure, this was because not enough literature was available to determine performance scores for that measure(Table 11).

Table 11. Overall values for poultry meat decontamination measures.

	Dutch poultry slaughterhouse Expert Consultation	Dutch poultry slaughterhouse Literature Review
Irradiation	0.164	0.588
Air chilling	1.257	1.613
Organic acids	0.643	1.122
Chlorine	1.108	1.122
Phosphate based treatments	0.643	0.643
Other chemical treatments	0.643	-
Steam ultrasound	-	1.298

“Air chilling” was the measure with the highest overall score independently of the source used to derive its value. The overall values of “phosphate based treatments” were the same regardless the source of the overall value; even more, it was the same overall value for “other chemical treatments” by expert consultation. In the same manner, “organic acids” and “chlorine” overall values were exactly the same under the literature review and close to the “chlorine” overall value by expert consultation.

For the German and Dutch pig meat decontamination measures there were not sufficient literature to derive the performance scores for “other chemical

treatments” measure, therefore it was not considered as part of the literature review (Table 12).

It can be observed that despite the source of the overall values “steam” was the measure with the highest overall values for the Dutch and German pig meat supply chains.

Table 12. Overall values for pig meat decontamination measures.

	Dutch pig slaughter + processing	Dutch pig slaughter + processing	German pig retail	German pig retail
	Expert Consultation	Literature Review	Expert Consultation	Literature Review
Organic acids	0.998	0.375	1.254	0.701
Steam	1.711	1.308	1.625	1.084
Ultraviolet-C	0.994	0.218	1.074	0.636
Other chemical treatments	0.782	-	1.218	-

3.7. Step 7: Examine the results

3.7.1. Dutch and German pig meat supply chains rankings

For the German and Dutch pig meat supply chains a ranking of measures was obtained for the expert consultation (Table 13) and for the literature review (Table 14).

Table 13. Ranking with overall values obtained using experts performance scores for the pig meat supply chains.

Ranking	Dutch pig meat slaughterhouse + processing	German pig meat retail
1	Steam= 1.711	Steam = 1.625
2	Organic acids= 0.998	Organic acids= 1.254
3	UV-C= 0.994	Other chemicals= 1.218
4	Other chemicals= 0.782	UV-C= 1.074

The measure ranked in the first place was “Steam” for the German and Dutch stakeholder. “Organic acids” occupied the second place for both stakeholders. Whereas for the third and fourth place differences in preferences among stakeholders were noticed.

Table 14. *Ranking with overall values obtained using literature review performance scores for the pig meat supply chains.*

Ranking	Dutch pig meat slaughterhouse + processing	German pig meat retail
1	Steam= 1.308	Steam= 1.084
2	Organic acids= 0.375	Organic acids= 0.701
3	UV-C=0.218	UV-C=0.636

By using the literature review the overall values ranked in the first place “steam” as the most preferred intervention for both stakeholders. “Organic acids” and “Ultraviolet-C irradiation” occupied the second and third place in the ranking respectively.

3.7.2. Dutch poultry meat supply chain rankings

With the results obtained it was possible to make rankings for the poultry meat Dutch supply chain. Ranking for the overall value of expert consultation can be seen in Table 15, and the ranking for the overall value of the literature review can be observed in Table 16.

Table 15. *Ranking with overall values obtained using experts performance scores for the poultry meat supply chain.*

Ranking	Dutch poultry meat slaughterhouse
1	Air chilling= 1.257
2	Chlorine based treatments= 1.108
3	Organic acids= 0.643
3	Phosphate based treatments= 0.643
3	Other chemical treatments=0.643
4	Irradiation=0.164

“Air chilling” measure was the first in the ranking, followed by “chlorine based treatments” in the second place. “Organic acids”, “phosphate based treatments”, and “other chemical treatments” measures had the same value therefore ranked in the third position. While “irradiation” measure was the last in the ranking for the expert consultation as well as for the literature review.

Table 16. *Ranking with overall values obtained using literature review performance scores for the poultry meat supply chain.*

Ranking	Dutch poultry meat slaughterhouse
1	Air chilling= 1.613
2	Steam ultrasound= 1.298
3	Organic acids= 1.122
3	Chlorine based treatments=1.122
4	Phosphate based treatment=0.643
5	Irradiation= 0.588

In this case, “air chilling” occupied the first place of the ranking, and “steam ultrasound” on the second place. For the third place “organic acids” and “chlorine

based treatments” were valued the same. “ Phosphate based treatments” and “irradiation” were in the fourth and fifth place respectively.

4. Discussion

4.1. Purpose of the study

Initially, this study was intended to focus on all the measures to reduce antimicrobial resistance in the poultry and pig meat supply chains in Netherlands and Germany; performing a MCDA to give insights of the agreements and disagreements that rise among stakeholders at the moment of deciding which measures to apply. A survey to explore the preferences of various stakeholders in the supply chains (from beyond farm level) was developed. The initial idea was to send out at least 15 surveys between pig and poultry meat stakeholders. Notwithstanding, after the initial contact with the sector representatives, it became clear that the survey could not be sent out to all the stakeholders. At the time when the survey was taking place, an outbreak of avian influenza occurred (OIE, 2017). Thus, stakeholders had the priority to focus on eradicating the outbreak.

Hence, a decision was made to change the purpose of the study. That is, to explore tendencies and preliminary conclusions of the stakeholders preferences for measures to reduce AMR bacteria through the pig and poultry meat supply chains.

4.2. Selection of criteria, and decontamination measures

The lack of information regarding the “moral hazard” criterion for all the measures studied can be understood with the article of Hirschauer & Zwoell, 2008; where they suggested that moral hazard is very difficult to determine using literature because there is no amount of information under that topic. Yet, they make a clear statement about the fact that experts in a field are the best sources to obtain moral hazards identification and therefore a performance score. For that reason, experts were asked to provide with “moral hazard” scores for each decontamination measures whereas for the literature review was extremely hard to find some useful information towards the topic.

“Other chemical treatments” such as electrolyzed water, and peroxides are not widely used either on poultry or pig meat used because some of the chemicals are mainly in research phase, thus not many publications were found to support the scoring (Loretz at al., 2010; Loretz et al., 2011).

4.3. Results

The most important criterion for the stakeholders was “consumer acceptance”, and the least important criterion was “moral hazard”. The exception for the most important criterion was “complexity of monitoring” by the German pig meat retail,

which might be explained by the fact that they have to rely on employees and equipment to perform these duties, which might involve arrangements that involve higher expenses. At the same time, **competitive pricing** and quality are important for retail (Bowman *et al.*, 2013).

The exception for the least preferred criterion was “costs of implementation and monitoring”. This can be explained because stakeholders might consider that the costs involved in reducing the prevalence of Bacteria, can be reflected into an increase in **willingness to pay** from consumers that are willing to buy safe food treated with **less invasive interventions**. At the same time, the **brand image** can be strengthened and **consumer trust** enhanced (Mørkbak *et al.*, 2012; Mørkbak *et al.*, 2011; Van der Gaag *et al.*, 2004).

Almost all the measure’s performance scores had similar values regardless the source of scoring. Nevertheless, there were some outstanding differences between the measures performance scores from the expert consultation and the literature review. “Irradiation” had completely different performance scores depending on the source of scoring. This can be explained because **lack of proper knowledge** about the technology is one of the factors that hinders the public acceptance and use of the technology. Although it is recognized as a safe and an effective decontamination measures by the Food and Agriculture Organization of the United Nations and the World Health Organization (Maherani *et al.*, 2016).

With the comparison made between the expert consultation and the literature review the preferences indicate a tendency for **non-invasive methods** being “**air chilling**” and “**steam**” the most preferred interventions. This can be explained due to the fact that stakeholders rely on consumer acceptance as the most important criterion for decision-making. Moreover, it is evident that from a consumer point of view, the measures perceived as **less invasive** are the ones with the **most acceptability** (Mørkbak *et al.*, 2012; Mørkbak *et al.*, 2011).

“Steam ultrasound” was ranked second and also had high scores among almost all criteria. Even though, this measure is not yet widely applied in poultry meat supply chains. This can be explained due to the need of **initial arrangements**, i.e. Investment in new equipment, for the implementation of the measure (Jensen, Lawson, & Lund, 2015; Musavian *et al.*, 2014; Lawson, Jensen, & Lund, 2009). Nevertheless, this study showed that this measure has the potential to achieve high levels of agreement between stakeholders.

4.4. Reflection on methods

As shown in numerous fields and applications MCDA is a widely used tool to approach decision-making issues (Thokala *et al.*, 2016; Wang *et al.*, 2009; Mourits *et al.*, 2006, Aenishaenslin *et al.*, 2013; Dodgson *et al.*, 2009).

The MCDA methodology performed in this study can be used as a **transparent** tool and reliable aid for decision-makers. The evidences of the method transparency can be observed in the step-wise approach required to perform a MCDA, where the inputs and outputs of each step can be clearly identified. The method also takes into consideration the preferences of decision-makers providing a reliable assessment of the common affinities and discrepancies between them.

5. Conclusion

This is an exploratory research on decontamination measures to reduce AMR Bacteria from poultry and pig meat supply chains. An important finding of this study was that the performance scores based on experts opinion and literature review had high levels of agreement. At the same time, the criteria preferences expressed by the three stakeholders surveyed also showed high levels of agreements.

In order to tackle effectively antimicrobial resistant bacteria of public health concern, further research need to be undertaken. Future studies should analyse all factors and stakeholders that influence a decision-making process for decontamination measures in the meat supply chains.

This study provided a first overview of the importance of acknowledges non-cost effectiveness criteria when considering AMR interventions. This study also showed that non-invasive measures, such as “air chilling” and “ steam” had higher scores and therefore were preferred when compared to invasive measures.

Multiple Criteria Decision Analysis was acknowledged as a transparent and reliable method for the analysis of decontamination measures to reduce AMR bacteria in the poultry and meat supply chains.

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Annex A. Survey template

Questionnaire to elicit criteria weights expressed as rank and points by stakeholders' in the pig and poultry meat supply chains

To complete this questionnaire, you may print it and then scan it or fill in it by digital means.

The questionnaire is divided into the following parts:

- A. General information questions
- B. Criteria description
- C. Example on how to weight the criteria
- D. Criteria weight elicitation expressed as rank and points

A. General information questions:

Please select your answer from the following options, if you fill in it by digital means, please highlight your answer.

Where are you located?

- Germany Netherlands

With which animal species do you work with?

- Poultry Pig

What is the **MAIN** area of the meat supply chain your organization works in?

- Transport Slaughterhouse Slaughterhouse+ processing
 Processing Slaughterhouse+ own transport

B. Criteria description:

Please read carefully the description of the criteria under evaluation.

The following criteria can influence the decision-making process when deciding to implement measures to reduce the prevalence of bacteria at your stage in the meat supply chain. The criteria that you are going to judge are described below:

- **Complexity of implementation:** easiness of applying a measure within **your** organization.
- **Complexity of performance monitoring:** easiness to monitor the performance of a measure, e.g., is additional personnel required? Has equipment or installations need to be adopted? Etc.

- **Costs of implementation and monitoring:** costs needed to implement and monitor a measure.
- **Consumer acceptance:** likelihood that a consumer will purchase the final product if a certain measure is implemented.
- **Conformity with international trade agreements:** compliance of a measure with international legal frameworks.
- **Moral hazard:** the risk that a supply chain participant does not apply measures at his specific stage of the supply chain, therefore relying on measures applied by other participants.

C. Example on how to weight the criteria:

*This is an **EXAMPLE** on how to fill in the table with the rank and the points.*

Suppose you are a stakeholder in the meat supply chain.

What criteria are the most important for your organization when deciding to implement measures to reduce the prevalence of bacteria at your stage of the meat supply chain?

Procedure:

1. Rank the criteria in order of the most important (1) to the least important (6).
2. The points to be allocated will vary from 100 to 0; you assign the amount of points you consider to represent the importance of each criterion.
3. The criterion ranked 1 will **ALWAYS** have 100 points, as shown in the example.
4. The criterion ranked 2 will always receive less than 100 points; the difference from 100 depends on the importance in your view, if the difference is small, e.g. 96 points could be allocated (as shown in the example).
5. The criteria ranked 3 has to receive less points than the assigned points for the criterion ranked 2; also depends on the importance in your view, if the difference is relatively large considerable lower points could be allocated, e.g. 60 points for this example.
6. Continue with the same procedure for the remaining criteria; as seen in the example, the criterion ranked 4 received 45 points, the ranked 5 had 30 points, and the ranked 6 had 4 points for this example.

For this example, these were the rank and points obtained per each criterion:

Criteria	Rank	Points
Complexity of practical application	4	45
Complexity of monitoring	3	60
Cost of implementation and monitoring	5	30
Consumer acceptance	2	96
Conformity with international trade agreements	6	4
Moral hazard	1	100

D. Criteria weight elicitation expressed as rank and points:

*Now it is your turn to rank the options and allocate the points. Please complete the table by answering the question and follow the procedure explained above. Provide your answers regarding the **MAIN** area of the meat supply chain you are involved in.*

What criteria are the most important for your organization when deciding to implement measures to reduce the prevalence of bacteria at your stage of the meat supply chain?

Please complete the table with the rank and points you assigned to each criterion:

Criteria	Rank	Points
Complexity of practical application		
Complexity of monitoring		
Cost of implementation and monitoring		
Consumer acceptance		
Conformity with international trade agreements		
Moral hazard		

Thank you for your valuable input!

Annex B. Cover letter survey



Research topic: Analysis of **Measures to Reduce Antimicrobial Resistant Bacteria** in German and Dutch pig and poultry meat supply chains

Supervised by: Dr. Helmut Saatkamp and Dr. Eva Gocsik

Dear Sir or Madam

My name is Diana Mora Bustamante, I am a Master student at Wageningen University & Research in food safety. For my master's thesis, a pilot research will be conducted on measures that influence the **Prevalence of Antimicrobial Resistant Bacteria** in the pig and poultry meat supply chains in Netherlands and Germany e.g. steam ultrasound and heat treatments. The aim is to elicit the importance of criteria for stakeholders' with reference to the implementation of those measures. Some of these criteria are for example, legal aspects, consumer perception, and moral hazard. These criteria can influence the decision making of implementing **measures to reduce the prevalence of Antimicrobial Resistance Bacteria**. To my knowledge, these criteria have not been evaluated yet with measures to reduce the prevalence of bacteria in the poultry and pig meat supply chains.

Because you are working in the pig or poultry meat supply chains in Germany or Netherlands, I wish to kindly invite you to participate in this research by completing the attached questionnaire. The questionnaire will require approximately **10 Minutes** to complete. Your response will remain confidential and anonymous. If you decide to participate, please return the completed questionnaire by the 20th of December 2016 and you will receive a copy of the final report in April 2017.

Your input will provide valuable information to determine the stakeholders' preferences of measures to tackle antimicrobial resistant bacteria in the poultry and pig meat supply chains. If you require additional information or have questions, please contact me at the email address listed below.

Thank you for taking the time to assist me in my educational endeavours.

