Prioritising Foodborne Disease with Multi-Criteria Decision Analysis

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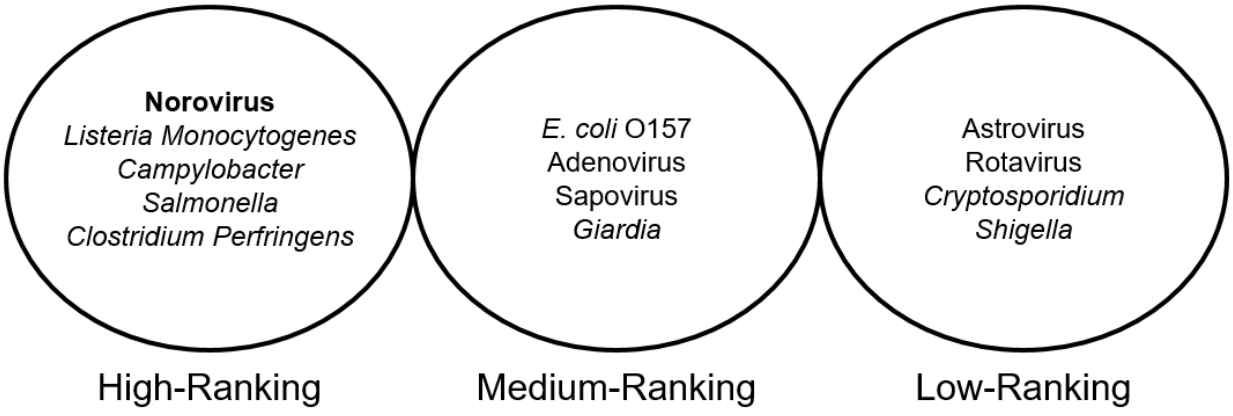
1. Summary

This document outlines the methodology and results of a multi-criteria decision analysis (MCDA) used by the Food Standards Agency (FSA) to rank thirteen foodborne pathogens in order of their detrimental effect on UK society. This overall approach to prioritisation comes off the back of a series of foodborne disease-related estimates produced by the FSA's Analytics Unit.

A simplified version of the results of the MCDA can be seen in Figure 1, where the pathogens have been separated into three main categories that represent their detriment to society: high-ranking, medium-ranking or low-ranking. The average ranking results show that norovirus, *Listeria Monocytogenes*, *Campylobacter*, *Salmonella* and *Cl. Perfringens* all ranked high in their detriment to society. *E. coli* O157, adenovirus, sapovirus and *Giardia* all ranked mid-range and astrovirus, rotavirus, *Cryptosporidium* and *Shigella* all ranked low.



The pathogens were ranked in the MCDA using six different weighted criteria. The list of these criteria are given below. The processes of selecting and weighting these criteria are integral to MCDA and occurred through a series of discussions, surveys and workshops that took place over several months and included various teams in the FSA. The weighting of the criteria was done by senior members of the FSA.

List of the six criteria used in the MCDA to assess the pathogens:

- Estimated Number of Annual Cases
- Quality Adjusted Life Years per Case of the Pathogen
- Public Concern
- Total Cost to Society per Annum
- Estimated Number of Annual Fatalities
- Scientist Confidence

The MCDA tool ranks the pathogens by greatest impact on society based on the chosen criteria, however it does not provide any insight into the effectiveness of the policy evaluations that may be deployed to minimise these impacts.

2. Background

Over the last few years, a series of projects were undertaken by the Food Standards Agency's Analytics Unit with the aim of producing estimates on different measures of the frequency and burden of thirteen different foodborne diseases. The thirteen pathogens were selected as they were the same ones covered in the IID2 Extension paper (Costed extension to the Second Study of Infectious Intestinal Disease in the Community, O'Brien, S. et al, 2014).

The estimates produced include the number of annual UK cases of each pathogen, the number of annual UK fatalities of each pathogen, the total cost to the UK per annum of each pathogen and the quality-adjusted life years of each pathogen. Details of this work can be found on the FSA website.

- Foodborne Disease Estimates for the United Kingdom in 2018, Holland, D., Mahmoudzadeh, N., 2020
- Estimating deaths from foodborne disease in the UK for 11 key pathogens, Holland, D. et al, 2020
- The Burden of Foodborne Disease in the UK 2018, Daniel, N. et al, 2020
- Estimating Quality Adjusted Life Years and Willingness to Pay Values for Microbiological Foodborne Disease, Daniel, N. et al, 2017

The thirteen pathogens selected to be assessed and prioritised in the MCDA are:

Bacteria:
- *Campylobacter*
- *Cl. perfringens*
- *E. coli O157*
- *Listeria monocytogenes*
- *Salmonella*
- *Shigella*

Protozoa
- *Cryptosporidium*
- *Giardia*

Virus:

- Adenovirus
- Astrovirus
- Norovirus
- Rotavirus
- Sapovirus

The foodborne disease estimates provided several different variables with which to assess the thirteen pathogens. The six different pathogen rankings for each of the variables can be seen in Table 1. The table shows that the pathogens' rank can vary significantly depending on the variable that is used. For instance, *Listeria monocytogenes* ranks first for 'deaths as a % of total cases', 'total cost per case' and 'quality adjusted life-years loss per case' (see Annex I.i for description of QALYs) but ranks last for 'number of cases'. This illustrates the point that the choice of variable can have a huge impact on the prioritisation of the pathogens. Therefore, an approach was needed to rank the pathogens that would take account of these different criteria.

Table 1 – Six different pathogen rankings for each of the variables with foodborne disease estimates

Rank	Number of cases	Deaths as % of total cases	Total economic cost	Total cost per case	QALY loss per case	Total QALY burden
1	Norovirus	*Listeria*	Norovirus	*Listeria*	*Listeria*	Norovirus
2	*Campylo.*	*E.coli* O157	*Campylo.*	*E.coli* O157	*Giardia*	*Campylo.*
3	*Cl. Perf.*	*Salmonella*	*Salmonella*	*Shigella*	Norovirus	Sapovirus
4	Sapovirus	*Cl. Perf.*	Sapovirus	*Salmonella*	Rotavirus	*Giardia*
5	*Salmonella*	Norovirus	*Giardia*	*Giardia*	Adenovirus	Adenovirus
6	*Giardia*	*Campylo.*	*Cl. Perf.*	Norovirus	Sapovirus	*Salmonella*
7	Adenovirus	*Cryptosp.* =	Adenovirus	Rotavirus	Astrovirus	Astrovirus
8	Astrovirus	*Shigella* =	*Listeria*	Adenovirus	*Campylo.*	Rotavirus
9	*Cryptosp.*	Adenovirus =	*Shigella*	Astrovirus	*Salmonella*	*Listeria*
10	Rotavirus	Rotavirus =	Astrovirus	Sapovirus	*E.coli* O157	*Cl. Perf.*
11	*Shigella*	*Giardia* =	Rotavirus	*Campylo.*	*Shigella*	*Cryptosp.*
12	*E.coli* O157	Astrovirus =	*E.coli* O157	*Cl. Perf.*	*Cryptosp.*	*Shigella*
13	*Listeria*	Sapovirus =	*Cryptosp.*	*Cryptosp.*	*Cl. Perf.*	*E.coli* O157

= indicates these pathogens all have the same score for that criteria.

3. Methodology

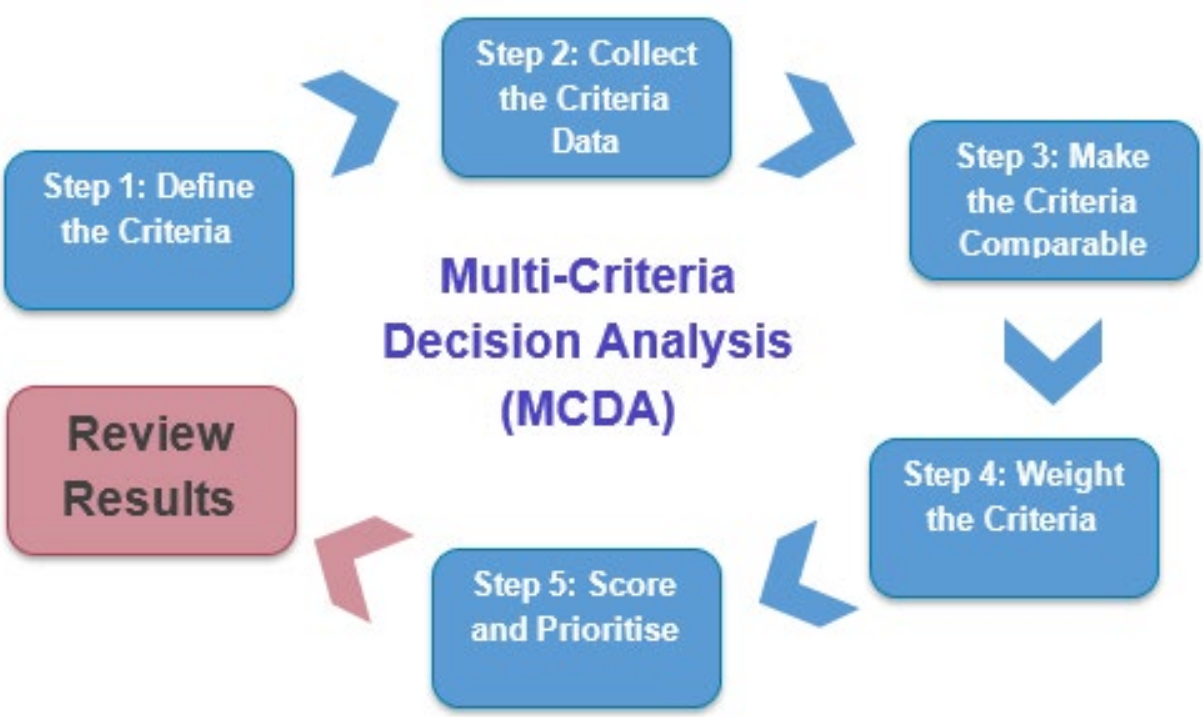
As an alternative to using a single variable, a multi-criteria decision analysis enables a more overall approach to prioritisation. The aim of using multi-criteria decision analysis was to assess the thirteen foodborne pathogens in terms of their detrimental effect on UK society using a range of criteria. The purpose of this being to provide the Food Standards Agency with a scientific and logical means of prioritising its focus, funding and resources for each of the thirteen pathogens.

What is Multi-Criteria Decision Analysis (MCDA)?

MCDA is an approach with the goal of providing an overall ordering of options, from the most preferred to the least preferred option. This overall approach involves assessing different options against multiple criteria, which often includes combinations of conflicting costs and benefits (see Multi-criteria analysis manual, CLG, 2009).

There are five main steps to an MCDA. The first is to define the criteria that will achieve your objective, this often requires brainstorming sessions and workshops to provide a variety of perspectives. It is also necessary that the defined criteria meet several requirements for example, they don't overlap, they're relevant to the objectives and they have available or attainable data. The second step is to collect the data for the criteria and the third is making the criteria comparable with one another. The fourth step is to weight the criteria which is normally done through a further workshop and finally, for the fifth step the options can be scored and prioritised. A workflow outlining the MCDA process can be seen in Figure 2.

Figure 2 – Multi-criteria decision analysis workflow



Multi-Criteria Decision Analysis (MCDA):

- Step 1: Define the criteria
- Step 2: Collect the criteria data
- Step 3: Make the criteria comparable
- Step 4: Weight the criteria
- Step 5: Score and prioritise
- Review Results

There are some key advantages to MCDA (see Multiple Criteria Decision Analysis, Janse, B., 2018) over other prioritisation methods:

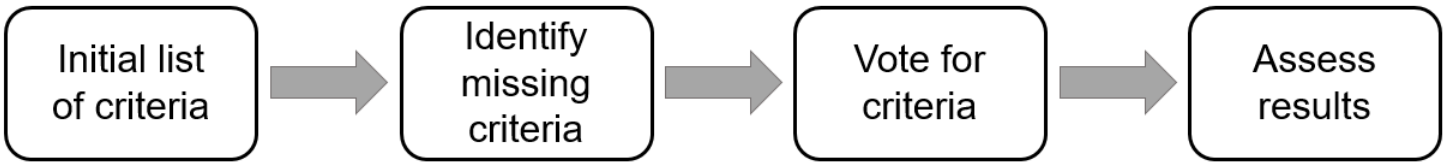
- It allows decisions to be formed using different factors.
- It is an explicit and open form of decision analysis that enables every step of the process to be easily communicated with stakeholders.
- The MCDA criteria can be adjusted and revised which provides flexibility to the analysis.
- Important performance measurements can be left to experts, which further validates the data that is used.

- MCDA incorporates the perspectives and judgements of a variety of parties, which helps to reduce subjectivity in the decision-making process.

Step 1: Defining the Criteria

The criteria that are used in MCDA can have a substantial impact on the overall prioritisation results, therefore it's important that the criteria selection process is methodologically rigorous. The workflow outlining the steps involved in defining the criteria can be seen in Figure 3.

Figure 3 – Workflow outlining the criteria selection process



Criteria Selection Process:

- Initial list of criteria
- Identify missing criteria
- Vote for criteria
- Assess results

An initial set of criteria was produced based on the work described above in Section 2 - Background. The list was taken into a workshop consisting of members from different teams across the FSA. The first step in the workshop was to identify any missing criteria from the list before participants voted on their favoured criteria (see Annex I). The following key requirements were used to determine the final criteria selection: the criteria must satisfy the objectives of the MCDA, overlap between criteria must be minimised, the criteria must be measurable, and data is available or can be generated for each criterion.

Literature on MCDA recommends using up to eight criteria. If you use larger numbers of criteria then the impact of the less important criteria starts to get very diluted. We settled on using seven. The initial top seven criteria (see Annex I.ii) were 'number of cases', 'quality adjusted life years', 'reputational risk', 'total cost to society per annum', 'consumer concern', 'political interest', and 'fatality rate'. However, it was decided that there was considerable overlap between 'reputational risk', 'consumer concern' and 'political

interest'. It was agreed that 'reputational risk' sufficiently covered the other two criteria; therefore, they were dropped from the selection.

The remaining selected criteria were 'number of cases', 'quality adjusted life years', 'reputational risk', 'total cost to society per annum', and 'fatality rate'. It was agreed that only two of the remaining unselected criteria did not overlap with the five selected criteria. These two were 'scientist concern' and 'impacts on exports/ trade'. They were therefore selected as also being part of the final criteria.

After looking at the values for 'fatality rate' it was realised that *Listeria monocytogenes*' exceptionally high fatality rate makes the values of the twelve other pathogens negligible. Comparatively, the criterion 'annual number of fatalities' has more evenly distributed values and so does not drastically favour any one pathogen. This information was discussed by those involved in the MCDA workshop to see which of the two criteria they felt was more suitable. The group consensus was to move ahead with 'annual number of fatalities' therefore 'fatality rate' was dropped from the MCDA.

To minimise ambiguity, 'scientist concern' was defined as assessing "scientists' confidence in the basis of their understanding of each pathogen as well as the likelihood that the risks associated with each pathogen will change". For clarity, the criterion was renamed from 'scientist concern' to 'scientist confidence'.

The criterion 'reputational risk' was subsequently changed to 'public concern' as it was felt that 'public concern' better reflected the aim of the analysis whilst retaining the sentiment of 'reputational risk', 'consumer concern' and 'political interest'.

After discussions with different teams in the FSA, it was decided that the variables involved in estimating the thirteen foodborne pathogens' impact on trade were too complex for any robust estimates to be easily produced. Furthermore, given the criterion's sensitivity to the varying economic and political climate such as the introduction of new trade agreements, it was concluded that there was a great amount of uncertainty surrounding this criterion; therefore, 'impact on trade/exports' was dropped from the MCDA.

The final criteria selected from the workshop were:

- Estimated Number of Annual Cases
- Quality Adjusted Life Years per Case of the Pathogen
- Public Concern
- Total Cost to Society per Annum
- Estimated Number of Annual Fatalities
- Scientist Confidence

Step 2: Collecting the Criteria Data

Available Data

Data was available for 'number of annual cases', 'quality adjusted life years', 'total cost to society per annum' and 'number of annual fatalities' (see Section 2). Table 2 shows the available data for the four criteria for each pathogen.

Table 2 – Available data for four out of seven of the selected criteria

Pathogen	Number of Annual Cases	Quality Adjusted Life Years Per Case	Total Cost to Society per Annum (£)	Number of Annual Fatalities
Campylobacter	299,392	0.26	712,648,487	21
Cl. perfringens	84,854	0.00	101,504,586	25
E. coli O157	468	0.06	3,924,758	1
Listeria monocytogenes	162	4.03	37,381,154	26
Salmonella	31,601	0.21	212,022,034	33
Shigella	1,634	0.03	12,292,279	0
Cryptosporidium	2,072	0.02	2,104,944	0
Giardia	13,142	1.01	74,999,465	0
Adenovirus	12,454	0.67	48,749,928	0
Astrovirus	2,552	0.67	9,988,141	0
Norovirus	383,182	0.67	1,678,156,534	56
Rotavirus	2,065	0.67	8,536,199	0
Sapovirus	43,621	0.67	169,527,829	0

Although Table 2 presents the data as single terms, the estimates for 'number of annual cases', 'total cost to society' and 'number of annual fatalities' include credible intervals to account for uncertainty. The single terms in Table 2 are the median of the distributions. To account for the uncertainty in the data, the pathogens will be scored against the criteria using a Monte-Carlo simulation, which is discussed in greater depth in Step 5.

Scientist Confidence

To assess each pathogen against this criterion a qualitative scale (see Annex II.i) was used as quantifying confidence did not seem realistic. The pathogens were given a score of either ‘very low’, ‘low’, ‘moderate’ or ‘high’, where a score of ‘very low’ suggests further research into the pathogen may be needed, thereby giving a high score in the MCDA and a score of ‘high’ suggests further research into the pathogen may not be needed, thereby giving a low score in the MCDA.

Several of the FSA’s microbiology team were asked to assess the pathogens using the scale mentioned above and a few points to consider (see Annex II.ii). The experts’ discussion notes can be found in Annex II.iii and the results of the expert elicitation can be found in Table 3.

Table 3 – Scientific confidence score for each of the thirteen pathogens

Pathogen	**Confidence in Our Understanding of the Pathogen**
Campylobacter	Moderate
Cl. perfringens	Low
E. coli O157	Moderate
Listeria monocytogenes	Moderate
Salmonella	High
Shigella	Low
Cryptosporidium	Low
Giardia	Low
Adenovirus	Very Low
Astrovirus	Moderate
Norovirus	Low
Rotavirus	Low
Sapovirus	Low

Public Concern

To assess the pathogens on this criterion, several experts in the communications team were asked to complete a survey to score the thirteen pathogens on their likelihood to cause public concern using a qualitative scale (see Annex II.iv). They were asked to consider several points (see Annex II.v) and were provided with data on numbers of outbreaks, data from previously conducted public awareness and consumer concern surveys and the results from the 'scientist confidence' criterion. The survey was followed by a group discussion (see Annex II.vi) to reach a consensus score. The scores resulting from the survey and group discussion can be found in Table 4.

Table 4 – Results of the public concern survey and public concern consensus score for each of the thirteen pathogens

Pathogen	Respondents who gave very low score	Respondents who gave low score	Respondents who gave a moderate score	Respondents who gave a high score	Consensus Score
Campylobacter	1	2	4	1	Moderate
Cl. perfringens	4	4	0	0	Low
E. coli O157	0	1	3	4	High
Listeria monocytogenes	0	2	0	6	High
Salmonella	0	0	4	4	High
Shigella	6	2	0	0	Very Low
Cryptosporidium	5	3	0	0	Very Low
Giardia	7	1	0	0	Very Low
Adenovirus	6	2	0	0	Very Low
Astrovirus	7	1	0	0	Very Low
Norovirus	0	1	2	5	High
Rotavirus	5	3	0	0	Very Low
Sapovirus	7	1	0	0	Very Low

Step 3: Making the Criteria Comparable

Scaling the Criteria

A performance matrix showing the data for each pathogen and each criterion can be seen in Table 5.

Table 5 – Performance matrix showing the data for all six criteria

Pathogen	Annual Number of Cases	QALY per Case	Total Cost to Society (£)	Annual Number of Fatalities	Scientist Confidence	Public Concern
Campylobacter	299,392	0.26	712,648,487	21	Moderate	Moderate
Cl. perfringens	84,854	0.00	101,504,586	25	Low	Low
E. coli O157	468	0.06	3,924,758	1	Moderate	High
Listeria monocytogenes	162	4.03	37,381,154	26	Moderate	High
Salmonella	31,601	0.21	212,022,034	33	High	High
Shigella	1,634	0.03	12,292,279	0	Low	Very Low
Cryptosporidium	2,072	0.02	2,104,944	0	Low	Very Low
Giardia	13,142	1.01	74,999,465	0	Low	Very Low
Adenovirus	12,454	0.67	48,749,928	0	Very Low	Very Low
Astrovirus	2,552	0.67	9,988,141	0	Low	Very Low
Norovirus	383,182	0.67	1,678,156,534	56	Moderate	High
Rotavirus	2,065	0.67	8,536,199	0	Low	Very Low
Sapovirus	43,621	0.67	169,527,829	0	Low	Very Low

To assess the pathogens on the various criteria it is crucial that the criteria can be appropriately compared with one another. For instance, the figures for 'total cost to society' range from £2.1 million to £1.6 billion whilst the figures for 'number of deaths' range from 0 to 56. If these criteria aren't uniformly scaled, then 'total cost to society' will be massively prioritised due to its vastly bigger values. Furthermore, it is not clear how

one could compare the qualitative criteria (such as 'public concern') with the quantitative without placing them both on a uniform scale.

For each criterion, a local uniform scale from 0 to 100 was applied so that the value with the lowest importance for that criterion corresponded to 0 and the value with the highest importance corresponded to 100. For instance, for 'total cost to society' the value £2.1 million for *Cryptosporidium* was given a new scaled value of 0 whilst the value £1.6 billion for norovirus was given a new scaled value of 100.

A complete performance matrix showing the new scaled values for each pathogen and each criterion can be seen in Table 6.

Table 6 – Performance matrix with criteria placed on a uniform linear scale from 0 to 100

Pathogen	Annual Number of Cases	QALY per Case	Total Cost to Society	Annual Number of Fatalities	Scientist Confidence	Public Concern
Campylobacter	78	6	41	38	33	67
Cl. perfringens	22	0	6	45	67	33
E. coli O157	0	1	0	2	33	100
Listeria monocytogenes	0	100	2	46	33	100
Salmonella	8	5	12	59	0	100
Shigella	0	1	1	0	67	0
Cryptosporidium	1	1	0	0	67	0
Giardia	3	25	5	0	67	0
Adenovirus	3	17	3	0	100	0
Astrovirus	1	17	1	0	67	0
Norovirus	100	17	100	100	33	100
Rotavirus	1	17	0	0	67	0
Sapovirus	11	17	10	0	67	0

Correlation Analysis

To check for overlap between the six selected criteria, a correlation matrix was produced, seen in Table 7, using the scaled data. The matrix shows overlap between multiple criteria. There is a very strong positive correlation between 'annual cases' and 'total cost to society' (0.94) and a strong correlation between 'annual fatalities' and three other criteria: 'annual cases' (0.73), 'total cost to society' (0.79) and 'public concern' (0.75). There is a very strong negative correlation between 'scientist confidence' and 'public concern' (-0.87).

Table 7 – Correlation matrix showing correlation between the scaled data of each criterion.

	Annual Cases	QALY per Case	Total Cost to Society	Annual Fatalities	Scientist Confidence
QALY per Case	-0.13	NA	NA	NA	NA
Total Cost to Society	0.94	-0.06	NA	NA	NA
Annual Fatalities	0.73	0.19	0.79	NA	NA
Scientist Confidence	-0.35	-0.14	-0.37	-0.65	NA
Public Concern	0.44	0.28	0.47	0.75	-0.87

Although the matrix shows significant amounts of overlap, it is worth noting that the correlation was calculated using only thirteen data points per criterion. With so few data points, one cannot be overly confident in the calculated correlations. Furthermore, a few of the individuals that weighted the criteria attempted to account for overlap by not heavily weighting any two criteria that they deemed to be overlapping.

Overall, it was felt that the selected criteria were all worth including as they each measured a different aspect and included slightly different information. However, the presence of significant overlap in this MCDA is not to be ignored as it highlights a drawback with using this prioritisation method to assess foodborne pathogens, where many of the criteria are interlinked. Despite this, MCDA does provide a more balanced approach, using information from more criteria and resolving the issue of using different criteria to prioritise different pathogens, as seen in Table 1. The impact of this correlation was tested in the sensitivity analysis (see Section 4. Results).

Step 4: Weighting the Criteria

The weightings for the criteria were made by nine senior members of the FSA. They were asked to complete a survey that involved weighting each criterion, with the condition that the weightings of all six criteria must sum to 100. The mean, maximum and minimum weightings for each criterion can be seen in Table 8.

Table 8 – Results of the weighting survey; Mean, maximum and minimum weights for each of the criteria

Weight	Annual Number of Cases	QALY per Case	Total Cost to Society	Annual Number of Fatalities	Scientist Confidence	Public Concern
Mean Weight	15	19	21	18	12	15
Max. Weight	25	25	40	25	15	20
Min. Weight	5	10	15	10	8	10

It was originally intended that these weightings would be discussed, and individuals given the opportunity to re-weight based on this discussion. However, the results from initial weightings were consistent enough that when they were presented back to the team it was agreed re-weighting was not required. This consistency was demonstrated by comparing results from each individual member's scores (see Annex III).

Step 5: Scoring the Pathogens

The weightings were then applied to the criteria for each pathogen. The weighted scores for each criterion were added to produce the total score for each pathogen, thereby ordering the pathogens in terms of their detrimental effects.

The weightings were applied using a Monte-Carlo Simulation. Monte-Carlo Simulation allows inputs to be a distribution of possible values for a parameter. This was used as it allowed all sets of individual weightings of the relevant importance of the criteria to be incorporated in the scoring of the pathogens. The model was run 100,000 times. For each of these iterations one of the sets of weightings was chosen at random by the model and applied to the criteria for each pathogen. The results achieved for the scores

for each pathogen were therefore a distribution of scores created by each of those 100,000 iterations of the model. Additionally, as some of the estimates for some of the criteria (namely ‘annual number of cases’, ‘annual number of fatalities’ and ‘cost to society’) had ranges of possible values rather than point values, it was possible to represent this uncertainty as a distribution and select a different value from this distribution on each run of the model. A more detailed explanation of the Monte Carlo Method and how it was used is given in Annex IV.

4. Results

Table 9 – Scores from the MCDA for each pathogen

Pathogen	Mean score	Lower 95% CI	Upper 95% CI	Minimum score	Maximum score
Campylobacter	42	26	62	15	76
Cl. Perfringens	27	15	44	11	62
E. coli O157	20	14	26	14	26
Listeria monocytogenes	46	33	60	29	70
Salmonella	32	16	52	11	76
Shigella	9	6	11	6	12
Cryptosporidium	9	6	11	5	26
Giardia	15	11	21	10	63
Adenovirus	17	13	21	12	27
Astrovirus	12	9	14	9	16
Norovirus	73	59	82	37	82
Rotavirus	12	9	14	9	15
Sapovirus	15	12	18	11	23

Table 9 shows the scores obtained for each of the pathogens. The MCDA tool assigned norovirus the highest mean score of 73, with *Listeria monocytogenes* second with a mean score of 46. Each of the scores are out of 100, with the higher the score the higher the burden to society.

Figure 4 and Table 10 show how the scores relate to the rankings of the pathogens, showing the proportion of times the pathogen was placed in each rank in the 100,000 iterations of the Monte Carlo Simulation. Norovirus was ranked first in 98% of the 100,000 runs. In the remaining 2% of runs norovirus ranked either second or third.

Listeria monocytogenes, *Campylobacter*, *Salmonella* and *Clostridium Perfringens* all ranked first during a small proportion of the 100,000 runs.

Figure 4 – Chart visualising how the score of each pathogen relates to its ranking

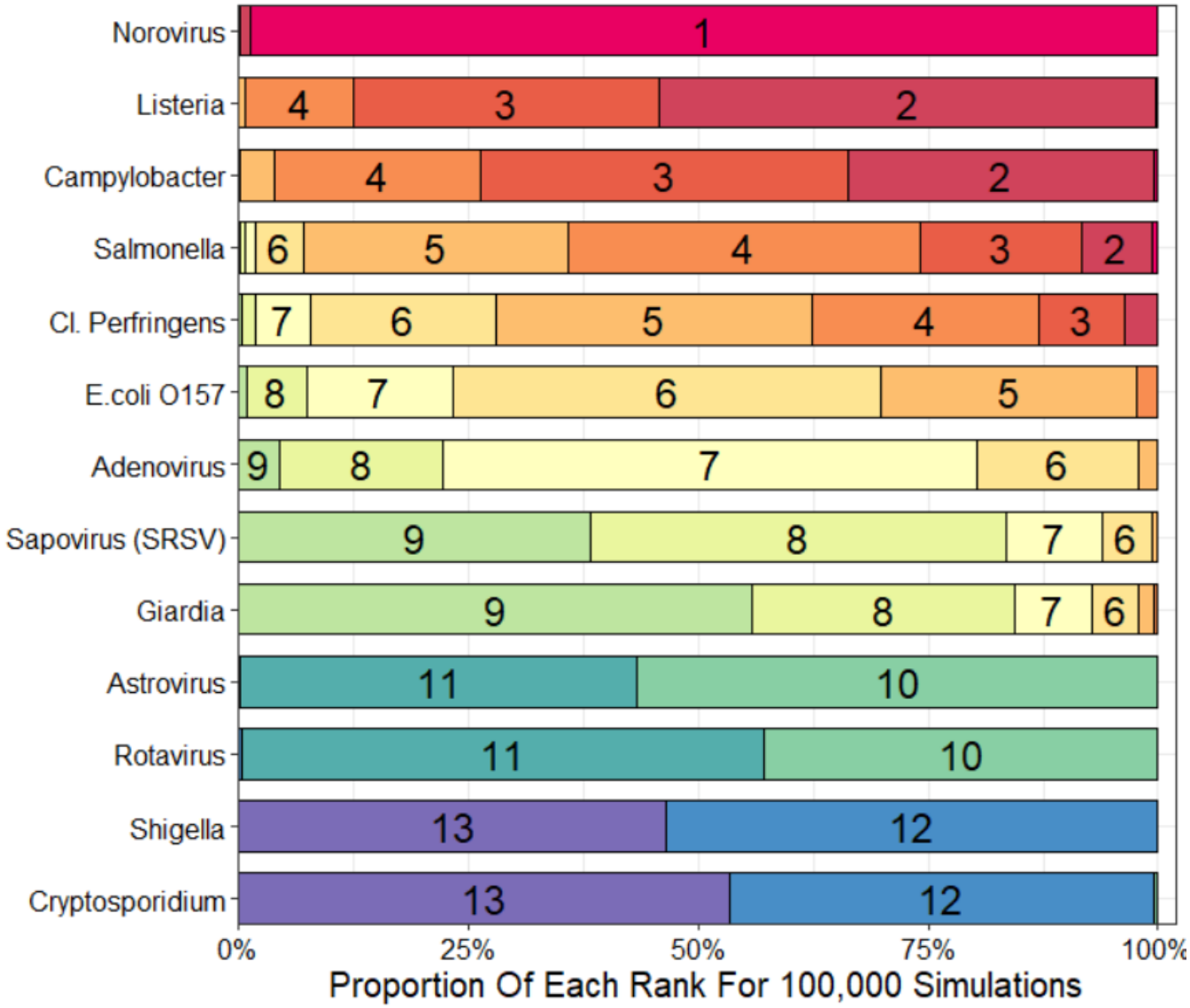


Table 10 – Proportion of times each pathogen received each rank in 100,000 simulations (%)

Pathogen	Rank												
	1	2	3	4	5	6	7	8	9	10	11	12	13
Norovirus	98.6	1.3	0.1	0	0	0	0	0	0	0	0	0	0
Listeria	0.3	54	33.2	11.8	0.7	0	0	0	0	0	0	0	0
Campylobacter	0.5	33.3	40	22.3	3.9	0.1	0	0	0	0	0	0	0
Salmonella	0.6	7.8	17.5	38.4	28.7	5.3	1.1	0.6	0.2	0	0	0	0
Cl. Perfringens	0.01	3.7	9.2	24.7	34.4	20.2	5.9	1.5	0.3	0	0	0	0
E.coli O157	0	0	0.01	2.3	27.9	46.4	16	6.5	0.9	0	0	0	0
Adenovirus	0	0	0	0.1	2.1	17.5	58	17.8	4.4	0	0	0	0
Sapovirus	0	0	0	0.02	0.7	5.4	10.5	45.2	38.2	0.01	0	0	0
Giardia	0	0.02	0.03	0.4	1.7	5.1	8.4	28.5	55.8	0.1	0	0	0
Astrovirus	0	0	0	0	0	0	0	0	0.01	56.7	43.1	0.2	0
Rotavirus	0	0	0	0	0	0	0	0	0	42.9	56.8	0.3	0
Shigella	0	0	0	0	0	0	0	0	0	0	0	53.4	46.6
Cryptosporidium	0	0	0	0	0	0.01	0.01	0.01	0.04	0.3	0.1	46.1	53.4

From Figure 4 and Table 10, the pathogens can be split into three broad categories. Norovirus, *Listeria monocytogenes*, *Campylobacter*, *Salmonella* and *Clostridium perfringens* are the high-ranking pathogens, grouped in order of average ranking. They are the top 5 ranked pathogens by mean, and each one of these 5 achieved first position rankings at least once during the 100,000 iterations. As mentioned above, norovirus positioned first for 98.6% of runs, with first place for the remaining 1.4% of runs being split, in different proportions, between the other four pathogens.

The medium-ranking pathogens are *E. coli* O157, adenovirus, sapovirus and *Giardia*, and the low-ranking pathogens are astrovirus, rotavirus, *Cryptosporidium* and *Shigella*.

Sensitivity Analysis

Due to the high correlation between the criteria, there was concern of overlap (as outlined in Step 3). A sensitivity analysis was run to determine the effect that this overlap has on the results of the MCDA. The MCDA was run three more times, each time

excluding one of the three most highly correlated criteria, namely, ‘annual number of cases’, ‘annual number of fatalities’ and ‘total cost to society’.

The score results and the rank results of the sensitivity analysis can be seen in Annex V. They show that despite the overlap, the results of the MCDA are relatively unaffected. There was very little change between the overall mean ranking of the pathogens when including all criteria compared to the overall mean ranking for the three sensitivity runs. Five of the pathogens’ rankings were completely unchanged by the exclusion of these criteria, including the number 1 ranked pathogen norovirus. However, in the remaining eight there were some slight variations in ranking. For instance, when ‘annual number of cases’ was removed from the MCDA *Campylobacter’s* mean ranking changed from 3 to 4, *Listeria monocytogenes’* changed from 3 to 2 and sapovirus’ changed from 8 to 9. Despite the changes no pathogen moved rank by greater than 1 for each of the sensitivity runs. Furthermore, the broad categorisation outlined in Figure 5 was unaffected by the exclusion of the criteria with only one exception – the exclusion of ‘annual number of fatalities’ caused the mean rank of *E.coli* O157 to increase to 5 and the mean rank of *Cl. perfringens* to decrease to 6.

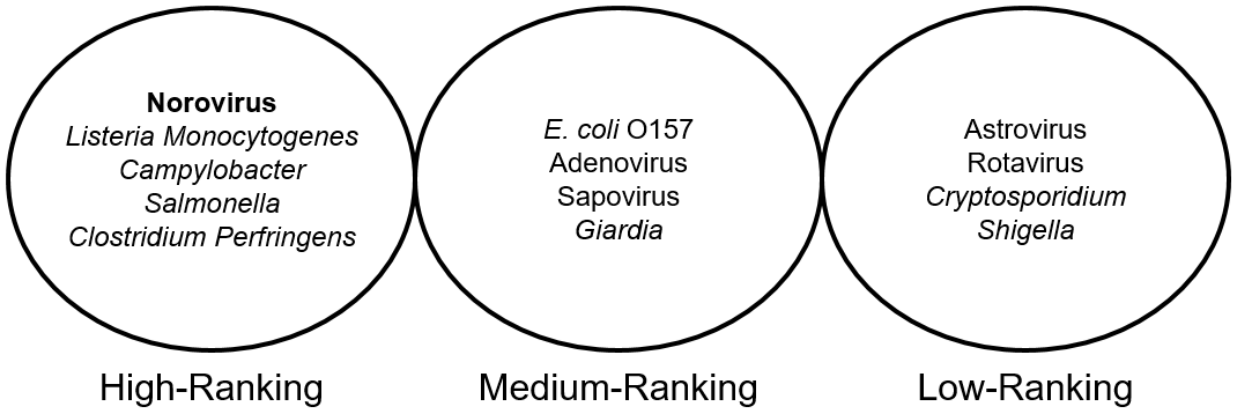
Overall, the results of the MCDA were largely unaffected by the exclusion of the more strongly correlated criteria. It was therefore concluded that the overlap between criteria did not undermine the integrity of the MCDA and so the overlap could be considered acceptable for the purposes of the MCDA.

5. Conclusion

The MCDA tool ranks the pathogens by greatest impact based on the chosen criteria, however it does not provide any insight into the effectiveness of the policy evaluations that may be deployed to minimise these impacts. To do this there needs to be consideration of the efficacy and cost effectiveness of interventions that could be used to reduce the detrimental impacts from foodborne disease caused by the pathogens.

The MCDA allowed the grouping of the pathogens into three broad categories – high-ranking, medium-ranking, and low-ranking, ordered by their average rank. It's worth noting that norovirus ranked first in such a high proportion of simulations that it could reasonably be considered in a separate category altogether.

Figure 5 – Ranking the pathogens into three main categories in order of their average rank



Annex I – Criteria Selection

i) Identifying Criteria

List of criteria taken into the criteria selection process

Criteria	Description
Number of cases	Total number of cases per annum for each pathogen
Fatality rate	The proportion of cases with fatalities for each pathogen
Number of annual fatalities	Total number of deaths attributed to the pathogen annually
Proportion of outbreaks	The proportion of all foodborne outbreaks attributed to the pathogen. An outbreak is an incident in which two or more people experiencing a similar illness are linked in time or place
Impact on exports/trade	Qualitative assessment of impact of pathogen on exports/trade
Media interest in pathogen/consumer concern	Qualitative assessment of consumer concern and media interests in pathogen
Total cost to NHS/ OGDs per annum	Includes medical care expenditures associated with diagnosis, treatment, management, and other costs to the NHS (National Health Service) and OGDS (Other Government Departments).
Total cost to businesses per annum	Disturbance cost to business - work-reorganisation costs to the employer due to employee sick absence related to an FBD related illness
Total cost to individuals per annum	Costs borne by individuals and carers, comprised of lost earnings from absence due to sickness, individual expenses and pain, grief, and suffering
Total cost to society per annum	Total societal cost burden (aggregation of costs to NHS/ OGDs, individuals and businesses) by pathogen
Total cost per case	Total societal cost on a per case basis by pathogen per annum

Criteria	Description
Quality Adjusted Life Years	A generic measure of the state of health of an individual in terms of length of life; adjusted to reflect the quality of life.
Number of children affected	Number of children affected, which could be measured in terms of cases or fatalities
Death data in terms of age	Number of annual deaths attributed to the pathogen for different age bands
Political interest (Parliamentary Questions, ministers' correspondence to the media)	Qualitative assessment of the likelihood of there being interest surrounding the pathogen from politicians
Industry concern (economic issues)	Qualitative assessment of industry's concern for the pathogen and how it may affect business
Reputational risk	Qualitative assessment of the likelihood of an outbreak of the pathogen having a detrimental effect on the reputation of the FSA
Scientist concern	Qualitative assessment of scientists' confidence in the basis of their understanding of the pathogen and the likelihood that their understanding may change

ii) Selecting Criteria

This was the order of priority as voted on in the workshop

Order	Criteria
1	Number of Cases
2	Quality Adjusted Life Years
2	Reputational Risk
3	Total Cost to Society per Annum
4	Consumer Concern
4	Political Interest
5	Fatality Rate

Order	Criteria
6	Number of Annual Fatalities
6	Total Cost to NHS / OGDs per Annum
7	Proportion of Outbreaks
7	Total Cost to Individuals per Annum
7	Scientist Concern
7	Number of Children Affected
7	Industry Concern
8	Impact on Exports/Trade
8	Total Cost to Businesses per Annum
8	Total Cost per Case
8	Deaths Relative to Age
8	Government Competency
9	Other Government Priorities

Annex II – Criteria Data

i) Scientist Confidence – Qualitative Scale

Qualitative scale used to score each pathogen on 'scientist confidence'

Level of Confidence in our understanding of the Pathogen	Scale descriptor
High	We have a high level of confidence in the basis of our understanding of the pathogen. Further evidence is very unlikely to change the basis of our understanding
Moderate	We have a moderate level of confidence in the basis of our understanding of the pathogen. Further evidence may change the basis of our understanding
Low	We have a low level of confidence in the basis of our understanding of the pathogen. Further evidence is likely to change the basis of our understanding
Very Low	We have a very low level of confidence in the basis of our understanding of the pathogen. Further evidence is very likely to change the basis of our understanding

ii) Scientist Confidence – Points to Consider

List of points that we asked the Microbiological Team to consider when assessing the scientist confidence for each pathogen

- Variations in pathogen strains and likelihood of new strains emerging
- Uncertainties in our underlying assumptions about the pathogen's microbiology for example, how it spreads, infectivity
- Adaptability of pathogen and ability to evolve due to selection pressures
- Likelihood of pathogen becoming resistant to antibiotics

- Pathogen resistance to processing and cooking
- Pathogen host range and geographical variation

iii) Scientist Confidence – Discussion Notes

Results and comments from the 'scientist confidence' discussion with the Microbiological Team

Pathogen	Results	Comments
Campylobacter	Moderate	Has good surveillance including for AMR (Anti-Microbial Resistance). There has been a lot of research that has provided a good level of understanding
Cl. perfringens	Low	A lot of research and data is available but somewhat dated. Surveillance is weak and confirmed laboratory reports only come from outbreaks
E. coli O157	Moderate	Moderately confident on *E. coli* O157 but greater concern for other *E. coli* strains including other STECs (Shiga toxin-producing *Escherichia coli*). Some surveillance in AMR.
Listeria monocytogenes	Moderate	There has been a lot of research, providing a good level of understanding
Salmonella	High	Good surveillance both in humans and animals. Up-to-date research and generally good understanding of disease
Shigella	Low	Research on pathogen is old and surveillance is weak.
Cryptosporidium	Low	Tends to be a water spread pathogen. Most of understanding comes from work on water. Pathogen is difficult to culture, so hard to detect

Pathogen	Results	Comments
Giardia	Low	Associated with travel and water. Testing methods getting better although typing is not commonly done.
Adenovirus	Very Low	Infection with adenovirus causes a range of symptoms, mostly in babies and young children. These include cold-like symptoms, fever and a sore throat, but infection can cause gastroenteritis. Surveillance is lacking and both transmission routes and the proportion of infections resulting in gastrointestinal disease, as well as which factors contribute to the likelihood of this happening, are not well understood.
Astrovirus	Low	Astrovirus, rotavirus and sapovirus are primarily transmitted via food and water and are mostly associated with gastroenteritis in babies and young children; infection can occur in adulthood but is rarely associated with disease except in the elderly or immunocompromised. We have some understanding of routes of transmission, but surveillance is lacking.
Norovirus	Moderate	Borders between low and moderate confidence. More confident than other viruses. Reasonable surveillance and a large body of research available, although gaps remain which are difficult to resolve.
Rotavirus	Low	See Astrovirus
Sapovirus	Low	See Astrovirus

iv) Public Concern – Qualitative Scale

Qualitative scale used to assess the public concern for each pathogen

Public Concern for the Pathogen	Level description
High	Public awareness of the pathogen is *high*. Enquiries and questions from the public, media and other stakeholders are *frequent*. Outbreaks of the pathogen *are likely to* generate interest in the media and pose a reputational risk to the FSA
Moderate	Public awareness of the pathogen is *moderate*. Enquiries and questions from the public, media and other stakeholders are *occasional*. Outbreaks of the pathogen *may* generate interest in the media and pose a reputational risk to the FSA
Low	Public awareness of the pathogen is *low*. Enquiries and questions from the public, media and other stakeholders are *rare*. Outbreaks of the pathogen *are unlikely to* generate interest in the media and pose a reputational risk to the FSA
Very low	Public awareness of the pathogen is *very low*. Enquiries and questions from the public, media and other stakeholders are *very rare*. Outbreaks of the pathogen *are very unlikely to* generate interest in the media and pose a reputational risk to the FSA

v) Public Concern – Points to Consider

List of points that we asked the Communications Team to consider when assessing the public concern for each pathogen

- How concerned do we think the consumer is about the pathogen?
- What is the general public's level of awareness of the pathogen?
- Is an outbreak of the pathogen likely to generate media interest due to the number of outbreak fatalities and/or the demographics affected?
- Is an outbreak of the pathogen likely to generate political interest? For example, in PMQs (Prime Minister's Questions)
- Is an outbreak of the pathogen likely to pose a reputational risk to the FSA?

vi) Public Concern – Discussion Notes

Results and comments from the 'public concern' survey and discussion with the Communications Team

Pathogen	Results	Comments
Campylobacter	High	Awareness and media interest in pathogen are moderate and outbreak numbers mid-range
Cl. perfringens	Moderate	Awareness of pathogen very low but mid-range in terms of outbreaks
E. coli O157	High	Awareness of pathogen (at least *E. coli* rather than *E. coli* O157) very high and outbreaks attract lots of media attention (particularly if children get sick)
Listeria monocytogenes	High	High fatality rate (particularly for vulnerable people) causes lots of media attention in the case of outbreaks
Salmonella	High	Awareness of pathogen very high and prevalence of outbreak cases high
Shigella	Very Low	Awareness of pathogen very low and limited media coverage
Cryptosporidium	Very Low	Awareness of pathogen very low and limited media coverage
Giardia	Very Low	Awareness of pathogen very low and limited media coverage
Adenovirus	Very Low	Awareness of pathogen very low and limited media coverage
Astrovirus	Very Low	Awareness of pathogen very low and limited media coverage
Norovirus	High	Awareness of pathogen very high and high volume of outbreaks
Rotavirus	Very Low	Awareness of pathogen very low and limited media coverage
Sapovirus	Very Low	Awareness of pathogen very low and limited media coverage

Annex III – Criteria Weighting

Each member's weights for each of the criteria

Respondent (in no particular order)	**Annual Number of Cases**	**QALY per Case**	**Total Cost to Society**	**Annual Number of Fatalities**	**Scientist Confidence**	**Public Concern**
1	5	25	15	20	15	20
2	20	15	20	25	10	10
3	15	18	15	19	15	18
4	21	13	17	21	12	16
5	16	21	19	20	12	12
6	25	15	20	20	10	10
7	10	10	40	10	15	15
8	5	25	25	10	15	20
9	15	25	20	14	8	18

Annex IV – Monte-Carlo Simulation

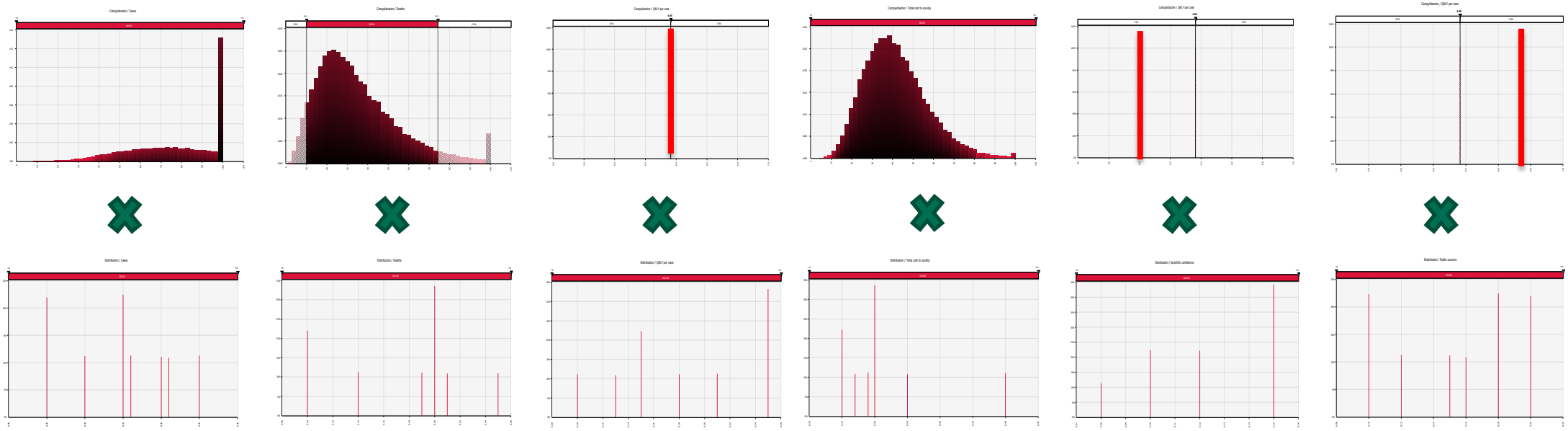
Monte-Carlo Simulation Breakdown

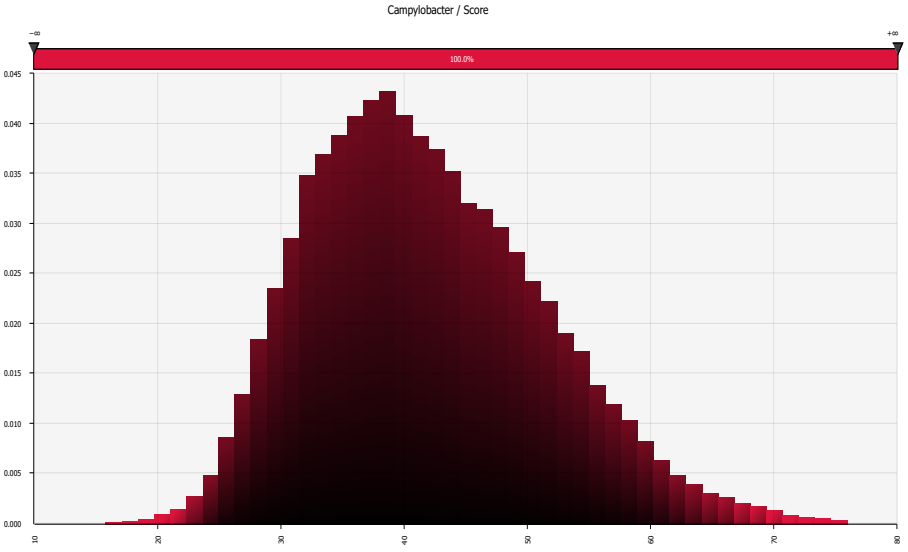
The first rows in the diagram (figure 6) below show the distributions for each criterion for *Campylobacter* after being made comparable (see Step 3 of the methodology). The graphs in the second row show the distribution of weightings for each of the criteria given by each of the FSA senior managers.

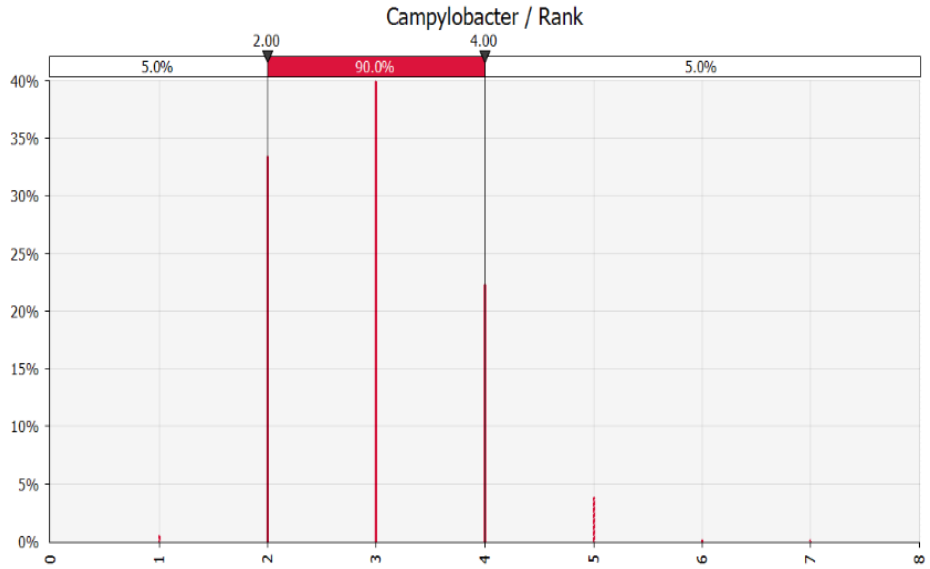
Taking cases as an example, a possible value for number of cases is picked from the distribution for number of cases. One of the weighting for number of cases by one of the senior managers is also picked at random. These are multiplied together to create a weighted score for number of cases for Campylobacter. The same is done for each of the criterion (the same senior managers weightings are used for each run of the model). The 6 scores of the criteria are then added to create the total score for Campylobacter. This is also done for the 12 other pathogens. The pathogens can then be ranked by the score they receive. This is done 100,000 times to give 100,000 scores to each pathogen and 100,000 rankings. The output distribution of scores and rank for *Campylobacter* can be seen in the graphs in the third row.

Figure 6 – Diagram showing the distributions for *Campylobacter* for each criterion and the distribution of weightings for each criterion to help illustrate the Monte-Carlo simulation

Number of cases | Number of fatalities | QALY per case | Cost to society | Scientist confidence | Public concern







Annex V – Sensitivity Analysis

i) Sensitivity Analysis Results

Mean score and 95% confidence interval for each pathogen in the MCDA with all criteria included and with 'annual number of cases' excluded, 'annual number of fatalities' excluded and 'total cost to society per annum' excluded

Pathogen	All criteria: Mean score	95% CI	Cases excluded: Mean score	95% CI	Fatalities excluded: Mean Score	95% CI	Cost to society excluded: Mean Score	95% CI
Campylobacter	42	(26-62)	36	(24-54)	43	(29-61)	42	(28-61)
Cl. Perfringens	27	(15-44)	27	(14-45)	22	(16-31)	32	(18-52)
E.coli O157	20	(14-26)	23	(17-28)	24	(17-32)	26	(17-34)
Listeria monocytogenes	46	(33-60)	53	(37-65)	47	(34-63)	57	(42-74)
Salmonella	32	(16-52)	35	(19-56)	26	(16-42)	36	(19-51)
Shigella	9	(6-11)	10	(7-12)	11	(6-13)	11	(7-17)
Cryptosporidium	9	(6-11)	10	(6-12)	11	(6-13)	11	(7-17)
Giardia	15	(11-21)	17	(14-22)	18	(14-25)	18	(13-23)
Adenovirus	17	(13-21)	19	(15-22)	20	(15-25)	21	(16-29)
Astrovirus	12	(9-14)	13	(11-15)	13	(11-18)	15	(12-20)

Pathogen	All criteria: Mean score	95% CI	Cases excluded: Mean score	95% CI	Fatalities excluded: Mean Score	95% CI	Cost to society excluded: Mean Score	95% CI
Norovirus	73	(59-82)	69	(54-80)	69	(61-80)	65	(50-78)
Rotavirus	12	(9-14)	13	(11-15)	13	(11-18)	15	(12-20)
Sapovirus	15	(12-18)	16	(13-18)	18	(15-21)	17	(13-22)

Mean rank and 95% confidence interval for each pathogen in the MCDA with all criteria included and with 'annual number of cases' excluded, 'annual number of fatalities' excluded and 'total cost to society per annum' excluded

Pathogen	All criteria: Mean rank	95% CI	Cases excluded: Mean rank	95% CI	Fatalities excluded: Mean rank	95% CI	Cost to society excluded: Mean rank	95% CI
Campylobacter	3	(2-5)	4	(2-5)	3	(2-4)	3	(2-5)
Cl. Perfringens	5	(2-7)	5	(3-8)	6	(4-9)	5	(2-7)
E.coli O157	6	(5-8)	6	(4-7)	5	(4-8)	6	(4-7)
Listeria monocytogenes	3	(2-4)	2	(1-3)	2	(1-3)	2	(1-4)
Salmonella	4	(2-6)	4	(2-6)	5	(3-9)	4	(2-6)
Shigella	13	(12-13)	12	(12-13)	12	(12-13)	13	(12-13)
Cryptosporidium	13	(12-13)	13	(12-13)	13	(12-13)	12	(12-13)

Giardia	8	(6-9)	8	(6-9)	8	(4-9)	8	(7-9)
Adenovirus	7	(6-9)	7	(6-8)	7	(4-9)	7	(6-8)
Astrovirus	10	(10-11)	10	(10-11)	10	(10-11)	10	(10-11)
Norovirus	1	(1-1)	1	(1-2)	1	(1-2)	1	(1-2)
Rotavirus	11	(10-11)	11	(10-11)	11	(10-11)	11	(10-11)
Sapovirus	8	(6-9)	9	(8-9)	8	(5-9)	9	(8-9)

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