INVESTIGATION OF DE-ICING USING PRE-WETTED SALT: BENEFIT-COST ANALYSIS

by M H Burtwell, R W Jordan and F Ofori-Darko

PR/IS/74/01
3/261

TRL Limited

PROJECT REPORT PR/IS/74/01

Investigation of de-icing using pre-wetted salt: benefit-cost analysis

by M H Burtwell, R W Jordan and F Ofori-Darko (TRL Limited)

Prepared for: **Project Record:** **3/261 Investigate de-icing using wetted salt**
Client: **Safety Standards and Research (SSR), Highways Agency**
[Peter Whitfield]

	Approvals
Project Manager	**Marilyn Burtwell**
Quality Reviewed	**Richard Jordan**

CIRCULATION LIST

This report has been classified as having a limited circulation. It should not be copied or shown to any other parties without the permission of Highways Agency.

Initially copies have been sent to:

1. Highways Agency

CONTENTS

		Page
Executive Summary		**i**
1	**Introduction**	**1**
2	**Methodology**	**1**
2.1	Whole-life cost analysis	1
2.2	Benefit-cost analysis	2
3	**Data for whole-life cost and benefit-cost analyses**	**3**
3.1	Cost data	3
3.1.1	Direct costs	3
3.1.2	Indirect costs	6
3.2	Benefit data	6
4	**Benefit-cost analysis**	**7**
4.1	Whole-life cost and benefit-cost ratio for dry and pre-wetted salting	7
4.2	Comparison of dry and pre-wetted salting	8
4.3	The advantages and disadvantages of pre-wetted salting	10
5	**Strategy for introducing pre-wetted salt technology**	**11**
5.1	Background	11
5.2	Options for the introduction of pre-wetted salting	12
5.3	Comparison of options for the introduction of pre-wetted salting	14
5.4	Factors to consider when determining the best option for HA	15
6	**Conclusions**	**17**
Acknowledgements		**17**
References		**17**
Appendix A	**Derivation of indirect costs and benefits**	**19**
Appendix B	**Output from benefit-cost model**	**22**
Appendix C	**Whole-life costs and sum of present values for options 0 to 4 for the parameter values shown in table 5.3**	**28**
Appendix D	**Calculation of whole-life costs and sum of present values for options 0 to 4 different parameter values**	**40**

Executive summary

TRL PR/IS/74/01: **Investigation of de-icing using pre-wetted salt: benefit-cost analysis**
by M H Burtwell, R W Jordan and F Ofori-Darko

Project Reference: **3/261: Investigate de-icing using pre-wetted salt**
Project Officer: **Mr Peter Whitfield, Safety Standards and Research (SSR), Highways Agency.**
Project Manager: **Mrs M H Burtwell, TRL Ltd.**

Scope

Safety Standards and Research (SSR), Highways Agency (HA), have commissioned TRL to evaluate the applicability and cost of introducing pre-wetted salt on the motorway and trunk road network and to verify favourable claims made by highway authorities about pre-wetted salting technology. The work has been carried out in two stages. The first stage covered the environmental issues, cost and safety aspects of pre-wetted salt. The second stage concerns field trials and a Draft Departmental Advice Note. In addition, a benefit-cost analysis has been carried out to enable the HA to address some of the socio-economic benefits of adopting pre-wetted salt technology.

This report describes the benefit-cost analysis of using pre-wetted salt for winter maintenance and presents a socio-economic case in favour of adopting pre-wetted salt for highway de-icing. The socio-economic information needed to carry out the analysis was obtained from highway authorities and relevant literature. The main aims of the report are as follows:

- To estimate the level of savings to be made by changing from dry salting to pre-wetted salting.
- To carry out a benefit-cost analysis for winter maintenance.
- To use whole-life cost principles to develop a strategy upon which the pre-wetted salt technology may be introduced.

Summary

In order to carry out the whole-life cost and benefit-cost of winter maintenance, data have been obtained on the direct costs, indirect costs and monetary benefits of salting from HA, local authorities, salting vehicle and salt suppliers and a literature search.

The direct costs of salting include the cost of salting vehicles, the cost of saturators for manufacturing brine for pre-wetted salting, the cost of civil and electrical works for the installation of the saturators for pre-wetted salting, the running and maintenance costs of vehicles, the running and maintenance costs of saturators, the cost of salt and the salvage value of the vehicles and the saturators. The indirect costs are the cost of vehicle corrosion, the cost of structural corrosion/damage and environmental damage. The benefits of salting that were assumed are a reduction in the cost of road traffic accidents, traffic delays, work for emergency service and fuel consumptions.

Benefit-cost ratios have been calculated as the ratio of the monetary benefits to the total cost (the sum of the direct and indirect costs). It has been assumed that indirect costs are proportional to the chloride content of the salt. Therefore, because the chloride content of pre-wetted salt is lower than that of dry salt, lower total costs were assumed for the latter.

The benefit-cost ratios for dry and pre-wetted salting, based on best estimates of the parameters concerned, are 8.78 and 10.62, respectively. Therefore, for every pound spent on dry and pre-wetted salting, there are cost savings of £8.78 and £10.62, respectively. Sensitivity analyses have shown that the benefit-cost ratio is higher for pre-wetted salting than dry salting for parameter values that cover

the credible range. Therefore, the probability that the benefit-cost ratio will be higher for pre-wetted salting than dry salting is high.

On the basis of the above, pre-wetted salting technology should be introduced by HA. However, HA may not benefit from the introduction of pre-wetted salting in the same way as the wider community. The whole-life cost of pre-wetted salting operations can be higher than that of dry salting operations when the amount of salt used is low and/or the difference in the cost of dry and pre-wetted salt is low. This is because the extra cost of pre-wetted salting vehicles and the cost of saturators and their installation are not offset by the reduction in the cost of the salt. On the other hand, pre-wetted salting has been assumed to cause less structural damage than dry salting. Therefore, the overall difference in the cost of dry and pre-wetted salting to HA should take into account the reduction in the cost of structural repairs, although the reduction may not be realised until some time after pre-wetted salting has been introduced.

The whole-life cost of dry salting and four options for the introduction of pre-wetted salting technology have been calculated for the existing stock of HA salting vehicles. Options 1 and 2 assume that pre-wetted salting is introduced immediately. Option 1 assumes that the existing dry salting vehicles are retrofitted for pre-wetted salting or replaced by pre-wetted salting vehicles, dependent on their age. Option 2 assumes that existing vehicles less than a certain age are retrofitted, whilst the others are used for dry salting until they are replaced with pre-wetted salting vehicles at the end of their service life. Options 3 and 4 assume that the existing dry salting vehicles are replaced at the end of their service life. Option 3 assumes that the saturators are installed when the oldest vehicles are replaced, whereas the Option 4 assumes that the saturators are installed when the youngest vehicles are replaced. For the Option 3, pre-wetted salting commences as soon as the vehicles are available.

Sensitivity analysis have been carried out that show that the option with the lowest whole-life cost varies according to the amount of salt used and difference in the cost of dry and pre-wetted salt. If the amount of salt used is high and the cost difference is high, Option 1 generally gives the lowest whole-life cost. However, if the opposite is the case, Option 4 has the lowest cost. These whole-life costs take into account the annual cost of repairing structural damage caused by de-icing salt, amounting to £20 million.

Implementation

The information in this report should be used to aid the Highways Agency's decision on whether or not to adopt pre-wetted salt technology and if so, how best to implement the change in terms of whole-life costs.

As indicated above, to benefit the wider community, pre-wetted salting should be introduced as soon as possible. As Option 1 can involve much investment in the first year, a more gradual introduction may be preferred.

The methodology developed should be used to determine the best option for the introduction of pre-wetted salting for different Areas that have different numbers of vehicles and depots and use different amounts of salt.

1 INTRODUCTION

Traditionally, dry salt is applied to roads to reduce hazards faced by the travelling public due to frost, ice and snow during winter months. In recent years, significant attention has been drawn to the benefits of pre-wetted salt technology whereby dry salt is wetted with a chemical solution such as Sodium Chloride (NaCl) or Calcium Chloride ($CaCl_2$) brine before it is applied to the road surface. Pre-wetted salt technology has been introduced in continental Europe and America, in several local authorities in England and by Carillion-URS in Area 8 of the motorway and trunk road network.

In 1999, the Highways Agency (HA) commissioned TRL to evaluate the applicability and cost of adopting pre-wetted salt technology over the whole of the motorway and trunk road network in England. The study was carried out in two stages. The first stage attempted to verify claims that have been made about pre-wetted salting with regards to the performance and likely cost savings (Hird et al, 1999). It was found that:

- Pre-wetted salt may be more effective than dry salt because the deliquescence process starts earlier and the salt remains on the road longer, even in drying conditions.
- Using pre-wetted salt may decrease the quantity of salt required, bringing with it likely environmental and economic benefits.
- The spread width of pre-wetted salt may be nearly 25 per cent less than that of dry salt because pre-wetted salt particles are likely to be smaller.
- A pre-wetted salting vehicle is likely to have a lower life expectancy than a dry salting vehicle.
- An increase in expenditure on salting operations by HA would be required to introduce pre-wetted salt technology.

The above findings suggest that there are both advantages and disadvantages in adopting the use of pre-wetted salt technology. In order to arrive at an informed decision on whether pre-wetted salting is likely to be beneficial on the HA network, the second stage, which is the subject of this report, involved whole-life cost and benefit-cost analyses to assess the short-term and long-term socio-economic consequences of adopting the technology. The main objectives of the analysis were:

- To compare the cost of de-icing using dry and pre-wetted salt.
- To estimate the direct and indirect costs and the benefits of using pre-wetted salt.
- To recommend an investment strategy for introducing pre-wetted salt technology on the HA network.

Section 2 describes the principles of the analysis, Section 3 describes the data used in the analysis, and Sections 4 and 5 describe their application to winter maintenance in relation to the main objectives. Section 6 summarises the main conclusions.

2 METHODOLOGY

Two interdependent methodologies have been used in order to estimate the economic consequences of adopting pre-wetted salt technology for winter maintenance. They are whole-life cost analysis (WLCA) and benefit-cost analysis (BCA).

2.1 Whole-life cost analysis

The principle of WLCA is to calculate all the costs associated with a project throughout its life to a common base so that comparisons can be made between options. Thus, in practice, the whole-life cost (WLC) represents the sum of money to be set aside today to meet all the eventual costs, both present and future, after allowing for the accumulation of interest on that part of it intended for future commitments (Tilly, 1995). The WLC is estimated by discounting all the anticipated operation and maintenance costs, calculated at present day prices, by a factor which takes account of time from the start of the project to when the expenditure would be incurred. It is defined as follows:

$$WLC = \sum_{t=1}^{N} \frac{(c_t)}{(1+r/100)^t} \quad (1)$$

where

N = Analysis period (years)
r = Discount rate (%)
t = Year of cost/benefit
c_t = Cost (initial cost, operation & maintenance cost)

The WLC would have more validity if infrastructure owners actually set aside discounted funds in one way or another for future operation and maintenance commitments. In reality, no one does this. Nevertheless, the WLC provides:

- An indicator of the relevance of considering the future maintenance at the time of design and construction.
- An economic and engineering basis for comparison of various alternatives.

The choice of discount rate normally reflects the nature of risk inherent with the project. For Treasury-funded projects of duration up to 30 years, a discount rate of 3.5 per cent is used.

For the purposes of this study, two separate WLC analyses have been carried out. One concerns the direct cost of winter maintenance operations that have been evaluated as part of the Benefit-Cost Analysis (BCA, Section 4). The other concerns the WLC analysis (WLCA) of introducing pre-wetted salting on the HA network (Section 5).

Indirect costs incurred as a result of winter maintenance, such as structural and environmental damage, contribute to the total cost of winter maintenance. They are not included in the WLCA but they are included in the BCA.

2.2 Benefit-cost analysis

BCA is one of numerous methods of analysing costs, benefits and risks associated with a decision or plan. The outcomes of the analysis are the Benefit-cost and the Benefit-Cost Ratio (BCR) which are defined as follows:

Benefit-cost = Monetary Benefit - Total Cost

Benefit-cost Ratio = Monetary Benefit / Total Cost

The Total Cost is the sum of the direct (see Section 3.1.1) and indirect costs (see Section 3.1.2) associated with winter maintenance. As for the WLC defined in equation (1), the Monetary Benefits and the Total Cost are the sum of separate values, calculated at present day prices, which are discounted by a factor which takes account of time from the start of the project to when the benefit or cost occurs.

The BCR, simply the cost saving (benefit) for every one pound spent, is a measure of "worthwhileness" generally used by both public and private institutions at national, regional and local levels to justify their selection of projects among the many vying for attention (Lang and Merino, 1993).

According to Snell (1997), the main types of decision guided by BCA are:

- Investment-type or yes/no decisions, i.e. whether or not a single project or course of action will be undertaken.
- Design-type or either/or decisions. i.e. what way a technical goal should be achieved.

Whether dry or pre-wetted salting should be used is dependent on what technology has the higher BCR and whether the BCR is greater than 1.

Irrespective of the type, the general procedure for the methodology is as follows:

1. Definition of the criteria and parameters to be used in the analysis and derivation of the cost and benefit models.
2. Collation of the cost and benefit data for the model.
3. Comparison of the sum of the benefits with the sum of costs.

In most instances, because a degree of uncertainty surrounds the quantification of the costs and benefits, it is important to include risk and sensitivity analysis in the procedure.

3 DATA FOR WHOLE-LIFE COST AND BENEFIT-COST ANALYSES

3.1 Cost data

For the purposes of this report, the cost data have been divided principally into (1) direct and (2) indirect costs.

3.1.1 Direct costs

The direct costs that have been included in the WLCA and BCA comprise the following:

- Cost of salting vehicles
- Cost of saturator for manufacturing brine for pre-wetted salting
- Cost of civil and electrical works for installation of saturator for pre-wetted salting
- Running and maintenance costs of vehicles
- Running and maintenance costs of saturator
- Cost of salt
- Salvage value of vehicles (and saturator)

The salvage value is counted as a negative cost, which will reduce the net direct cost.

The direct cost and performance data that has been assumed in the WLCA and BCA are listed in Table 3-1. The data were derived from data provided by HA, local authorities and two vehicle suppliers, as explained in the following sections. The values in parenthesis represent those assumed in sensitivity analyses.

It should be noted that when comparing the WLC of dry and pre-wetted salting, it is the differences in the costs of the dry and pre-wetted salting vehicles, and the differences in the cost of dry and wet salt that are significant, not the absolute values. However, both the differences and absolute values are significant to the BCR.

3.1.1.1 Vehicles

The total number of vehicles used on the HA network has been assumed to total 550. HA own about 313 vehicles. The remaining 237 vehicles are owned by Agents and DBFOs, including 32 pre-wetted salting vehicles owned by Area 8.

The newest dry salting vehicles owned by HA cost £108,000. They have a good quality paint system that is designed to limit the amount and rate of corrosion of the vehicles so their estimated service life is 15 to 20 years.

Schmidt has supplied pre-wetted salting vehicles to the National Assembly of Wales. Their cost and estimated service life are £100,000 and 15 years, respectively. Budget cost figures provided by

Schmidt for a $9m^3$ spreader on a 6x4 26 tonne chassis were £71,000 for dry and £74,000 for pre-wetted salting vehicles.

Econ has also supplied local authorities with pre-wetted salting vehicles. The estimated cost and service lives of dry and pre-wetted vehicles are £53,000 and 10 years, and £60,000 and 7 years, respectively.

The differences in the cost of the HA, Econ and Schmidt vehicles would appear to be due to their size and, possibly, the standard of the paint system. The latter would also affect the estimated service lives. Area 8 has indicated that pre-wetted salting has no particularly adverse effect on the service life of salting vehicles, but it is not known if this finding is based on a like-for-like comparison of pre-wetted and dry salting vehicles with the same paint system.

Econ has indicated that the cost of retrofitting a dry salting vehicle for pre-wetted salting may vary from £6,000 to £18,000, but consider it is not cost effective. Schmidt has indicated that the cost of retrofitting may be as low as £4,000 if the valve for the tanks was fitted when the vehicle was supplied.

All vehicle suppliers estimated that the salvage value at the end of the service life is about 10% of the initial cost. A linear rate of depreciation has been assumed, e.g. the salvage value of a vehicle with half its service life remaining is estimated to be 55% of the initial cost.

The annual running cost of a vehicle has been assumed to be £4000.

3.1.1.2 Saturators

Pre-wetted salting is carried out in Area 8 from 7 depots. A further 144 depots would require saturators if pre-wetted salting was applied to the whole HA network.

The cost of the type of saturator that would be suitable for the HA network varies from £15,000 to £25,000. Civil works must be carried out at compounds before a saturator can be installed. A bund is normally required, and some authorities have facilities for washing down vehicles and using the salt retrieved. Dependant on what is required, the setup costs may range from £5,000 to £15,000.

No data are available on the service life of saturators. The pump and impeller and other small components may need to be replaced at a cost of about £2,500/saturator every 5 years (averaged out at £500/year/saturator). It is thought that the body would last at least 20 years. The annual running cost of a saturator has been assumed to be £1500.

It has been assumed that there is no salvage value.

3.1.1.3 Salt

The quantity of salt used on the HA network has been assumed to be 500,000 tonnes (dry salt equivalent), as quoted on HA's website. This figure is somewhat lower than that estimated in the first stage of the project.

The cost of salt has been derived from information provided by Salt Union and Salinity (UK). The cost of salt varies throughout the year. The costs shown in Table 3-1 are for bulk supply in the summer.

The amount of salt applied during pre-wetted salting is dependent on the composition of the dry salt and brine mixture. The composition most commonly applied in the UK is a 70:30 dry salt to brine mixture, with a brine concentration of 23.5 per cent. The total salt (NaCl) content of 10 grams of this composition is 7.7grams. It has been assumed that 10 grams of pre-wetted salt is as effective as 10 grams of dry salt.

In order to make brine, Salt Union provides a high purity salt, as and when required, at a cost of about £62/tonne. For the pre-wetted salt composition specified above, the cost of an application of Salt Union pre-wetted salt equivalent to a tonne of dry salt costing £23/tonne is £20.47/tonne.

The dry salt provided by Salinity is also suitable for making brine. The cost of an application of Salinity pre-wetted salt equivalent to a tonne of dry salt costing £26/tonne is £20.03/tonne. Therefore, despite differences in the costs of the ingredients, the cost of pre-wetted salt does not vary significantly with the supplier. A figure of £20.5/tonne has been assumed.

Some argue that because dry salt scatters more than pre-wetted salt, for the same degree of de-icing, more dry salt should be applied than pre-wetted salt. The cost of dry salt has been assumed to range from £23/tonne to £30/tonne so the effect of a small increase in the amount applied, and hence the cost, can be assessed.

Table 3-1 Direct cost data

Vehicles	
Parameter	**Value**
Number of dry salting vehicles owned by HA	313
Number of dry salting vehicles owned by Agents/DBFOs	205
Number of pre-wetted salting vehicles owned by Agents/DBFOs (Area 8)	32
TOTAL NUMBER OF VEHICLES USED ON HA (AND DBFO) NETWORK	550
Service life of dry salting vehicles	15 (20) years
Service life of pre-wetted salting vehicles	12 (10, 15) years
Service life of retrofitted	12 (10, 15) years
Age range of dry salting vehicles	7 to 13 (2 to 8)years
Cost of dry salting vehicles	£108,000
Cost of pre-wetted salting vehicles	£116,000 (£112,000)
Cost of retrofitting dry salting vehicles for pre-wetting salting	£10,000
Salvage value of dry salting vehicles (linear depreciation)	£10,800
Salvage value of pre-wetted/retrofitted salting vehicles (linear depreciation)	£11,600 (£11,200)
Annual running (and salt handling) costs	£4,000
Saturators	
Parameter	**Value**
Number of saturators owned by HA	0
Number of saturators owned by Agents and (DBFOs) (Area 8)	7
TOTAL NUMBER OF SATURATORS REQUIRED FOR 100% PRE-WETTED SALTING	151
Service life of saturator	20 years
Cost of saturator	£25,000 (£15,000, £20,000)
Set-up costs for new saturators	£5,000 (£15,000)
Salvage value	£0
Annual running costs	£1,500 (routine maintenance) £500 (major maintenance)
Salt	
Parameter	**Value**
Dry salt required for whole of HA network	500,000 tonnes
Pre-wetted salt currently used on HA network (equivalent dry salt tonnage)	23,179 tonnes (=500,000x7/151)
Cost of dry salt	£23 (£26, £30)/tonne
Cost of prewetted salt (equivalent to a tonne of dry salt)	£20.5/tonne

3.1.2 Indirect costs

The use of salt during winter months causes:

- Vehicle corrosion
- Structural corrosion/damage
- Environmental damage to vegetation, soil, water courses etc.

The costs associated with these factors are included in the BCA and, for the purposes of this study, they are called indirect costs.

The indirect costs that have been assumed for an annual application of 500,000 tonnes of salt are summarised in Table 3-2. Their source and derivation are given in Appendix A. Costs for higher or lower application rates of salt have been calculated on a pro rata basis. To allow for the reduction in the amount of salt spread when pre-wetted salt is used instead of dry salt, it has been assumed that the indirect costs for pre-wetted salting are 77% of those for dry salting.

No allowance has been made for the possible variation in the indirect costs due to the characteristics of the salt itself, such as the sizes and grading of the salt particles and their wetness.

The reductions in the indirect costs following the introduction of pre-wetted salting are unlikely to be realised immediately. However, as the time delays are not known, none have been assumed.

Table 3-2 Annual indirect costs for 500,000 tonnes of salt

Indirect cost	Value
Vehicle corrosion associated with dry salting	£47,440,000
Structural corrosion/damage associated with dry salting	£20,000,000
Environmental damage associated with dry salting	£250,000
Vehicle corrosion associated with pre-wetted salting	£36,530,000
Structural corrosion/damage associated with pre-wetted salting	£15,400,000
Environmental damage associated with pre-wetted salting	£192,500

3.2 Benefit data

According to Brenner and Moshman (1976), Hanbali (1994) and Thornes (1996) the following are the economic benefits of winter maintenance:

- Reduction in road traffic accidents;
- Reduction in traffic delays;
- Reduction in work for emergency services; and
- Fuel economy.

In order to quantify the benefits of a reduced number of road traffic accidents, it has been assumed that 70 per cent of accidents reported on icy roads are on roads that should have been salted (Fraser et al, 1998). The benefits of reduced traffic delays include wage losses for lateness to work, absenteeism, lost production and delivery losses. These benefits are associated with traffic volume and the stock of vehicles on the network, and they have been estimated as shown in Appendix A.

The benefits to the emergency services are based on the supposition that if roads are not salted, ambulances, fire engines, police and other emergency vehicles would have difficulty answering emergency calls quickly. This would lead to reduced response times for heart attacks, strokes, burns, home accidents and work accidents (Thornes, 1996).

For fuel economy, it is known that driving in higher gears can save fuel and it is reasonable to assume that these responses are achieved more in winter on salted roads than on unsalted roads.

The benefits assumed for an annual application of 500,000 tonnes of salt are summarised in Table 3-3. These data have being produced by using and extrapolating data from Thornes (1996), and UK and Northern Ireland Transport Statistics (DfT, 2001). Thornes's report provides cost estimates for the

UK. The Northern Ireland and UK Transport Statistics provide data relating to the total stock of vehicles on UK roads, the volume of traffic (billion vehicle km), the kilometre length of roads and some cost data. The result for the extrapolation is included in Appendix A. Benefits for higher applications of salt have been calculated on a pro rata basis.

The same benefits have been assumed for dry and pre-wetted salting because no studies have identified differences in the performance of the two types of salting.

Table 3-3 Annual benefits for 500,000 tonnes of salt

Benefit	Value
Reduced traffic accidents	£199,230,000
Reduced traffic delays	£474,360,000
Reduced emergency response times	£75,900,000
Reduced fuel economy	£6,320,000

4 BENEFIT-COST ANALYSIS

4.1 Whole-life cost and benefit-cost ratio for dry and pre-wetted salting

Models to determine the WLC and BCR for dry and pre-wetted salting have been designed in Microsoft Excel. Appendix B shows the detailed output from the model.

Table 4-1 summarises the output from the model that was obtained assuming the direct cost data shown in Table 3-1 that are not in parenthesis, and the indirect costs and benefits shown in Table 3-2 and Table 3-3, respectively.

The WLC (sum of the discounted direct costs) for dry salting is £350 million, and the WLC for pre-wetted salting is £12.9 million higher. It is apparent that, for the assumptions made, the reduction in the cost of salt applied is less than the extra cost of the pre-wetted salting vehicles and the cost of the saturators and their installation.

The sum of the discounted benefits is £14378.1 million over a 30 year period. The sum of the discounted direct and indirect costs is £1637.8 million for dry salting and £1354.5 million for pre-wetted salting. Therefore, when the effect of vehicle corrosion, and structural and environmental damage are included, the total discounted cost is £293.3 million lower for pre-wetted salting than for dry salting.

Table 4-1 Benefit-cost analysis for dry and pre-wetted salting in £million

Parameter (total over 30 years)	Dry salting (£ million)	Pre-wetted salting (£ million)
Undiscounted direct costs	517.9	532.5
Discounted direct costs	350.0	362.9
Undiscounted indirect costs	2030.7	1563.6
Discounted indirect costs	1288.5	992.2
Undiscounted benefits	22674.3	22674.3
Discounted benefits	14387.4	14387.4
Discounted direct and indirect costs	1638.5	1355.1
Benefit-cost ratio	8.78	10.62

The differences in the total discounted costs mean that the BCR is significantly higher for pre-wetted salting than for dry salting, being 10.62 as compared to 8.78. Therefore, for every £1 spent on winter maintenance, the saving is £1.84 higher for pre-wetted salting than for dry salting.

4.2 Comparison of dry and pre-wetted salting

Table 4-2 gives the results of sensitivity analyses that show how the WLC and BCR vary with a number of parameter values. The influence of the parameters and their significance for dry and pre-wetted salting can be determined by comparing different rows in the table. When making the comparisons, the effect of the differences in the costs for dry and pre-wetted salting and changes in costs should be considered rather more than the absolute costs.

Rows 1 and 2 correspond to the cases considered in Table 4-1. When compared with Rows 1 and 2, Rows 3 and 4 show the effect of an increase in the number of salting vehicles, Rows 5 and 6 show the effect of the absolute cost of the vehicles, and Rows 7 and 8 show the effect of the amount of salt applied. It has been assumed that the indirect costs and the benefits are proportional to the amount of salt applied. For example, these parameters were chosen to be 20 per cent higher for Rows 7 and 8 than for Rows 1 to 6. In this way, it is possible to assess how the BCR may vary from one part of the country to another where different weather conditions dictate the amount of salt that must be applied.

Rows 1, 9 and 10 show the effect of the cost of salt on dry salting.

Rows 2, 11 and 12 show that the effect of the difference in the cost of dry and pre-wetted salting vehicles and the cost of the saturator is small.

Rows 1 and 13 show the effect of the service life of dry salting vehicles, and Rows 2, 14 and 15 show the effect of the service life of pre-wetted salting vehicles.

Rows 16 and 17 compare dry and pre-wetted salting for a scenario which is highly favourable for dry salting. The differences in the cost and service life of dry and pre-wetted vehicles are high. The difference in the cost of dry and pre-wetted salt is low and the amount of salt used is low.

Rows 18 and 19 compare dry and pre-wetted salting for a scenario which is highly favourable for pre-wetted salting. The differences in the cost and service life of dry and pre-wetted vehicles are low. The difference in the cost of dry and pre-wetted salt is high and the amount of salt used is also high.

Row 20 shows that the effect of the installation cost of the saturator is small.

It is possible that pre-wetted salt compositions may be used other than the 70:30 dry salt to brine mixture, with a brine concentration of 23.5 per cent, assumed thus far. Table 4-3 shows the cost of pre-wetted salt per tonne and the BCR for a number of different mixtures and brine concentrations. Calculations are shown for pre-wetted salt from the two sources described in Section 3.1.1. One pre-wetted salt is manufactured from two types of salt, one for the dry salt and another for the brine. The other is manufactured from one salt.

The indirect costs have been calculated assuming that they are proportional to the salt content of the pre-wetted salt. Although this is not proven, it has been assumed that the pre-wetted salt, whatever its composition, is as effective as the same amount of dry salt. On this basis, the same benefits have been assumed for all compositions.

Table 4-3 shows that the source of the pre-wetted salt has little effect on the BCR. The BCR increases as the brine concentration and the proportion of dry salt decreases. If the brine concentration is reduced but the proportion of dry salt is increased to maintain the salt content, the BCR increases very little if the pre-wetted salt is manufactured from two types of salt. Of course, there is no increase in the BCR if the salt is manufactured from one type of salt.

Table 4-2 Whole-life cost and BCR for different parameter values

Parameter						Whole life cost (£m)	Benefit-cost ratio
Ref. no.	No. of vehicles (type)	Cost of vehicle (£) (service life (years))	Cost of saturator (£) (Initial setup costs (£))	Quantity of salt (dry salt equivalent in tonnes)	Cost of salt (£)		
1	550 (dry)	108,000 (15)	-	500,000	23.0	350.0	8.78
2	*550 (wet)*	*116,000 (12)*	*25,000 (5,000)*	*500,000*	*20.5*	*362.9*	*10.62*
3	650 (dry)	108,000 (15)	-	500,000	23.0	373.8	8.65
4	*650 (wet)*	*116,000 (12)*	*25,000 (5,000)*	*500,000*	*20.5*	*391.4*	*10.40*
5	550 (dry)	78,000 (15)	-	500,000	23.0	325.2	8.92
6	*550 (wet)*	*86,000 (12)*	*25,000 (5,000)*	*500,000*	*20.5*	*333.4*	*10.85*
7	550 (dry)	108,000 (15)	-	600,000	23.0	393.8	8.90
8	*550 (wet)*	*116,000 (12)*	*25,000 (5,000)*	*600,000*	*20.5*	*402.0*	*10.84*
9	550 (dry)	108,000 (15)	-	500,000	26.0	378.5	8.63
10	550 (dry)	108,000 (15)	-	500,000	30.0	416.6	8.44
11	*550 (wet)*	*112,000 (12)*	*25,000 (5,000)*	*500,000*	*20.5*	*359.0*	*10.65*
12	*550 (wet)*	*116,000 (12)*	*15,000 (5,000)*	*500,000*	*20.5*	*360.9*	*10.63*
13	550 (dry)	108,000 (20)	-	500,000	23	335.4	8.86
14	*550 (wet)*	*116,000 (15)*	*25,000 (5,000)*	*500,000*	*20.5*	*344.3*	*10.77*
15	*550 (wet)*	*116,000 (10)*	*25,000 (5,000)*	*500,000*	*20.5*	*379.6*	*10.49*
16	550 (dry)	108,000 (20)	-	400,000	23	291.6	8.70
17	*550 (wet)*	*116,000 (10)*	*25,000 (5,000)*	*400,000*	*20.5*	*340.6*	*10.15*
18	550 (dry)	108,000 (15)	-	600,000	26	428.0	8.74
19	*550 (wet)*	*112,000 (15)*	*20,000 (5,000)*	*600,000*	*20.5*	*379.0*	*11.00*
20	*550 (wet)*	*116,000 (12)*	*25,000 (15,000)*	*500,000*	*20.5*	*364.5*	*10.61*

Table 4-3 Benefit-cost ratios for different pre-wetted salt mixtures and brine concentrations

Salt/brine mixture		Brine concentration	Salt content in10g (g)	Cost (£)			Benefit-cost ratio
				Dry salt	Brine salt	Pre-wetted salt	
80%	20%	23.5%	8.47	23	62	21.31	9.84
80%	20%	20%	8.40	23	62	20.88	9.93
80%	20%	15%	8.30	23	62	20.26	10.06
80%	20%	23.5%	8.47	26	26	22.02	9.80
80%	20%	20%	8.40	26	26	21.84	9.87
80%	20%	15%	8.30	26	26	21.58	9.97
70%	30%	23.5%	7.70	23	62	20.47	10.62
70%	30%	20%	7.60	23	62	19.82	10.77
70%	30%	15%	7.45	23	62	18.89	11.00
70%	30%	23.5%	7.70	26	26	20.03	10.65
70%	30%	20%	7.60	26	26	19.76	10.78
70%	30%	15%	7.45	26	26	19.37	10.96
71.3%	28.7%	20%	7.70	23	62	19.96	10.66
73%	27%	15%	7.70	23	62	19.30	10.71
71.3%	28.7%	20%	7.70	26	26	20.03	10.65
73%	27%	15%	7.70	26	26	20.03	10.65
60%	40%	23.5%	6.94	23	62	19.63	11.52
60%	40%	20%	6.80	23	62	18.76	11.77
60%	40%	15%	6.60	23	62	17.52	12.14
60%	40%	23.5%	6.94	26	26	18.04	11.66
60%	40%	20%	6.80	26	26	17.68	11.87
60%	40%	15%	6.60	26	26	17.16	12.18

4.3 The advantages and disadvantages of pre-wetted salting

Table 4-2 shows that the WLC (excluding indirect costs) of pre-wetted salting operations can be significantly higher than the WLC of dry salting operations under some circumstances. For example, the WLC of pre-wetted salting may be the lower only if the service lives of dry and pre-wetted salting vehicles are similar (c.f. Rows 1 and 14 of Table 4-2) or the cost of dry salt is at least about £4 per tonne higher than the cost of pre-wetted salt if 500,000 tonnes of salt is applied per annum (c.f. Rows 1, 2 and 9 of Table 4-2). The cost difference may be lower than £4 per tonne if more than 500,000 tonnes of salt is applied, the cost of saturators and their installation is lower or the difference in the cost of dry and pre-wetted vehicles is lower. For example, the difference may be nearer £3 per tonne if 600,000 tonnes of salt are applied, or £3.5 per tonne if 500,000 tonnes of salt are applied and the saturators cost £15,000 rather than £25,000. Of course, one supplier supplies dry salt costing about £5.5/tonne more than the cost of pre-wetted salt (see Section 3.1.1.3). Nevertheless, even with such a

cost difference, it is likely that the amount of salt used in some parts of the country will be too low for the WLC of pre-wetted salting to be less than the WLC of dry salting.

Even if the WLC of dry salting is lower than the WLC of pre-wetted salting, if the assumptions made above are accurate, the analyses described in this section show that there would be considerable savings to tax payers and motorists if pre-wetted salting was introduced on HA's motorway and trunk road network. For none of the cases considered in Table 4-2 and Table 4-3 is the BCR for dry salting higher than the BCR for pre-wetted salting. Clearly, HA will gain very little in financial terms from any savings in indirect costs associated with vehicle corrosion and environmental damage that are listed in Table 3-2 and from the benefits listed in Table 3-3. However, there will be significant benefits in the reduction in the cost of repairs for structural damage. Based on the data given in Appendix B (c.f. Table 4-1), these are estimated to be £4.6 million per year (Table 3-2). When these reduced savings are discounted over a 30 year period they total £87.6 million. Since structural damage occurs over a period of time, and the cost of repairs are not incurred until a considerable time after salt is applied, it could be argued that the savings from lower repair costs should not be taken into account immediately. For example, if these savings were realised only in the final 10 years of the 30 year accounting period they would total £19.9 million. This represents very much a lower bound value as there would be further savings beyond 30 years equivalent to a salvage value.

The significance of the savings due to reduced repair costs means that the total cost of pre-wetted salting to HA is likely to be less than the total cost of dry salting if the difference in the WLCs of the two options is £19.9 million (for 500,000 tonnes of salt). The worst case scenario for pre-wetted salting in Rows 16 and 17 of Table 4-2 shows a difference of £49 million. For the reduced amount of salt, the saving in repair costs would be £16 million rather than £19.9 million. Therefore, there may be circumstances when the total cost to HA of pre-wetted salting would be higher than the cost of dry salting, but the probability of all of the parameters having such values is considered to be extremely low. Therefore, in the long-term, HA are likely to benefit if pre-wetted salting is introduced, as would tax payers and motorists.

5 STRATEGY FOR INTRODUCING PRE-WETTED SALT TECHNOLOGY

5.1 Background

In the preceding section it was shown that the probability that the introduction of pre-wetted salting technology will result in savings to HA is extremely high when the savings that would arise from reduced structural repair costs are taken into account. This section considers how HA might introduce the technology.

To introduce pre-wetted salting, HA and their Agents must either replace their existing dry salting vehicles with new pre-wetted salting vehicles or retrofit them for pre-wetted salting. Furthermore, saturators must be purchased, civil works must be undertaken for their installation within a bund, and they must be connected to water and electricity supplies. It may be necessary to provide additional storage for the salt used to manufacture the brine. These acquisitions will involve an increase in capital expenditure in the short term over and above what would be required if dry salting was to continue. There will be savings in the expenditure on salt. As indicated above, whether there are any net savings when all of the direct costs are taken into account is dependent on many factors, although the amount of salt applied and the difference in the cost of dry and pre-wetted salt are the most significant.

5.2 Options for the introduction of pre-wetted salting

So that HA can determine the most cost-effective way to introduce pre-wetted salting, four options (Options 1 to 4) have been considered for its introduction for comparison with the option to continue dry salting (Option 0). The options are summarised in Table 5-1.

Options 1 and 2 require the retrofitting of existing dry salting vehicles provided the retrofitted vehicles remain operational for at least three years. Option 1 requires existing dry salting vehicles that would not remain operational for at least three years to be replaced immediately. Option 2 requires those same vehicles to be used for dry salting until the end of their service life. Both options require the installation of saturators immediately, and the introduction of pre-wetted salting as soon as the dry salting vehicles are replaced or retrofitted.

The service life of the retrofitted vehicles has been calculated on a pro-rata basis assuming rates of deterioration for periods of dry and pre-wetted salting that are proportional to the service lives of dry and pre-wetted salting vehicles. For example, it has been assumed that a dry salting vehicle with a service life of 15 years that was retrofitted when it was 10 years old would remain operational for a further 4 years if the service life of pre-wetted vehicles is 12 years.

Options 3 and 4 require the replacement of dry salting vehicles with pre-wetted salting vehicles when the dry salting vehicles have reached the end of their service life. With Option 3, the saturators would be installed as soon as the first dry salting vehicles are replaced. With Option 4, the saturators would be installed as soon as the last dry salting vehicles are replaced. For Option 4, most pre-wetted salting vehicles would be used for dry salting for several years. It has been assumed that their service life corresponds to that calculated on a pro-rata basis as for retrofitted vehicles in Options 1 and 2.

Table 5-1: Options for introducing pre-wetted salting technology

Option	Description
0	Continue to use dry salting vehicles.
1	Retrofit all dry salting vehicles that will have at least 3 years of service remaining after retrofitting NOW. Replace all other dry salt vehicles with pre-wetted salting vehicles NOW. Install saturators NOW Apply pre-wetted salt NOW
2	Retrofit all dry salting vehicles that will have at least 3 years of service remaining after retrofitting NOW. Replace all other dry salt vehicles with pre-wetted salting vehicles when dry salting vehicles have reached end of service life. Install saturators NOW. Apply pre-wetted salt when pre-wetted salting vehicles are available.
3	Replace dry salt vehicles with pre-wetted salting vehicles when dry salting vehicles have reached end of service life. Install saturators when first pre-wetted salting vehicles are purchased. Apply pre-wetted salt when pre-wetted salting vehicles are available.
4	Replace dry salt vehicles with pre-wetted salting vehicles when dry salting vehicles have reached end of service life. Service life scaled pro-rata. Install saturators when last pre-wetted salting vehicles are purchased. Apply dry salt with pre-wetted salting vehicles until saturators are installed.

Area 8 has not been included in the calculations because pre-wetted salting is already carried out in that area. It has been assumed that 518 vehicles and 144 saturators are needed to salt the remainder of HA's motorway and trunk road network. Table 5-2 shows how the existing stock of dry salting vehicles owned by HA that range from 7 to 13 years old would be replaced or retrofitted under each option assuming that the service life of pre-wetted vehicles is 12, 10 and 15 years. A further case is shown for vehicles that range from 2 to 8 years old, assuming that the service life of the pre-wetted vehicles is 12 years.

Table 5-2: Replacement of existing dry vehicles

Option	Service life of dry vehicles (years)	Service life of pre-wetted vehicles (years)	Age range of vehicles (years)	Plans for replacement of existing dry vehicles
0	15	12	7-13	Purchase 74 dry vehicles at years 2, 3, 4, 5, 6, 7 and 8
1				Retrofit 370 vehicles at year 0 Purchase 148 pre-wetted vehicles at year 0 Purchase 74 pre-wetted vehicles at years 3, 4, 5, 6 and 7
2				Retrofit 370 vehicles at year 0 Purchase 148 pre-wetted vehicles at year 3 Purchase 74 pre-wetted vehicles at years 2, 4, 5, 6 and 7
3 and 4				Purchase 74 pre-wetted vehicles at years 2, 3, 4, 5, 6, 7 and 8
0	15	10	7-13	Purchase 74 dry vehicles at years 2, 3, 4, 5, 6, 7 and 8
1				Retrofit 370 vehicles at year 0 Purchase 148 pre-wetted vehicles at years 0, 3 and 5 Purchase 74 pre-wetted vehicles at year 4
2				Retrofit 370 vehicles at year 0 Purchase 222 pre-wetted vehicles at year 3 Purchase 148 pre-wetted vehicles at year 5 Purchase 74 pre-wetted vehicles at years 2 and 4
3 and 4				Purchase 74 pre-wetted vehicles at years 2, 3, 4, 5, 6, 7 and 8
0	15	15	7-13	Purchase 74 dry vehicles at years 2, 3, 4, 5, 6, 7 and 8
1				Retrofit 444 vehicles at year 0 Purchase 74 pre-wetted vehicles at years 0, 3, 4, 5, 6, 7 and 8
2				Retrofit 444 vehicles at year 0 Purchase 74 pre-wetted vehicles at years 2, 3, 4, 5, 6, 7 and 8
3 and 4				Purchase 74 pre-wetted vehicles at years 2, 3, 4, 5, 6, 7 and 8
0	15	12	2-8	Purchase 74 dry vehicles at years 7, 8, 9, 10, 11, 12 and 13
1				Retrofit 518 vehicles at year 0 Purchase 144 pre-wetted vehicles at years 6 and 10 Purchase 74 pre-wetted vehicles at years 7, 8 and 9
3 and 4				Purchase 74 pre-wetted vehicles at years 2, 3, 4, 5, 6, 7 and 8

Note: Options 1 and 2 are identical if the age of the existing vehicles range from 2 to 8 years

5.3 Comparison of options for the introduction of pre-wetted salting

The sum of the present values (undiscounted) and the WLC (sum of the discounted present values) have been calculated for Options 0 to 4 for an accounting period of 30 years. Sensitivity analyses have been carried out to determine the effect of the most significant parameters using the parameter values listed in Table 5-3. The amount of salt that has been assumed in the calculations is the amount in the table less the amount applied in Area 8. The values that have been assumed for the other parameters are those shown in Table 3-1.

The results calculated assuming that the service lives of dry and pre-wetted salting vehicles are 15 and 12 years, respectively, are shown in Table 5-4. The results for the other parameter values listed in Table 5-3 are shown in Table C-1 to Table C-4. Figure 5.1 shows, for one set of parameter values, the present values each year that associated with (i) the purchase of vehicles and the purchase and installation of saturators, (ii) the purchase of salt, (iii) operation and maintenance costs and (iv) the savage of vehicles and the total present value each year. Figures C1 to C14 show the present values for further sets of parameter values.

Table 5-3 Parameter values assumed in sensitivity analyses

Parameter	Value
Service life of pre-wetted salting vehicles	10, 12, or 15 years
Service life of retrofitted vehicles	10, 12, or 15 years
Age range of existing dry salting vehicles	7 to 13 years or 2 to 8 years (equal numbers of each age)
Salt required for whole of HA network	300,000, 500,000 or 700,000 tonnes
Cost of dry salt	£23, £26 or £30 per tonne

Table 5-4 Whole-life cost and BCR for different parameter values

Parameter						Sum of present values (£m)	Whole life cost (£m)
Option	Service life of dry vehicles (years)	Service life of pre-wetted vehicles (years)	Quantity of salt (dry salt equivalent in tonnes)	Cost of dry salt (£)	Cost of pre-wetted salt (£)		
0	15	12	500,000	23	20.5	469.5	308.1
1	15	12	500,000	23	20.5	484.7	321.3
2	15	12	500,000	23	20.5	484.7	320.7
3	15	12	500,000	23	20.5	482.3	317.5
4	15	12	500,000	23	20.5	480.5	315.6
0	15	12	500,000	26	20.5	512.4	335.3
1	15	12	500,000	26	20.5	484.7	321.3
2	15	12	500,000	26	20.5	485.7	321.7
3	15	12	500,000	26	20.5	489.4	324.1
4	15	12	500,000	26	20.5	491.9	325.8
0	15	12	500,000	30	20.5	569.6	371.6
1	15	12	500,000	30	20.5	484.7	321.3
2	15	12	500,000	30	20.5	487.1	323.0
3	15	12	500,000	30	20.5	498.9	332.9
4	15	12	500,000	30	20.5	507.2	339.4

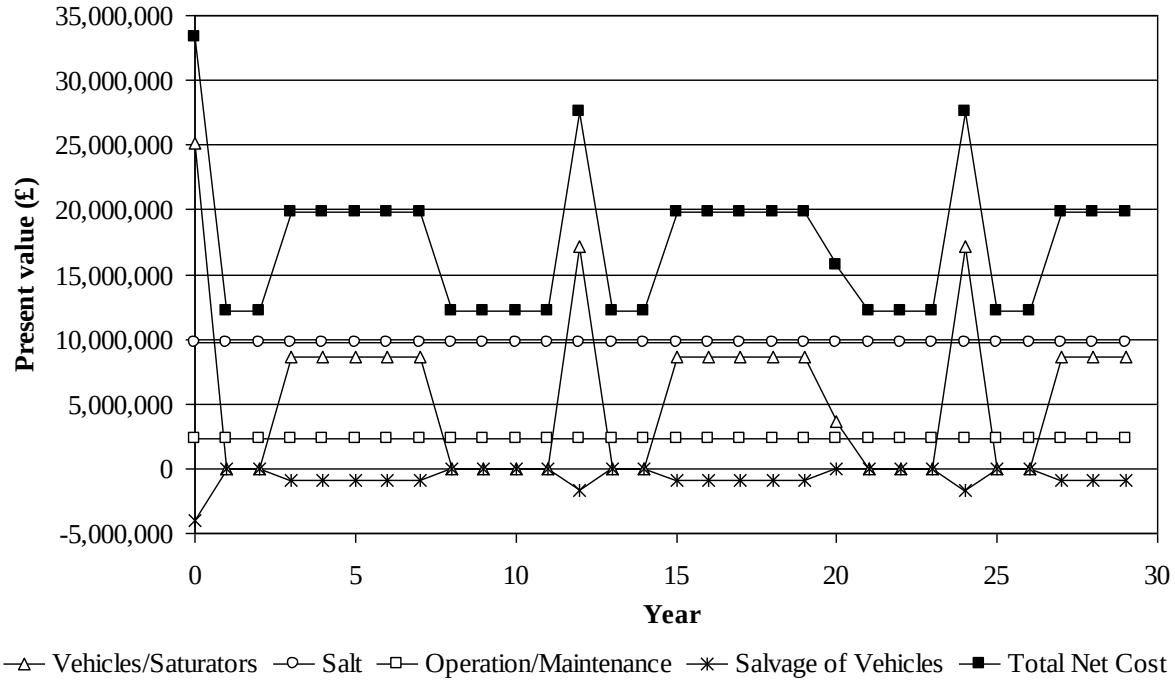

Figure 5-1 Option 1: Annual expenditure if service lives of dry and pre-wetted vehicles are 15 and 12 years, respectively, stock is aged from 7 to 13 years, dry salt is £23/tonne and salt used is 500,000 tonnes

Table 5-5 lists the first and second ranked pre-wetted options (Option 1 to 4) and the ranking of the dry salting option (Option 0) for the WLC and the sum of the present values assuming different parameter values. The lower the ranking, the lower the WLC or sum of the present values.

5.4 Factors to consider when determining the best option for HA

The analyses described above indicate when it is best to introduce pre-wetted salting technology. It is reasonable to choose the option which gives the lowest whole-life cost, although the rankings of the pre-wetted options are the same for the WLC and the sum of the present values. Table 5-5 shows that the best option varies according to the amount of salt, the cost of dry salt (i.e. the difference in the cost of dry and pre-wetted salt) and the service life of the pre-wetted salting vehicles.

If the cost of dry salt is £5.50 or more per tonne more expensive than the cost of pre-wetted salt, Option 1 is generally the pre-wetted option with the lowest WLC. The only exceptions are when only 300,000 tonnes of salt are used and the service life of the pre-wetted vehicles is 12 years or less, or when 500,000 tonnes of salt are used and service life of the pre-wetted vehicles is 10 years. Option 4 was found to be the pre-wetted option with the lowest whole-life cost in all other cases. It is interesting to note that when the service life of pre-wetted salting vehicles is 12 years, the option with the lowest WLC does not vary with the age range of the vehicles.

Whenever Option 1 is the pre-wetted option with the lowest WLC, the WLC of dry salting is the highest. Conversely, whenever Option 4 is the pre-wetted option with the lowest WLC, the WLC of dry salting is the lowest. These facts, and the results presented in Table 4-2, indicate that it is beneficial to introduce pre-wetted salting technology only if the amount of salt used and/or the difference in the cost of dry and pre-wetted salt are sufficiently high to offset the increased costs associated with the salting vehicles and the saturators. When this is not the case, the WLC is lower for dry salting or for the pre-wetted options which delay the introduction of pre-wetted salting as much as possible. However, as shown in the previous section , it must be re-iterated that the benefits of pre-wetted salting as a whole outweigh the sum of the direct and indirect costs for all reasonable scenarios.

Table 5-5 Ranking of options

Parameter				Top ranked pre-wetted option[1]	Second ranked pre-wetted option	Ranking of dry salting
Service life of pre-wetted vehicles (years)	Quantity of salt (dry salt equivalent in tonnes)	Cost of dry salt (£)	Age range of vehicles(years)			
12	500,000	23	7 to 13	4 (4)	3 (3)	1 (1)
12	500,000	26	7 to 13	1 (1)	2 (2)	5 (5)
12	500,000	30	7 to 13	1 (1)	2 (2)	5 (5)
12	700,000	23	7 to 13	4 (4)	3 (3)	1 (1)
12	700,000	26	7 to 13	1 (1)	2 (2)	5 (5)
12	700,000	30	7 to 13	1 (1)	2 (2)	5 (5)
12	300,000	23	7 to 13	4 (4)	3 (3)	1 (1)
12	300,000	26	7 to 13	4 (4)	3 (3)	1 (1)
12	300,000	30	7 to 13	1 (1)	2 (2)	5 (5)
10	500,000	23	7 to 13	4 (4)	3 (3)	1 (1)
10	500,000	26	7 to 13	4 (4)	3 (3)	1 (4=)
10	500,000	30	7 to 13	1 (1)	2 (2)	5 (5)
10	700,000	23	7 to 13	4 (4)	3 (3)	1 (1)
10	700,000	26	7 to 13	1 (1)	2 (2)	5 (5)
10	700,000	30	7 to 13	1 (1)	2 (2)	5 (5)
10	300,000	23	7 to 13	4 (4)	3 (3)	1 (1)
10	300,000	26	7 to 13	4 (4)	3 (3)	1 (1)
10	300,000	30	7 to 13	3/4 (1/3/4)	3/4 (1/3/4)	1 (5)
15	500,000	23	7 to 13	1 (1)	2/3/4 (2)	5 (5)
15	500,000	26	7 to 13	1 (1)	2 (2)	5 (5)
15	500,000	30	7 to 13	1 (1)	2 (2)	5 (5)
15	700,000	23	7 to 13	1 (1)	2 (2)	5 (5)
15	700,000	26	7 to 13	1 (1)	2 (2)	5 (5)
15	700,000	30	7 to 13	1 (1)	2 (2)	5 (5)
15	300,000	23	7 to 13	4 (4)	3 (3)	1 (1)
15	300,000	26	7 to 13	1 (1)	2 (2)	5 (5)
15	300,000	30	7 to 13	1 (1)	2 (2)	5 (5)
12	500,000	23	2 to 8	4 (4)	3 (3)	1 (1)
12	500,000	26	2 to 8	1 (1)	3 (3)	5 (5)
12	500,000	30	2 to 8	1 (1)	3 (3)	5 (5)
12	700,000	23	2 to 8	4 (4)	3 (3)	1 (2)
12	700,000	26	2 to 8	1 (1)	3 (3)	5 (5)
12	700,000	30	2 to 8	1 (1)	3 (3)	5 (5)
12	300,000	23	2 to 8	4 (4)	3 (3)	1 (1)
12	300,000	26	2 to 8	4 (4)	3 (3)	1 (1)
12	300,000	30	2 to 8	1 (1)	3 (3)	5 (5)

[1] Rankings are based on WLC, with ranking based on sum of present values in parenthesis

Another factor that will influence the decision as to when pre-wetted salting should be introduced is the annual expenditure required to make the change. Figure 5-1 shows that Option 1, that introduces the change quickly, requires considerable expenditure in the first year (year 0). In Appendix C, Figures C1 to C14 show that other options require a steadier increase in expenditure, and they may be preferred if the difference in the WLC of the options in question is small.

The results described above apply to the whole of HA's motorway and trunk road network apart from Area 8. As the amount of salt used differs from one Area to another, the option giving the lowest WLC may differ in these Areas. It may be preferable to retain dry salting in Areas where relatively

little salt is used. So that the appropriate decisions can be made, Appendix D describes a method for calculating the WLC for Options 0 to 4 for parameter values that are specific to an Area. Worked examples are included.

6 CONCLUSIONS

Benefit-cost analyses and whole-life cost analyses have been carried out to determine whether and how pre-wetted salting technology should be introduced on the HA motorway and trunk road network. It was found that:

1. The benefit-cost ratios for dry and pre-wetted salting, based on best estimates of the parameters concerned, are 8.78 and 10.62, respectively. Therefore, for every pound spent on dry and pre-wetted salting, there are cost savings of £8.78 and £10.62, respectively.
2. Sensitivity analyses have shown that the benefit-cost ratio is higher for pre-wetted salting than dry salting for parameter values that cover the credible range. Therefore, the probability that the benefit-cost ratio will be higher for pre-wetted salting than dry salting is high. On this basis, pre-wetted salting technology should be introduced by HA, although HA may not benefit from the introduction of pre-wetted salting in the same way as the wider community.
3. The whole-life cost of pre-wetted salting operations can be higher than that of dry salting operations. This is when the amount of salt used is low and/or the difference in the cost of dry and pre-wetted salt is low such that the extra cost of pre-wetted salting vehicles and the cost of saturators and their installation are not offset by the reduction in the cost of the salt.
4. Because pre-wetted salting should cause less structural damage than dry salting, the overall difference in the cost of dry and pre-wetted salting to HA should take into account the reduction in the cost of structural repairs. However, the reduction may not be realised until some time after pre-wetted salting has been introduced.
5. The whole-life cost of dry salting and four options for the introduction of pre-wetted salting technology have been calculated for the existing stock of HA salting vehicles. The option with the lowest whole-life cost varies according to the amount of salt used and difference in the cost of dry and pre-wetted salt. If pre-wetted salting is introduced immediately, a large investment is required in the first year. Therefore, a more gradual introduction may be preferred.
6. A methodology has been developed so that the best option for the introduction of pre-wetted salting can be determined for different Areas that have different numbers of vehicles and saturators and use different amounts of salt.

7 ACKNOWLEDGEMENTS

The authors would like to thank John Wainwright of HA, local authorities, salting vehicle suppliers and salt suppliers who provided data for this study.

The authors wish to thank Morteza Zohrabi for his contribution to the strategy and data analysis described in the report.

8 REFERENCES

BRENNER R and MOSHMAN (1976). *Benefits and Costs in the use of salt to de-ice highways. Institute for Safety Analysis (TISA), 140p,* 1976.

CSRB *(2002) Northern Ireland Transport Statistics 2001-2002. Compiled and produced by Central Statistics and Research Brach, Department for Regional Development. Belfast NI.* 2002

DfT (2001) *Transport Statistics Bulletin, Road Traffic Statistics: 2001, produced by Transport Statistics: DfT, London,* 2001.

FRASER G and DREW J (1998). *Route selection and salt management in Northern Ireland. Proc. Xth PIARC Winter Road Congress, Vol. 1 pp. 41-52.* 1998.

HANBALI RM (1994). *The economic impact of winter road maintenance on users. Transportation Research Record, 1442.* 1994.

HIRD A, WALKER R, ZOHRABI M, HILLIER PT, BURTWELL MH and BRADBURY T (1999). *A review of the use of pre-wetted salt for highway de-icing. TRL Unpublished Report PR/IS/19/99 Draft Issue 2, Project Record No. 3/261. TRL, Crowthorne, UK.* 1999.

LANG HJ and MERINO DN (1993). *The selection process for capital projects. Published by A Wiley-Interscience Publication, John Wiley & Sons INC. New York.* 1993. *pp 191-195.*

NAO (2003) *Maintaining England's Motorway's and Trunk Road. Report by the Comptroller and Auditor General of National Audit Office. Stationery Office, London.* March 2003.

SNELL M (1997). *Cost-benefit analysis for engineers and planners. Published by Thomas Telford Publication, London.* 1997.

THORNES JE (1996). *The cost benefit of winter road maintenance in the UK. Proc. of the 8th International Road Weather Conference, The University of Birmingham.* 1996.

TILLY G (1995). *The implications of whole-life costing. Proceedings of Concrete Bridge Development Group seminar on Whole-life costing. TRL, Crowthorne, UK.* 1995.

Appendix A. Derivation of Indirect Costs and Benefits

A.1 Estimation of vehicle corrosion costs on trunk roads

Vehicle Corrosion Cost for UK (£M) =	£150.00
Source	Thornes, 1996, NI Transport Statistics 2001-2002, TSB Road Traffic Statistic: 2001
Assumption	Vehicle corrosion cost is proportional to vehicle stock & vehicle-km

Country	**Vehicle Stock x10^3 (1999)**	**%**	**Veh. Corrosion Cost (£M)**
England	24782	85%	127.8
Wales	2179	7%	11.2
Scotland	1407	5%	7.3
Northern Ireland	721	2%	3.7
	29089	100%	150.0
Country	**Billion Veh. Km (1999)**	**%**	
England	404.9	79%	
Wales	25.6	5%	
Scotland	43.1	8%	
Northern Ireland	36	7%	
	509.6	100%	
England/Authorities	**Traffic Volume Billion Veh. Km**	**%**	**Veh. Corrosion Cost (£M)**
Highways Agency	150.30	37%	47.4
Local Authorities & Others	254.70	63%	80.4
	405		127.8

Vehicle Corrosion Cost, £M = £47.44

A.2 Estimation of structural corrosion costs on trunk roads

HA spends about £700 million each year on the maintenance of pavements and structures on their network. COST (2004) includes estimates of the cost of the maintenance, repair and renewal of bridges in terms of the total replacement cost of the bridges on the HA network. The total replacement cost of the bridges was estimated to be €22.4 billion (£14.9 billion). One per cent of this total, i.e. £149 million, was estimated to be the cost of their maintenance, repair and renewal. There are further costs for culverts, retaining wall and tunnels, but these are small compared to those for bridges. Some maintenance of structures is for strengthening to cater for increased vehicle weights, and some repair and renewal is because of deterioration due to factors that are not attributable to corrosion caused by de-icing salts. Therefore, taking these factors into account, it is estimated that the annual cost of repairing structural damage caused by de-icing salt is £20 million.

A.3 Estimation of environmental damage costs on trunk roads

Vegetation, Soil & Water contamination

Cost:UK (£M) = £10.00

Source Thornes, 1996

Assumption Environment cost is proportional to total length of the network

Country	**Length of Roads (1999)**	**%**	**Environment Cost (£M)**
England	299954	72%	7.190
Wales	32995	8%	0.79
Scotland	59458	14%	1.43
Northern Ireland	24750	6%	0.59
	417157	100%	10
England/Authorities	**Length of Roads (1999)**	**%**	**Environment Cost (£M)**
Highways Agency	10258.0	3.4%	0.246
Local Authorities & Others	289697.0	96.6%	6.945
	299955.0		7.190

Environmental Cost, £M = £0.25

A.4 Estimation of benefits from reduced traffic accidents, traffic delays, disruption to emergency services and fuel savings

Road Accident Cost UK (£M): £630.00
Road Traffic Delay Cost UK (£M): £1,500.00

Source: Transport Statistics Great Britain, Road Traffic Statistic: 2001

Assumption: Costs are proportional to the vehicle stock and vehicle-km

Country	Vehicle Stock x10^3 (1999)	%	Traffic Accident Cost (£M)	Traffic Delay Cost (£M)	Traffic Emergency Cost (£M)	Fuel Economy Cost (£M)
England	24782	85%	536.7	1277.9	204.5	17.0
Wales	2179	7%	47.2	112.4	18.0	1.5
Scotland	1407	5%	30.5	72.6	11.6	1.0
Northern Ireland	721	2%	15.6	37.2	5.9	0.5
	29089	100%	630	1500	240	20

Country	Traffic Volume Bn Veh. Km	%
England	405	79%
Wales	26	5%
Scotland	43	8%
Northern Ireland	36	7%
	510	100%

England/Authorities	Traffic Volume Bn Veh. Km	%	Traffic Accident Cost (£M)	Traffic Delay Cost (£M)	Traffic Emergency Cost (£M)	Fuel Economy Cost (£M)
Highways Agency	150	37%	199.2	474.4	75.9	6.3
Local Authorities & Others	255	63%	337.6	803.9	128.6	10.7
	405		536.9	1278.2	204.5	17.0

Road Accident Cost HA (£M): **£199.23**

Road Traffic Delay Cost HA (£M): **£474.36**

Emergency Cost HA (£M): **£75.90**

Fuel Economy Cost HA (£M): **£6.32**

A.5 References

COST (2004). *COST 345: Procedures required for assessing highway structures: Working Group 1 Report on the current stock of highway structures in European countries, the cost of their replacement and the annual costs of maintaining, repairing and renewing them. TRL, Crowthorne, UK.* 2004.

Appendix B. Output from benefit-cost model

Table B-1 and Table B-2 show the direct costs of dry and pre-wetted salting, respectively, over a 30-year accounting period, based on the data shown in Table 3-1 that are not in parenthesis. It has been assumed that vehicles are purchased at the start of this period.

Table B-3 and Table B-4 show the indirect costs and benefits of dry and pre-wetted salting, respectively, based on the data shown in Table 3-2 and Table 3-3. Table B-5 is the key to Table B-3 and Table B-4.

Table B-1 Benefit-cost analysis: whole life cost of dry salting in £million (direct costs only)

Year	Initial cost			Operation and maintenance			Salvage			Undis-counted costs	Discount factors	Dis-counted costs
	Set up	Sat'tor	Veh's	Sat'tor	Veh's	Salt	Set up	Sat'tor	Veh's			
0	0.00	0.00	59.40	0.00	2.20	11.50				73.10	1.000	73.10
1				0.00	2.20	11.50				13.70	0.966	13.24
2				0.00	2.20	11.50				13.70	0.934	12.79
3				0.00	2.20	11.50				13.70	0.902	12.36
4				0.00	2.20	11.50				13.70	0.871	11.94
5				0.00	2.20	11.50				13.70	0.842	11.54
6				0.00	2.20	11.50				13.70	0.814	11.14
7				0.00	2.20	11.50				13.70	0.786	10.77
8				0.00	2.20	11.50				13.70	0.759	10.40
9				0.00	2.20	11.50				13.70	0.734	10.05
10				0.00	2.20	11.50				13.70	0.709	9.71
11				0.00	2.20	11.50				13.70	0.685	9.38
12				0.00	2.20	11.50				13.70	0.662	9.07
13				0.00	2.20	11.50				13.70	0.639	8.76
14				0.00	2.20	11.50				13.70	0.618	8.46
15			59.40	0.00	2.20	11.50			5.94	67.16	0.597	40.09
16				0.00	2.20	11.50				13.70	0.577	7.90
17				0.00	2.20	11.50				13.70	0.557	7.63
18				0.00	2.20	11.50				13.70	0.538	7.38
19				0.00	2.20	11.50				13.70	0.520	7.13
20				0.00	2.20	11.50				13.70	0.503	6.89
21				0.00	2.20	11.50				13.70	0.486	6.65
22				0.00	2.20	11.50				13.70	0.469	6.43
23				0.00	2.20	11.50				13.70	0.453	6.21
24				0.00	2.20	11.50				13.70	0.438	6.00
25				0.00	2.20	11.50				13.70	0.423	5.80
26				0.00	2.20	11.50				13.70	0.409	5.60
27				0.00	2.20	11.50				13.70	0.395	5.41
28				0.00	2.20	11.50				13.70	0.382	5.23
29				0.00	2.20	11.50				13.70	0.369	5.05
30									5.94	-5.94	0.356	-2.12
									Total	**517.92**		**349.98**

Table B-2 Benefit-cost analysis: whole life cost of pre-wetted salting in £million (direct costs only)

Year	Initial cost			Operation and maintenance			Salvage			Undis-counted costs	Discount factors	Dis-counted costs
	Set up	Sat'tor	Veh's	Sat'tor	Veh's	Salt	Set up	Sat'tor	Veh's			
0	0.76	3.78	63.80	0.30	2.20	10.25				81.08	1.000	81.08
1				0.30	2.20	10.25				12.75	0.966	12.32
2				0.30	2.20	10.25				12.75	0.934	11.90
3				0.30	2.20	10.25				12.75	0.902	11.50
4				0.30	2.20	10.25				12.75	0.871	11.11
5				0.30	2.20	10.25				12.75	0.842	10.74
6				0.30	2.20	10.25				12.75	0.814	10.37
7				0.30	2.20	10.25				12.75	0.786	10.02
8				0.30	2.20	10.25				12.75	0.759	9.68
9				0.30	2.20	10.25				12.75	0.734	9.36
10				0.30	2.20	10.25				12.75	0.709	9.04
11				0.30	2.20	10.25				12.75	0.685	8.73
12			63.80	0.30	2.20	10.25			6.38	70.17	0.662	46.44
13				0.30	2.20	10.25				12.75	0.639	8.15
14				0.30	2.20	10.25				12.75	0.618	7.88
15				0.30	2.20	10.25				12.75	0.597	7.61
16				0.30	2.20	10.25				12.75	0.577	7.35
17				0.30	2.20	10.25				12.75	0.557	7.11
18				0.30	2.20	10.25				12.75	0.538	6.87
19				0.30	2.20	10.25				12.75	0.520	6.63
20		3.78		0.30	2.20	10.25				16.53	0.503	8.31
21				0.30	2.20	10.25				12.75	0.486	6.19
22				0.30	2.20	10.25				12.75	0.469	5.98
23				0.30	2.20	10.25				12.75	0.453	5.78
24			63.80	0.30	2.20	10.25			6.38	70.17	0.438	30.73
25				0.30	2.20	10.25				12.75	0.423	5.40
26				0.30	2.20	10.25				12.75	0.409	5.21
27				0.30	2.20	10.25				12.75	0.395	5.04
28				0.30	2.20	10.25				12.75	0.382	4.87
29				0.30	2.20	10.25				12.75	0.369	4.70
30								1.89	35.09	-36.98	0.356	-13.17
									Total	**532.53**		**362.94**

Table B-3 Benefit-cost analysis: benefits, costs, benefit-cost ratio for dry salting in £million

Year	Benefits				Direct costs	Indirect costs		Undis-counted Benefits	Undis-counted Costs	Discount factors	Dis-counted benefits	Dis-counted costs
	RTAcc	RTDC	EMRs	Fuel Ecmy		Veh. Cor.	Struct. Env.					
0	199.23	474.36	75.90	6.32	73.10	47.44	20.25	755.81	140.79	1.000	755.81	140.79
1	199.23	474.36	75.90	6.32	13.70	47.44	20.25	755.81	81.39	0.966	730.25	78.64
2	199.23	474.36	75.90	6.32	13.70	47.44	20.25	755.81	81.39	0.934	705.56	75.98
3	199.23	474.36	75.90	6.32	13.70	47.44	20.25	755.81	81.39	0.902	681.70	73.41
4	199.23	474.36	75.90	6.32	13.70	47.44	20.25	755.81	81.39	0.871	658.64	70.93
5	199.23	474.36	75.90	6.32	13.70	47.44	20.25	755.81	81.39	0.842	636.37	68.53
6	199.23	474.36	75.90	6.32	13.70	47.44	20.25	755.81	81.39	0.814	614.85	66.21
7	199.23	474.36	75.90	6.32	13.70	47.44	20.25	755.81	81.39	0.786	594.06	63.97
8	199.23	474.36	75.90	6.32	13.70	47.44	20.25	755.81	81.39	0.759	573.97	61.81
9	199.23	474.36	75.90	6.32	13.70	47.44	20.25	755.81	81.39	0.734	554.56	59.72
10	199.23	474.36	75.90	6.32	13.70	47.44	20.25	755.81	81.39	0.709	535.81	57.70
11	199.23	474.36	75.90	6.32	13.70	47.44	20.25	755.81	81.39	0.685	517.69	55.75
12	199.23	474.36	75.90	6.32	13.70	47.44	20.25	755.81	81.39	0.662	500.18	53.86
13	199.23	474.36	75.90	6.32	13.70	47.44	20.25	755.81	81.39	0.639	483.27	52.04
14	199.23	474.36	75.90	6.32	13.70	47.44	20.25	755.81	81.39	0.618	466.93	50.28
15	199.23	474.36	75.90	6.32	67.16	47.44	20.25	755.81	134.85	0.597	451.14	80.49
16	199.23	474.36	75.90	6.32	13.70	47.44	20.25	755.81	81.39	0.577	435.88	46.94
17	199.23	474.36	75.90	6.32	13.70	47.44	20.25	755.81	81.39	0.557	421.14	45.35
18	199.23	474.36	75.90	6.32	13.70	47.44	20.25	755.81	81.39	0.538	406.90	43.82
19	199.23	474.36	75.90	6.32	13.70	47.44	20.25	755.81	81.39	0.520	393.14	42.34
20	199.23	474.36	75.90	6.32	13.70	47.44	20.25	755.81	81.39	0.503	379.84	40.90
21	199.23	474.36	75.90	6.32	13.70	47.44	20.25	755.81	81.39	0.486	367.00	39.52
22	199.23	474.36	75.90	6.32	13.70	47.44	20.25	755.81	81.39	0.469	354.59	38.18
23	199.23	474.36	75.90	6.32	13.70	47.44	20.25	755.81	81.39	0.453	342.60	36.89
24	199.23	474.36	75.90	6.32	13.70	47.44	20.25	755.81	81.39	0.438	331.01	35.65
25	199.23	474.36	75.90	6.32	13.70	47.44	20.25	755.81	81.39	0.423	319.82	34.44
26	199.23	474.36	75.90	6.32	13.70	47.44	20.25	755.81	81.39	0.409	309.00	33.28
27	199.23	474.36	75.90	6.32	13.70	47.44	20.25	755.81	81.39	0.395	298.55	32.15
28	199.23	474.36	75.90	6.32	13.70	47.44	20.25	755.81	81.39	0.382	288.46	31.06
29	199.23	474.36	75.90	6.32	13.70	47.44	20.25	755.81	81.39	0.369	278.70	30.01
30					-5.94			0.00	-5.94	0.356	0.00	-2.12
											Discounted benefits = 14387.4	
											Discounted costs = 1638.5	
											BCR = 8.78	

Table B-4 Benefit-cost analysis: benefits, costs, benefit-cost ratio for pre-wetted salting in £million

Year	Benefits				Direct costs	Indirect costs		Undis-counted Benefits	Undis-counted Costs	Discount factors	Dis-counted benefits	Dis-counted costs
	RTAcc	RTDC	EMRs	Fuel Ecmy		Veh. Cor.	Struct. Env.					
0	199.23	474.36	75.90	6.32	81.08	36.53	15.59	755.81	133.20	1.000	755.81	133.20
1	199.23	474.36	75.90	6.32	12.75	36.53	15.59	755.81	64.87	0.966	730.25	62.68
2	199.23	474.36	75.90	6.32	12.75	36.53	15.59	755.81	64.87	0.934	705.56	60.56
3	199.23	474.36	75.90	6.32	12.75	36.53	15.59	755.81	64.87	0.902	681.70	58.51
4	199.23	474.36	75.90	6.32	12.75	36.53	15.59	755.81	64.87	0.871	658.64	56.53
5	199.23	474.36	75.90	6.32	12.75	36.53	15.59	755.81	64.87	0.842	636.37	54.62
6	199.23	474.36	75.90	6.32	12.75	36.53	15.59	755.81	64.87	0.814	614.85	52.77
7	199.23	474.36	75.90	6.32	12.75	36.53	15.59	755.81	64.87	0.786	594.06	50.99
8	199.23	474.36	75.90	6.32	12.75	36.53	15.59	755.81	64.87	0.759	573.97	49.27
9	199.23	474.36	75.90	6.32	12.75	36.53	15.59	755.81	64.87	0.734	554.56	47.60
10	199.23	474.36	75.90	6.32	12.75	36.53	15.59	755.81	64.87	0.709	535.81	45.99
11	199.23	474.36	75.90	6.32	12.75	36.53	15.59	755.81	64.87	0.685	517.69	44.43
12	199.23	474.36	75.90	6.32	70.17	36.53	15.59	755.81	122.29	0.662	500.18	80.93
13	199.23	474.36	75.90	6.32	12.75	36.53	15.59	755.81	64.87	0.639	483.27	41.48
14	199.23	474.36	75.90	6.32	12.75	36.53	15.59	755.81	64.87	0.618	466.93	40.08
15	199.23	474.36	75.90	6.32	12.75	36.53	15.59	755.81	64.87	0.597	451.14	38.72
16	199.23	474.36	75.90	6.32	12.75	36.53	15.59	755.81	64.87	0.577	435.88	37.41
17	199.23	474.36	75.90	6.32	12.75	36.53	15.59	755.81	64.87	0.557	421.14	36.15
18	199.23	474.36	75.90	6.32	12.75	36.53	15.59	755.81	64.87	0.538	406.90	34.93
19	199.23	474.36	75.90	6.32	12.75	36.53	15.59	755.81	64.87	0.520	393.14	33.74
20	199.23	474.36	75.90	6.32	16.53	36.53	15.59	755.81	68.65	0.503	379.84	34.50
21	199.23	474.36	75.90	6.32	12.75	36.53	15.59	755.81	64.87	0.486	367.00	31.50
22	199.23	474.36	75.90	6.32	12.75	36.53	15.59	755.81	64.87	0.469	354.59	30.44
23	199.23	474.36	75.90	6.32	12.75	36.53	15.59	755.81	64.87	0.453	342.60	29.41
24	199.23	474.36	75.90	6.32	70.17	36.53	15.59	755.81	122.29	0.438	331.01	53.56
25	199.23	474.36	75.90	6.32	12.75	36.53	15.59	755.81	64.87	0.423	319.82	27.45
26	199.23	474.36	75.90	6.32	12.75	36.53	15.59	755.81	64.87	0.409	309.00	26.52
27	199.23	474.36	75.90	6.32	12.75	36.53	15.59	755.81	64.87	0.395	298.55	25.63
28	199.23	474.36	75.90	6.32	12.75	36.53	15.59	755.81	64.87	0.382	288.46	24.76
29	199.23	474.36	75.90	6.32	12.75	36.53	15.59	755.81	64.87	0.369	278.70	23.92
30					-36.98			0.00	-36.98	0.356	0.00	-13.17
											Discounted benefits = 14378.1	
											Discounted costs = 1355.1	
											BCR = 10.62	

Table B-5 Key to Table B-1 to Table B-4

Abbreviation	Description
Ver. Cor.	Vehicle corrosion cost
Struct.	Structural damage to bridges, retaining walls, etc.
Env.	Environmental damage to vegetation, soil, water courses etc.
RTAcc	Road traffic accident
RTDC	Road traffic delay cost
EMRs	Emergency rescues
Fuel Ecmy	Fuel economy

Appendix C. Whole-life costs and sum of present values for Options 0 to 4 for the parameter values shown in Table 5.3

Table C-1 Whole-life cost and BCR for different parameter values: existing vehicles 7-13 years

Parameter						Sum of present values (£m)	Whole life cost (£m)
Option	Service life of dry vehicles (years)	Service life of pre-wetted vehicles (years)	Quantity of salt (dry salt equivalent in tonnes)	Cost of dry salt (£)	Cost of pre-wetted salt (£)		
0	15	12	500,000	23	20.5	469.5	308.1
1	15	12	500,000	23	20.5	484.7	321.3
2	15	12	500,000	23	20.5	484.7	320.7
3	15	12	500,000	23	20.5	482.3	317.5
4	15	12	500,000	23	20.5	480.5	315.6
0	15	12	500,000	26	20.5	512.4	335.3
1	15	12	500,000	26	20.5	484.7	321.3
2	15	12	500,000	26	20.5	485.7	321.7
3	15	12	500,000	26	20.5	489.4	324.1
4	15	12	500,000	26	20.5	491.9	325.8
0	15	12	500,000	30	20.5	569.6	371.6
1	15	12	500,000	30	20.5	484.7	321.3
2	15	12	500,000	30	20.5	487.1	323.0
3	15	12	500,000	30	20.5	498.9	332.9
4	15	12	500,000	30	20.5	507.2	339.4
0	15	12	700,000	23	20.5	601.1	391.6
1	15	12	700,000	23	20.5	602.0	395.7
2	15	12	700,000	23	20.5	602.3	395.5
3	15	12	700,000	23	20.5	601.9	394.2
4	15	12	700,000	23	20.5	601.6	393.5
0	15	12	700,000	26	20.5	661.2	429.7
1	15	12	700,000	26	20.5	602.0	395.7
2	15	12	700,000	26	20.5	603.8	396.9
3	15	12	700,000	26	20.5	612.0	403.4
4	15	12	700,000	26	20.5	617.6	407.7
0	15	12	700,000	30	20.5	741.3	480.6
1	15	12	700,000	30	20.5	602.0	395.7
2	15	12	700,000	30	20.5	605.7	398.7
3	15	12	700,000	30	20.5	625.3	415.7
4	15	12	700,000	30	20.5	638.9	426.7
0	15	12	300,000	23	20.5	337.9	224.6
1	15	12	300,000	23	20.5	367.4	246.9
2	15	12	300,000	23	20.5	367.0	245.9
3	15	12	300,000	23	20.5	362.6	240.9
4	15	12	300,000	23	20.5	359.3	237.8
0	15	12	300,000	26	20.5	363.6	240.9
1	15	12	300,000	26	20.5	367.4	246.9
2	15	12	300,000	26	20.5	367.7	246.5
3	15	12	300,000	26	20.5	366.9	244.9
4	15	12	300,000	26	20.5	366.2	243.9
0	15	12	300,000	30	20.5	398.0	262.7
1	15	12	300,000	30	20.5	367.4	246.9
2	15	12	300,000	30	20.5	368.5	247.3
3	15	12	300,000	30	20.5	372.6	250.2
4	15	12	300,000	30	20.5	375.4	252.1

Table C-2 Whole-life cost and BCR for different parameter values: existing vehicles 7-13 years

Parameter						Sum of present values (£m)	Whole life cost (£m)
Option	Service life of dry vehicles (years)	Service life of pre-wetted vehicles (years)	Quantity of salt (dry salt equivalent in tonnes)	Cost of dry salt (£)	Cost of pre-wetted salt (£)		
0	15	10	500,000	23	20.5	469.5	308.1
1	15	10	500,000	23	20.5	512.4	338.9
2	15	10	500,000	23	20.5	511.9	338.1
3	15	10	500,000	23	20.5	504.8	330.4
4	15	10	500,000	23	20.5	500.2	326.6
0	15	10	500,000	26	20.5	512.4	335.3
1	15	10	500,000	26	20.5	512.4	338.9
2	15	10	500,000	26	20.5	513.1	339.3
3	15	10	500,000	26	20.5	511.9	337.0
4	15	10	500,000	26	20.5	511.6	336.7
0	15	10	500,000	30	20.5	569.6	371.6
1	15	10	500,000	30	20.5	512.4	338.9
2	15	10	500,000	30	20.5	514.7	340.9
3	15	10	500,000	30	20.5	521.5	345.8
4	15	10	500,000	30	20.5	526.9	350.3
0	15	10	700,000	23	20.5	601.1	391.6
1	15	10	700,000	23	20.5	629.6	413.3
2	15	10	700,000	23	20.5	629.6	413.0
3	15	10	700,000	23	20.5	624.5	407.0
4	15	10	700,000	23	20.5	621.3	404.4
0	15	10	700,000	26	20.5	661.2	429.7
1	15	10	700,000	26	20.5	629.6	413.3
2	15	10	700,000	26	20.5	631.3	414.6
3	15	10	700,000	26	20.5	634.5	416.3
4	15	10	700,000	26	20.5	637.3	418.6
0	15	10	700,000	30	20.5	741.3	480.6
1	15	10	700,000	30	20.5	629.6	413.3
2	15	10	700,000	30	20.5	633.6	416.9
3	15	10	700,000	30	20.5	647.8	428.6
4	15	10	700,000	30	20.5	658.6	437.6
0	15	10	300,000	23	20.5	337.9	224.6
1	15	10	300,000	23	20.5	395.1	264.5
2	15	10	300,000	23	20.5	394.2	263.3
3	15	10	300,000	23	20.5	385.1	253.8
4	15	10	300,000	23	20.5	379.0	248.7
0	15	10	300,000	26	20.5	363.6	240.9
1	15	10	300,000	26	20.5	395.1	264.5
2	15	10	300,000	26	20.5	394.9	264.0
3	15	10	300,000	26	20.5	389.4	257.7
4	15	10	300,000	26	20.5	385.9	254.9
0	15	10	300,000	30	20.5	398.0	262.7
1	15	10	300,000	30	20.5	395.1	264.5
2	15	10	300,000	30	20.5	395.9	265.0
3	15	10	300,000	30	20.5	395.1	263.0
4	15	10	300,000	30	20.5	395.1	263.0

Table C-3 Whole-life cost and BCR for different parameter values: existing vehicles 7-13 years

Parameter						Sum of present values (£m)	Whole life cost (£m)
Option	Service life of dry vehicles (years)	Service life of pre-wetted vehicles (years)	Quantity of salt (dry salt equivalent in tonnes)	Cost of dry salt (£)	Cost of pre-wetted salt (£)		
0	15	15	500,000	23	20.5	469.5	308.1
1	15	15	500,000	23	20.5	458.9	305.5
2	15	15	500,000	23	20.5	459.1	305.6
3	15	15	500,000	23	20.5	459.7	305.6
4	15	15	500,000	23	20.5	460.5	305.6
0	15	15	500,000	26	20.5	512.4	335.3
1	15	15	500,000	26	20.5	458.9	305.5
2	15	15	500,000	26	20.5	459.5	306.0
3	15	15	500,000	26	20.5	466.9	312.2
4	15	15	500,000	26	20.5	471.9	315.8
0	15	15	500,000	30	20.5	569.6	371.6
1	15	15	500,000	30	20.5	458.9	305.5
2	15	15	500,000	30	20.5	460.1	306.6
3	15	15	500,000	30	20.5	476.4	321.0
4	15	15	500,000	30	20.5	487.2	329.3
0	15	15	700,000	23	20.5	601.1	391.6
1	15	15	700,000	23	20.5	576.2	380.0
2	15	15	700,000	23	20.5	576.6	380.2
3	15	15	700,000	23	20.5	579.4	382.2
4	15	15	700,000	23	20.5	581.6	383.4
0	15	15	700,000	26	20.5	661.2	429.7
1	15	15	700,000	26	20.5	576.2	380.0
2	15	15	700,000	26	20.5	577.1	380.8
3	15	15	700,000	26	20.5	589.4	391.4
4	15	15	700,000	26	20.5	597.6	397.7
0	15	15	700,000	30	20.5	741.3	480.6
1	15	15	700,000	30	20.5	576.2	380.0
2	15	15	700,000	30	20.5	577.9	381.5
3	15	15	700,000	30	20.5	602.8	403.7
4	15	15	700,000	30	20.5	619.0	416.7
0	15	15	300,000	23	20.5	337.9	224.6
1	15	15	300,000	23	20.5	341.6	231.1
2	15	15	300,000	23	20.5	341.7	231.1
3	15	15	300,000	23	20.5	340.0	228.9
4	15	15	300,000	23	20.5	339.4	227.8
0	15	15	300,000	26	20.5	363.6	240.9
1	15	15	300,000	26	20.5	341.6	231.1
2	15	15	300,000	26	20.5	341.9	231.3
3	15	15	300,000	26	20.5	344.3	232.9
4	15	15	300,000	26	20.5	346.2	233.9
0	15	15	300,000	30	20.5	398.0	262.7
1	15	15	300,000	30	20.5	341.6	231.1
2	15	15	300,000	30	20.5	342.3	231.6
3	15	15	300,000	30	20.5	350.1	238.2
4	15	15	300,000	30	20.5	355.4	242.0

Table C-4 Whole-life cost and BCR for different parameter values: existing vehicles 2-8 years

Parameter						Sum of present values (£m)	Whole life cost (£m)
Option	Service life of dry vehicles (years)	Service life of pre-wetted vehicles (years)	Quantity of salt (dry salt equivalent in tonnes)	Cost of dry salt (£)	Cost of pre-wetted salt (£)		
0	15	12	500,000	23	20.5	452.7	291.4
1	15	12	500,000	23	20.5	468.5	304.7
3	15	12	500,000	23	20.5	463.3	298.7
4	15	12	500,000	23	20.5	460.3	296.8
0	15	12	500,000	26	20.5	495.6	318.6
1	15	12	500,000	26	20.5	468.5	304.7
3	15	12	500,000	26	20.5	477.7	310.9
4	15	12	500,000	26	20.5	478.8	312.0
0	15	12	500,000	30	20.5	552.8	354.9
1	15	12	500,000	30	20.5	468.5	304.7
3	15	12	500,000	30	20.5	496.7	327.3
4	15	12	500,000	30	20.5	503.6	332.4
0	15	12	700,000	23	20.5	584.3	374.9
1	15	12	700,000	23	20.5	585.8	379.1
3	15	12	700,000	23	20.5	585.4	377.2
4	15	12	700,000	23	20.5	583.7	376.3
0	15	12	700,000	26	20.5	644.4	413.0
1	15	12	700,000	26	20.5	585.8	379.1
3	15	12	700,000	26	20.5	605.4	394.3
4	15	12	700,000	26	20.5	609.8	397.7
0	15	12	700,000	30	20.5	724.5	463.8
1	15	12	700,000	30	20.5	585.8	379.1
3	15	12	700,000	30	20.5	632.1	417.2
4	15	12	700,000	30	20.5	644.5	426.1
0	15	12	300,000	23	20.5	321.1	207.9
1	15	12	300,000	23	20.5	351.2	230.2
3	15	12	300,000	23	20.5	341.3	220.2
4	15	12	300,000	23	20.5	336.8	217.3
0	15	12	300,000	26	20.5	346.9	224.2
1	15	12	300,000	26	20.5	351.2	230.2
3	15	12	300,000	26	20.5	349.9	227.5
4	15	12	300,000	26	20.5	347.9	226.4
0	15	12	300,000	30	20.5	381.2	246.0
1	15	12	300,000	30	20.5	351.2	230.2
3	15	12	300,000	30	20.5	361.3	237.3
4	15	12	300,000	30	20.5	362.8	238.6

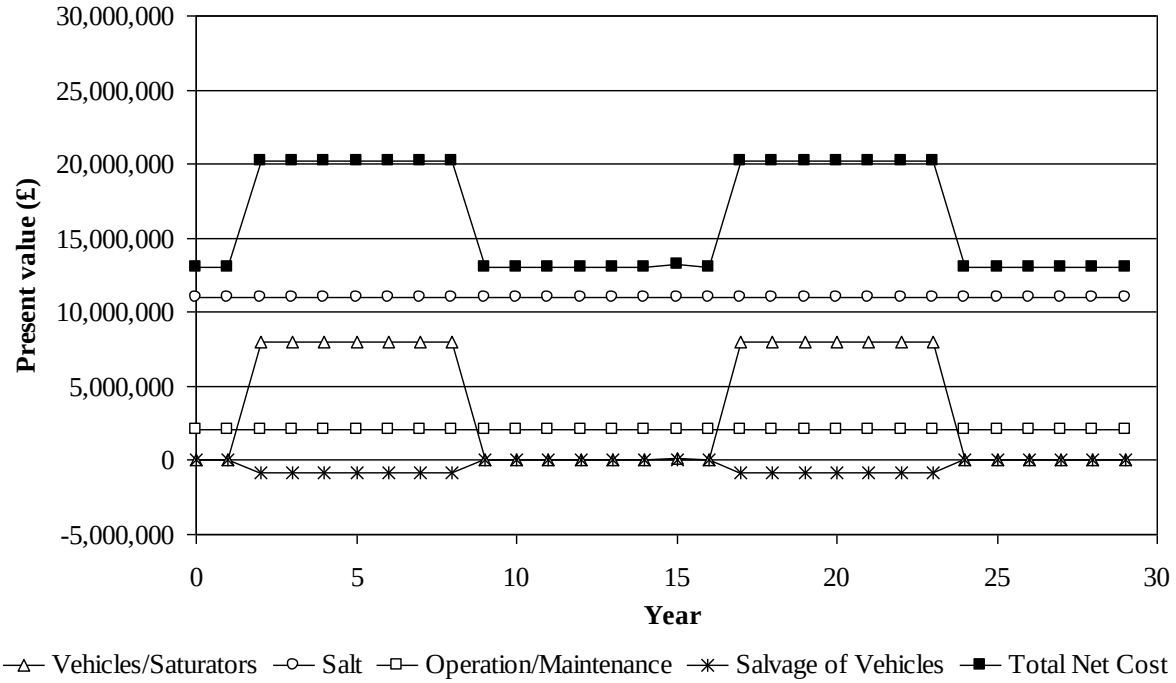

Figure C-1 Option 0: Annual expenditure if service lives of dry and pre-wetted vehicles are 15 and 12 years, respectively, stock is aged from 7 to 13 years, dry salt is £23/tonne and salt used is 500,000 tonnes

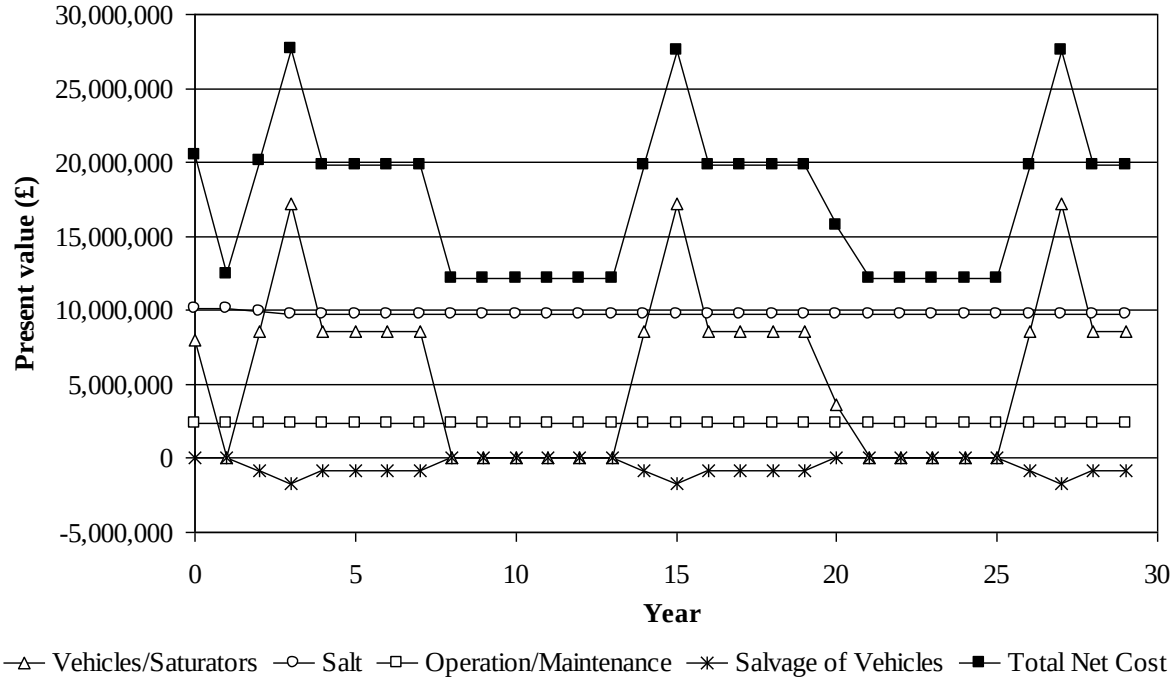

Figure C-2 Option 2: Annual expenditure if service lives of dry and pre-wetted vehicles are 15 and 12 years, respectively, stock is aged from 7 to 13 years, dry salt is £23/tonne and salt used is 500,000 tonnes

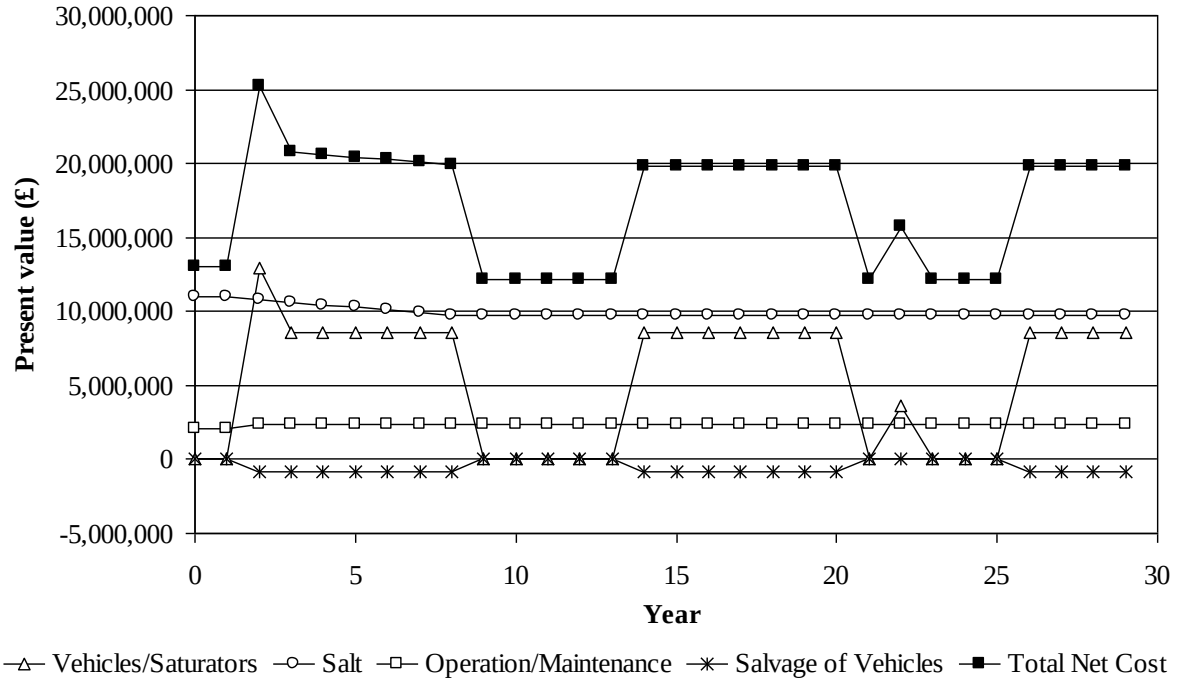

Figure C-3 Option 3: Annual expenditure if service lives of dry and pre-wetted vehicles are 15 and 12 years, respectively, stock is aged from 7 to 13 years, dry salt is £23/tonne and salt used is 500,000 tonnes

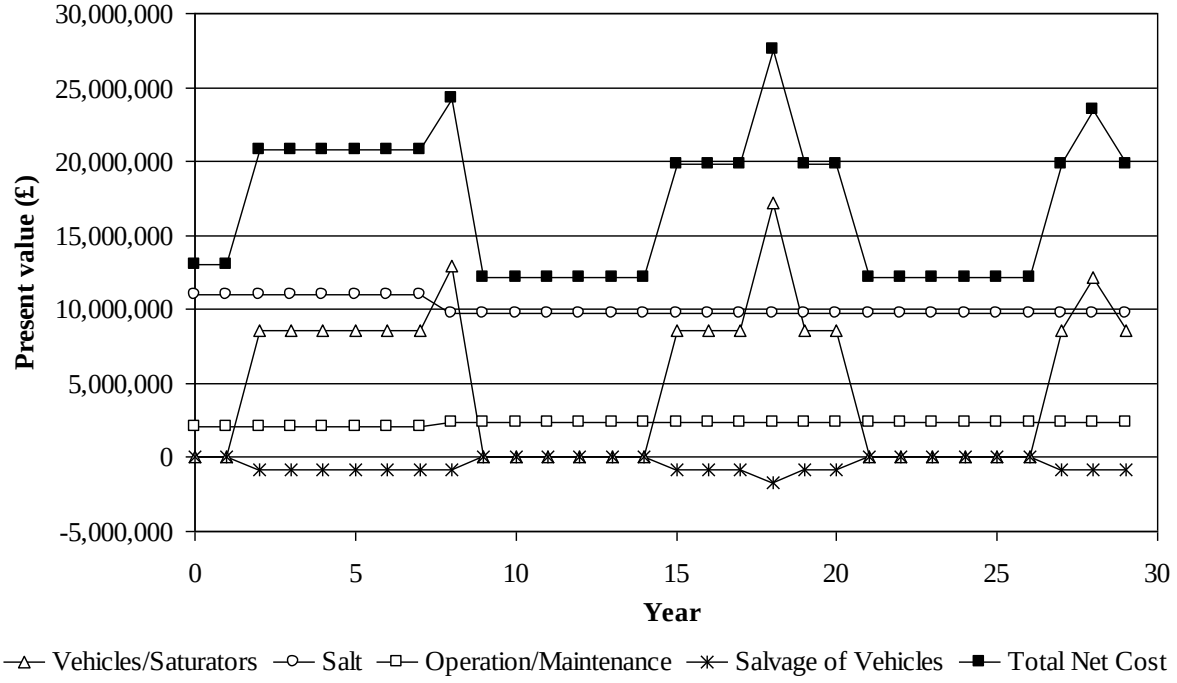

Figure C-4 Option 4: Annual expenditure if service lives of dry and pre-wetted vehicles are 15 and 12 years, respectively, stock is aged from 7 to 13 years, dry salt is £23/tonne and salt used is 500,000 tonnes

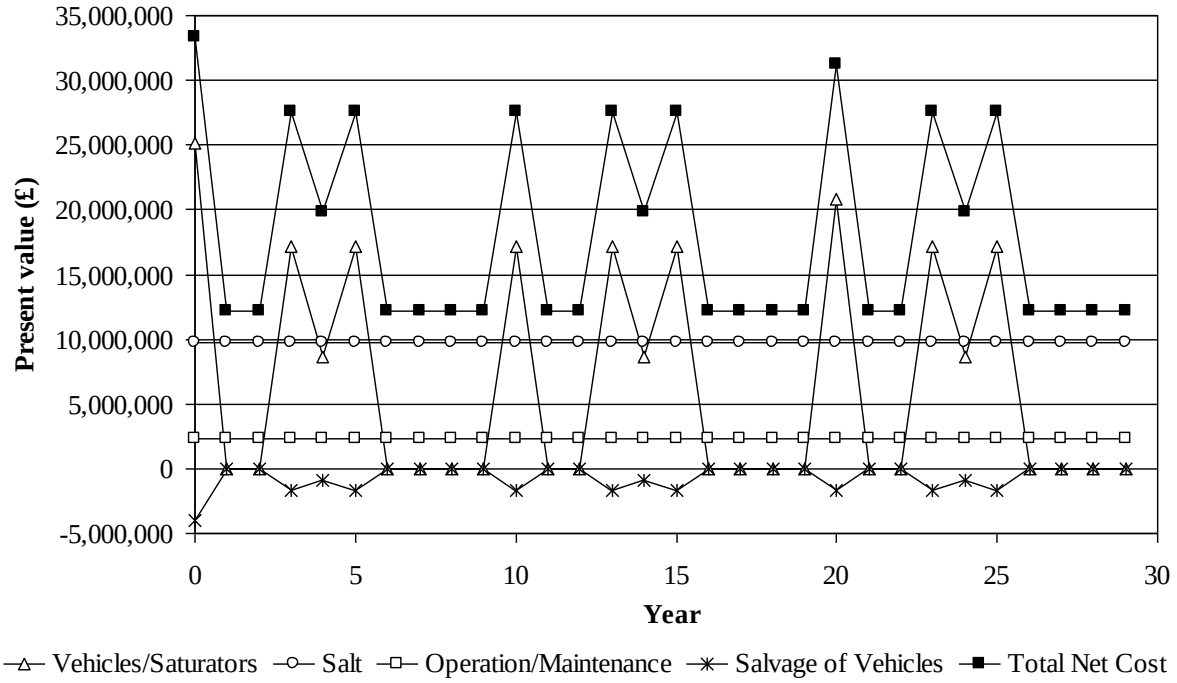

Figure C-5 Option 1: Annual expenditure if service lives of dry and pre-wetted vehicles are 15 and 10 years, respectively, stock is aged from 7 to 13 years, dry salt is £23/tonne and salt used is 500,000 tonnes

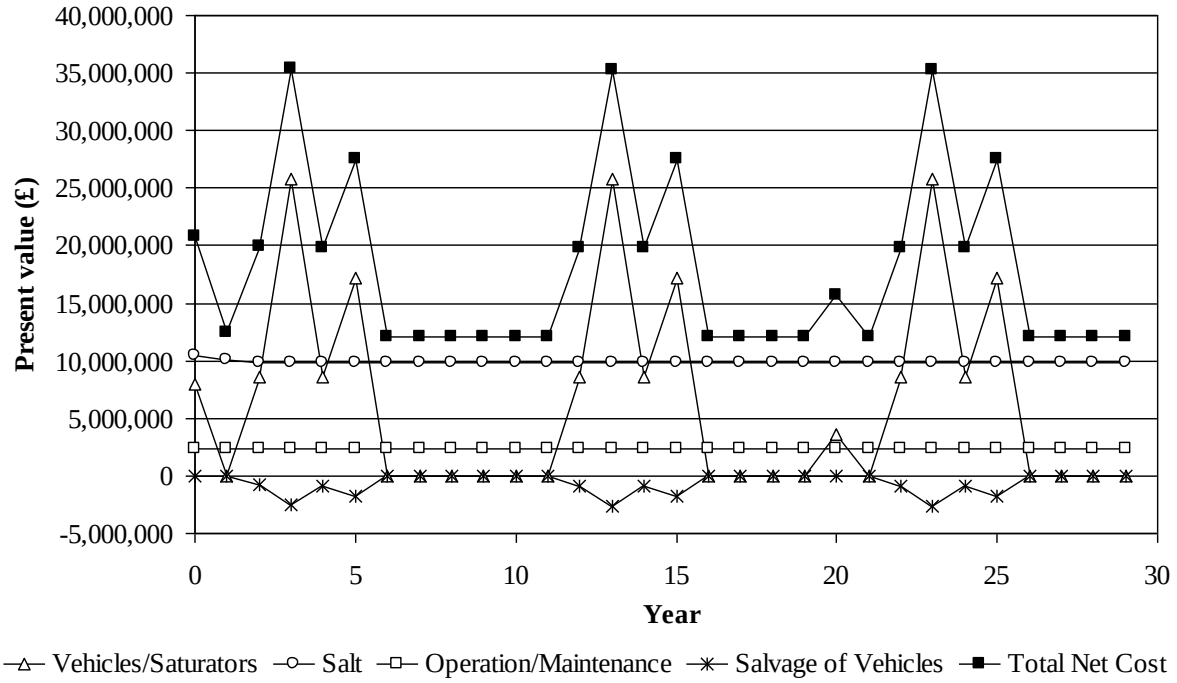

Figure C-6 Option 2: Annual expenditure if service lives of dry and pre-wetted vehicles are 15 and 10 years, respectively, stock is aged from 7 to 13 years, dry salt is £23/tonne and salt used is 500,000 tonnes

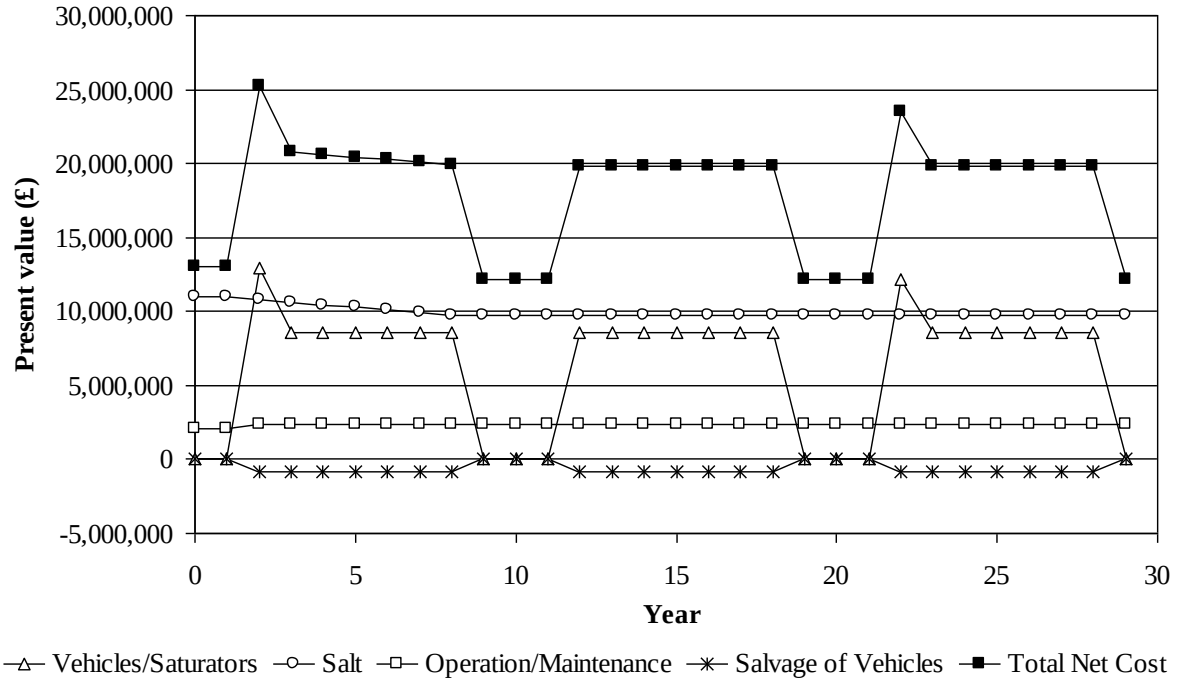

Figure C-7 Option 3: Annual expenditure if service lives of dry and pre-wetted vehicles are 15 and 10 years, respectively, stock is aged from 7 to 13 years, dry salt is £23/tonne and salt used is 500,000 tonnes

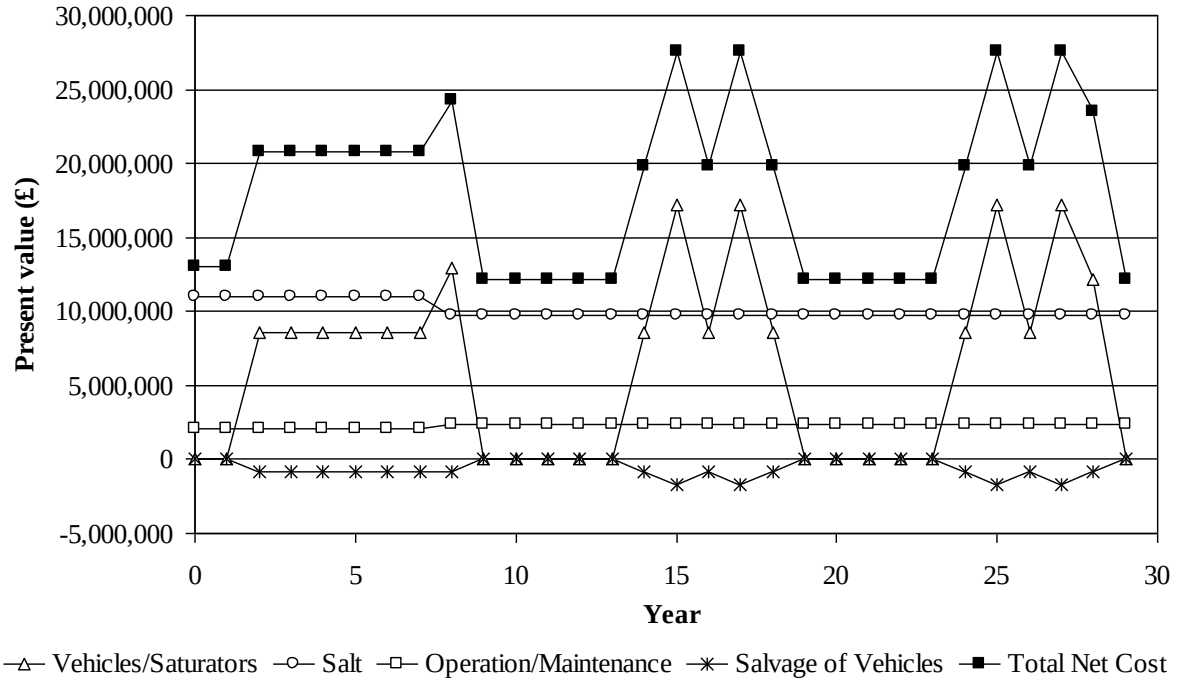

Figure C-8 Option 4: Annual expenditure if service lives of dry and pre-wetted vehicles are 15 and 10 years, respectively, stock is aged from 7 to 13 years, dry salt is £23/tonne and salt used is 500,000 tonnes

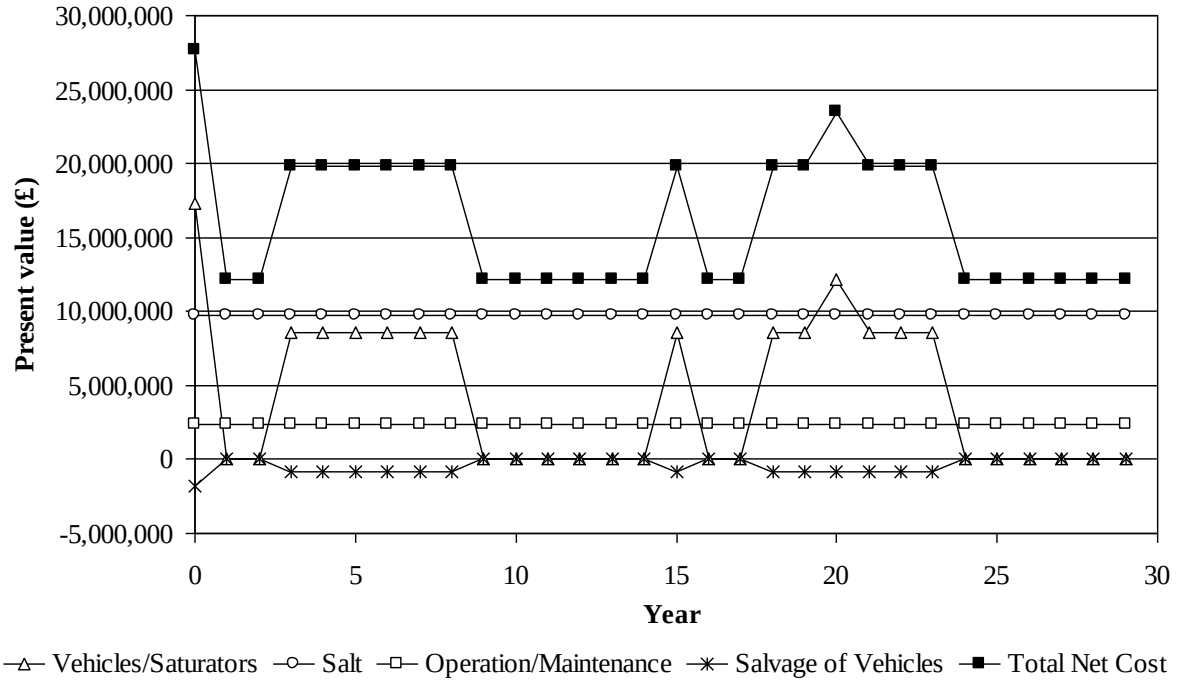

Figure C-9 Option 1: Annual expenditure if service lives of dry and pre-wetted vehicles are 15 years, stock is aged from 7 to 13 years, dry salt is £23/tonne and salt used is 500,000 tonnes

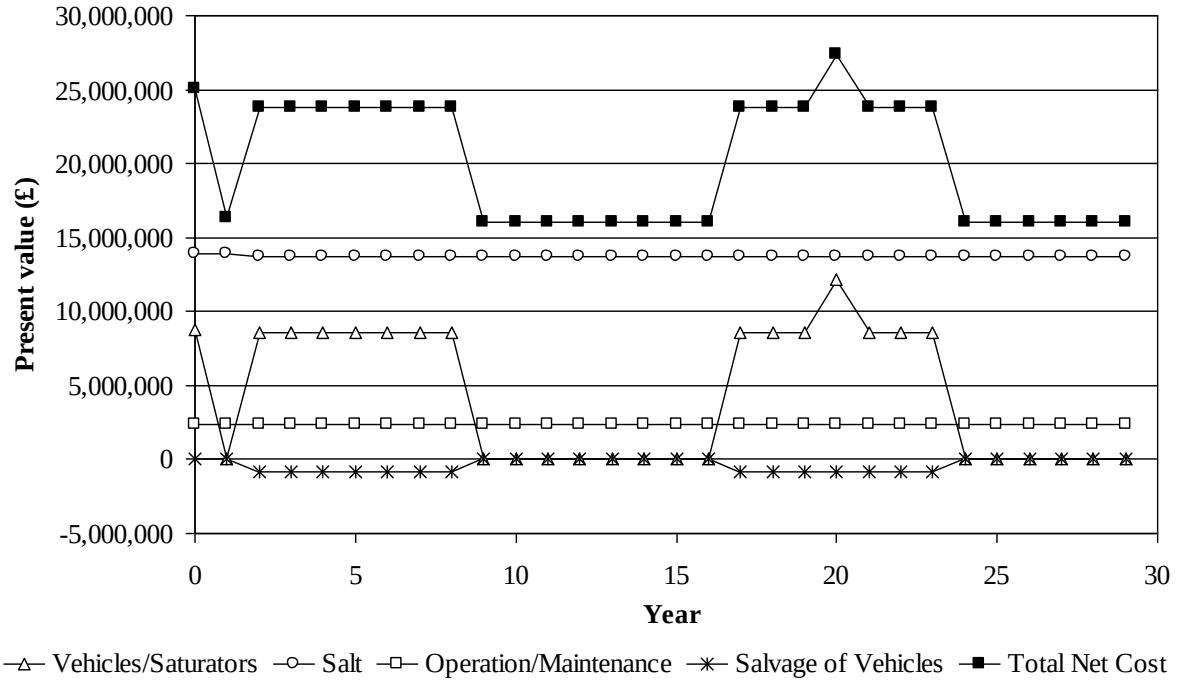

Figure C-10 Option 2: Annual expenditure if service lives of dry and pre-wetted vehicles are 15 years, stock is aged from 7 to 13 years, dry salt is £23/tonne and salt used is 500,000 tonnes

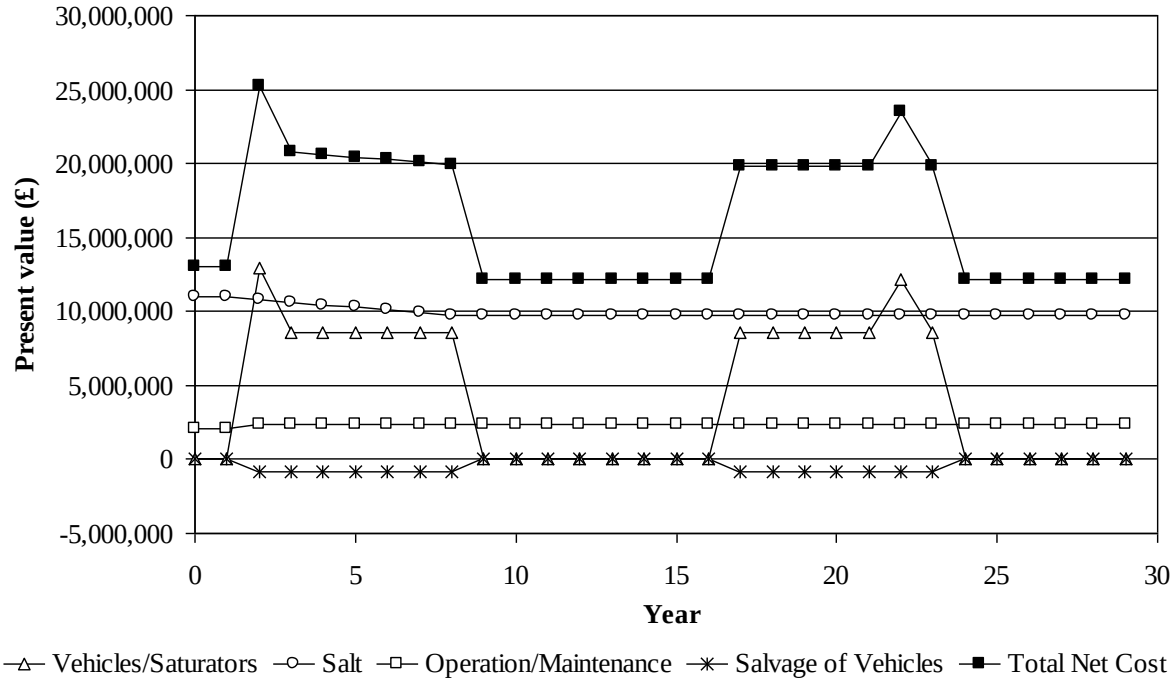

Figure C-11 Option 3: Annual expenditure if service lives of dry and pre-wetted vehicles are 15 years, stock is aged from 7 to 13 years, dry salt is £23/tonne and salt used is 500,000 tonnes

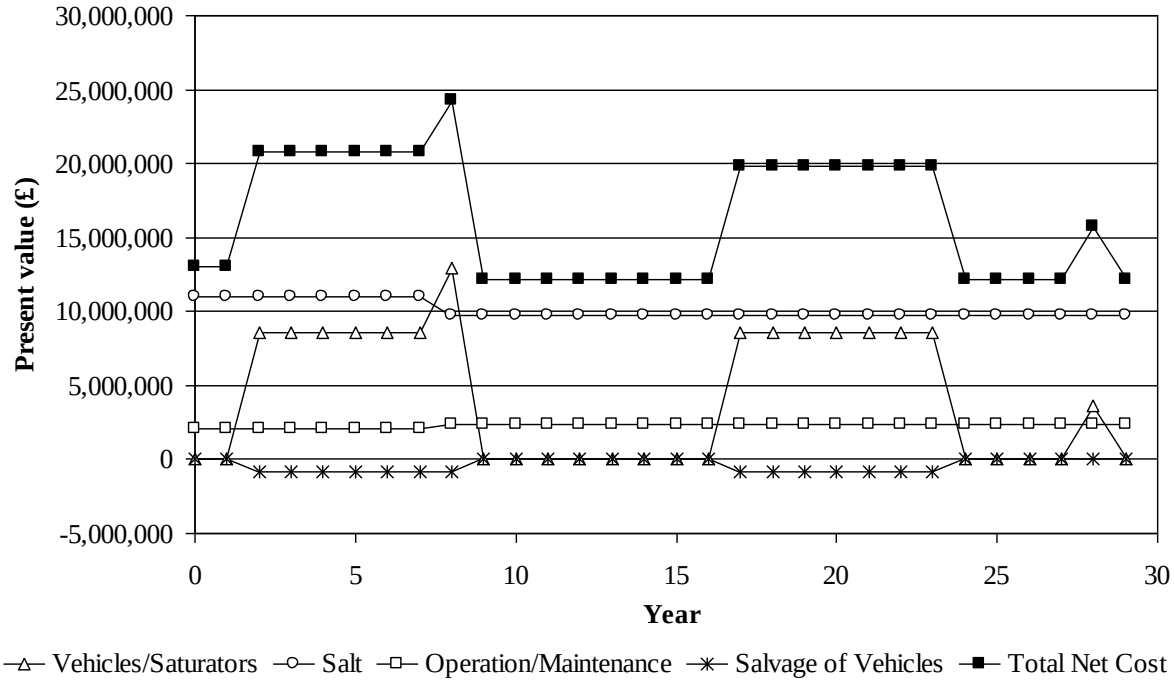

Figure C-12 Option 4: Annual expenditure if service lives of dry and pre-wetted vehicles are 15 years, stock is aged from 7 to 13 years, dry salt is £23/tonne and salt used is 500,000 tonnes

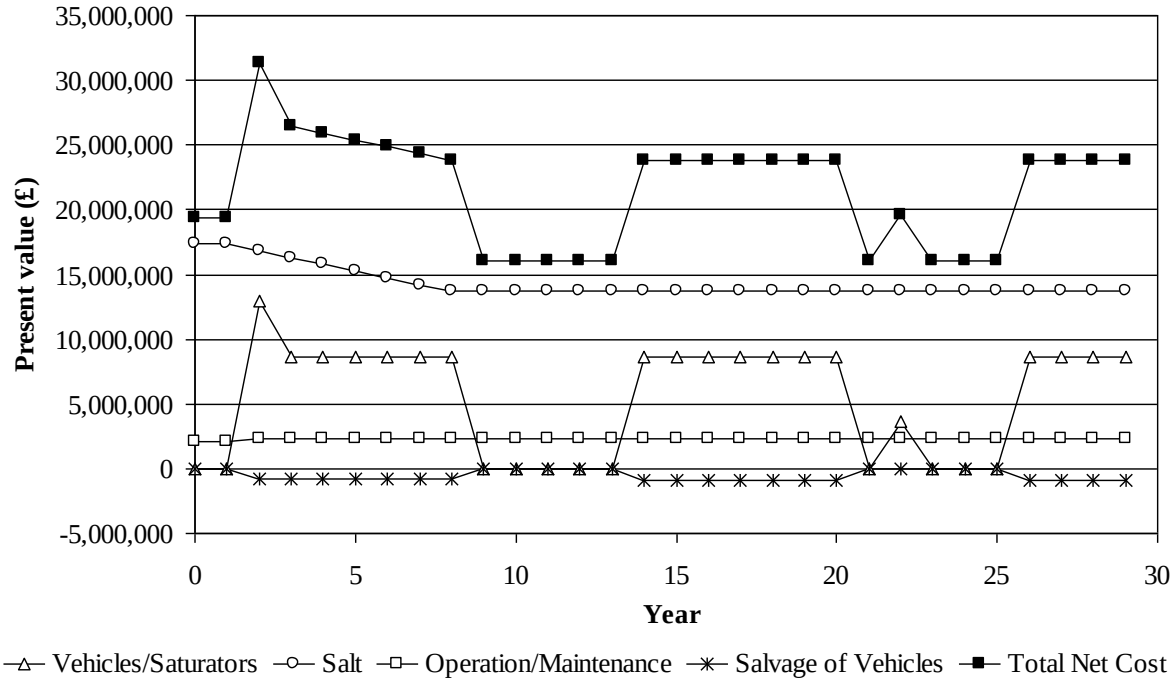

Figure C-13 Option 3: Annual expenditure if service lives of dry and pre-wetted vehicles are 15 and 12 years, respectively, stock is aged from 7 to 13 years, dry salt is £26/tonne and salt used is 700,000 tonnes

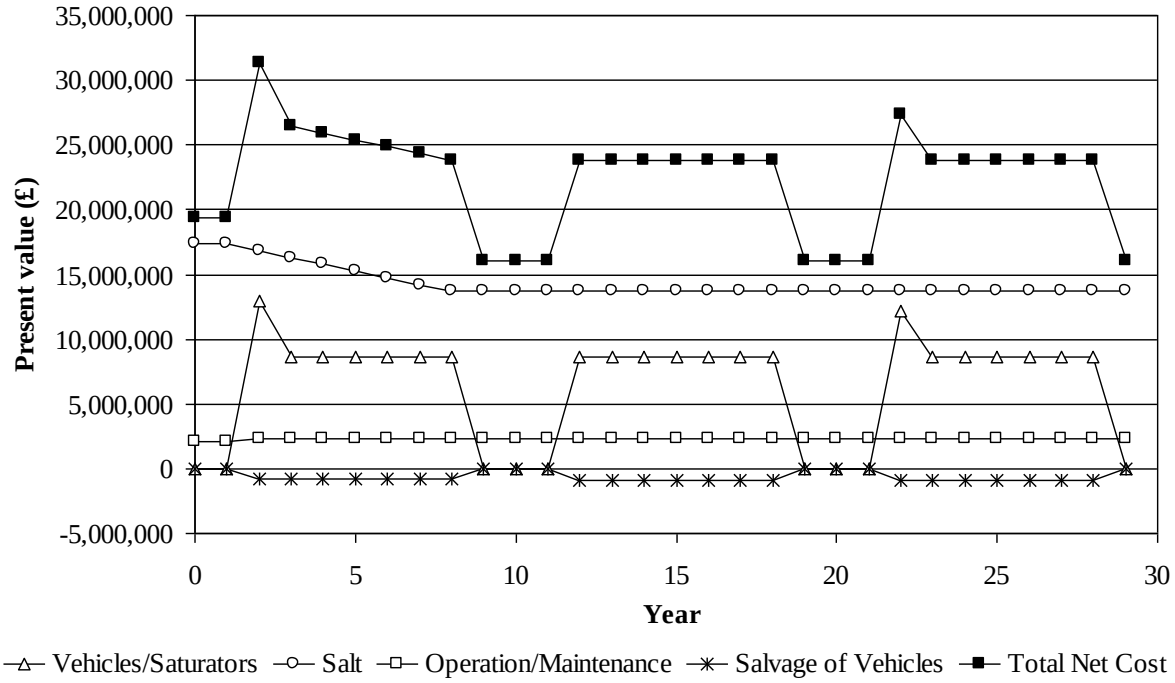

Figure C-14 Option 3: Annual expenditure if service lives of dry and pre-wetted vehicles are 15 and 10 years, respectively, stock is aged from 7 to 13 years, dry salt is £26/tonne and salt used is 700,000 tonnes

Appendix D. Calculation of whole-life costs and sum of present values for Options 0 to 4 for different parameter values

This appendix describes a method for calculating the WLC for Options 0 to 4 for specific parameter values. The WLC is calculated by determining the cost of the following items:

- Purchase, retrofitting, replacement and salvage of salting vehicles, and running and maintenance costs
- Purchase, installation, replacement and salvage of saturators, and running and maintenance costs
- Purchase of salt

The WLC and sum of the present values of these items are given in Tables D-1 to D-4 for different service lives and ages of salting vehicles. Although the tables give figures for one vehicle, they represent the average for a number of vehicles of the age range indicated.

D.1 Worked example no.1

The first example calculates the WLC for Option 1 for one of the cases given in Table C-1. This is for the whole of HA's motorway and trunk road network apart from Area 8.

Using figures from Table D-1:

The WLC of 518 vehicles = 518 x £239,890 = £124.26m

The WLC of 144 saturators = 144 x £76,182 = £10.97m

The WLC of 476,821 tonnes of salt at £20.5/tonne pre-wetted (£23/tonne dry) = 4768.21 x £39,023 = £186.07m

Note that the salt used on the HA network less Area 8 is calculated by multiplying the total amount of salt by the ratio of the number of saturators in all Areas less Area 8 and the number of saturators in all Areas.

Therefore, the total WLC is £321.3 million, as shown in Table C-1.

D.2 Worked example no.2

The second example calculates the WLC for Option 3 for one Area, assuming the following parameter values:

Service life of pre-wetted vehicles = 10 years

Age range of existing vehicles = 7 to 13 years

Number of vehicles = 40

Running and maintenance costs of vehicles = £3000/year (figures in Tables D-1 to D-4 assume £4000/year)

Number of saturators = 9

Running and maintenance costs of saturators = £2250/year (figures in Tables D-1 to D-4 assume £2000/year

Amount of salt used = 40,000 tonnes

Cost of dry salt = £26/tonne

Cost of pre-wetted salt = £20.5/tonne

The WLC of 40 vehicles = 40 x £248,942 (from Table D-2) – 40 x £19,036 (from Table D-1) = £9.196m

The WLC of 9 saturators = 9 x £68,529 (from Table D-1) + 9 x £8,535/2 (extra maintenance costs) = £0.655m

The WLC of 40,000 tonnes of salt at £20.5/tonne pre-wetted (£26/tonne dry) = 400 x 41,561 (from Table D-1) = £16.624m

Therefore, the total WLC is £26.5m.

Note that when a figure is not given in Tables D-2 to D-4 for a particular option, the figures in Table D-1 should be used.

D.3 Worked example no.3

The third example calculates the WLC for Option 3 for one Area, assuming the following parameter values:

Vehicles: As worked example no.2

Salt: As worked example no.2

Number of saturators = 9

Setup costs of saturators = £15,000

Cost of saturators = £30,000

Running and maintenance costs of saturators = £2000/year

The WLC of vehicles = £9.196m

The WLC of salt = £16.624m

The WLC of 9 saturators at £25,000 less setup and maintenance costs = 9 x £68,529 (from Table D-1) – 9 x £9,335/2 (setup costs) - 9 x £8,535 x 4 (maintenance costs) = £0.267m

The WLC of 9 saturators at £30,000 less setup and maintenance costs = £0.267m x 30/25 = £0.320m

The WLC of 9 saturators at £30,000 less maintenance costs = £0.320m + 9 x £9,335 x 15/10 = £0.447m

The WLC of 9 saturators = £0.447 + 9 x £8,535 x 4 = £0.754m

Therefore, the total WLC is £26.6m.

D.4 Worked example no.4

The third example calculates the WLC for Option 4 for one Area, assuming the following parameter values:

Service life of pre-wetted vehicles = 12 years

Age range of existing vehicles = 2 to 8 years

Number of vehicles = 30

Number of saturators = 6

Amount of salt used = 20,000 tonnes

Cost of dry salt = £29/tonne

Cost of pre-wetted salt = £22/tonne

The WLC of 30 vehicles = 30 x £179,579 (from Table D-4) = £5.387m

The WLC of 6 saturators = 6 x £34,591 (from Table D-2) = £0.208m

The WLC of 20,000 tonnes of salt at £20.5/tonne pre-wetted (£27.5/tonne dry) = 200 x ((49,153-44,888) x 1.5/4 +44,888) (from Table D-4) = £9.297m

The WLC of 20,000 tonnes of salt at £1.5/tonne = 200 x 1.5 x £1904 (from Table D-4) = £0.571.

Therefore, the total WLC is £15.5m.

When the cost of salt differs from the costs assumed in Tables D-1 to D-4, the WLC should be calculated in two stages. Firstly, the WLC should be calculated when the cost of pre-wetted salt is £20.5/tonne assuming both salts are reduced by the same amount. Some extrapolation is required if the reduced cost of the dry salt is not £23, £26, or £30/tonne etc. Secondly, the WLC of salt should be calculated assuming an increase in the costs of both salts to that required.

D.5 Worked example no.5

The fourth example calculates the WLC for the vehicles only for Option 1 for one Area, assuming the following parameter values:

Cost of dry salting vehicles = £90,000

Cost of pre-wetted salting vehicles = £100,000

Cost of retrofitting vehicles = £16,000

Service life of pre-wetted vehicles = 12 years

Age range of existing vehicles = 7 to 13 years

Number of vehicles = 40

The WLC of running and maintenance costs on 40 vehicles = 40 x £19,036 (from Table D-1) x 4 (£4000/vehicle) = £3.0458m

The WLC of 40 vehicles at £108,000 and £116,000 less running and maintenance costs = 40 x £239,890 (from Table D-1) - £3.0458 = £6.5498m

The WLC of 40 vehicles at £90,000 and £96,667 (= 90,000 / 108,000 x 116,000) less running and maintenance costs = £6.5498m x 90,000 / 108,000 = £5.4582m (including retrofitting at £8,333 (= £10,000 90,000 / 108,000) per vehicle)

The WLC of 40 vehicles at £90,000 and £100,000 = £5.4582m + 40 x £5,666 (from Table D-5) / 4,000 x (100,000 – 96,667) = £5.6470m (including retrofitting at £8,333 per vehicle)

The WLC of 40 vehicles at £90,000 and £100,000= £5.6470m + 40 x £2,857 (from Table D-5) / 4,000 x (16,000 – 8,333) = £5.8660m (including retrofitting at £16,000 per vehicle)

Therefore, the total WLC of 40 vehicles including running and maintenance costs = £5.8660m + £3.0458m = £8.912m.

Table D-1 Itemised whole-life costs and sum of present values: service life of pre-wetted vehicles 12 years, age range of vehicles 7 to 13 years

Option	Item: Service life of pre-wetted vehicle 12 years Age range 7 to 13 years	Increase in sum of present values (m)	Increase in whole life cost (m)
0	Purchase of 'one' vehicle (dry vehicle: £108,000 pre-wetted vehicle: £116,000 retrofit: £10,000) and annual maintenance at £4000/year	271,200	191,751
1		341,071	239,890
2		339,486	237,133
3		326,700	224,131
4		321,729	220,392
0-4	Running and maintenance costs on 'one vehicle £1000 extra/vehicle	30,000	19,036
0	Installation of one saturator at £25,000 with setup costs of £5,000 and running and maintenance costs at £2000/year	0	0
1		102,500	76,182
2		102,500	76,182
3		96,000	68,529
4		76,500	48,150
0	Setup costs of saturator £10,000 extra	0	0
1		10,000	10,000
2		10,000	10,000
3		10,000	9,335
4		10,000	7,594
0	Running and maintenance costs on one saturator £500 extra/year	0	0
1		15,000	9,518
2		15,000	9,518
3		14,000	8,535
4		11,000	5,961
0	100 tonnes of salt (dry salt £23/tonne)	69,000	43,782
1		61,500	39,023
2		61,679	39,197
3		62,750	40,177
4		63,500	40,802
0	100 tonnes of salt (dry salt £26/tonne)	78,000	49,493
1		61,500	39,023
2		61,893	39,406
3		64,250	41,561
4		65,900	42,936
0	100 tonnes of salt (dry salt £30/tonne)	90,000	57,107
1		61,500	39,023
2		62,179	39,684
3		66,250	43,407
4		69,100	45,782
0-4	100 tonnes of salt £1 extra/tonne	3,000	1,904

Table D-2 Itemised whole-life costs and sum of present values: service life of pre-wetted vehicles 10 years, age range of vehicles 7 to 13 years

Option	Item: (Service life of pre-wetted vehicle 10 years Age range 7 to 13 years	Increase in sum of present values (m)	Increase in whole life cost (m)
0	Purchase of 'one' vehicle (dry vehicle: £108,000 pre-wetted vehicle: £116,000 retrofit: £10,000) and annual maintenance at £4000/year	271,200	191.751
1		394,514	273,872
2		391,686	270,398
3		370,200	248,942
4		359,760	241,473
2	100 tonnes of salt (dry salt £23/tonne)	61,714	39,235
2	100 tonnes of salt (dry salt £26/tonne)	61,971	39,489
2	100 tonnes of salt (dry salt £30/tonne)	62,314	39,828

Table D-3 Itemised whole-life costs and sum of present values: service life of pre-wetted vehicles 15 years, age range of vehicles 7 to 13 years

Option	Item: (Service life of pre-wetted vehicle 15 years Age range 7 to 13 years	Increase in sum of present values (m)	Increase in whole life cost (m)
0	Purchase of 'one' vehicle (dry vehicle: £108,000 pre-wetted vehicle: £116,000 retrofit: £10,000) and annual maintenance at £4000/year	271,200	191.751
1		291,223	209,440
2		291,086	208,992
3		283,200	200,989
4		283,200	200,989
2	100 tonnes of salt (dry salt £23/tonne)	61,571	39,094
2	100 tonnes of salt (dry salt £26/tonne)	61,657	39,178
2	100 tonnes of salt (dry salt £30/tonne)	62,771	39,290

Table D-4 Itemised whole-life costs and sum of present values: service life of pre-wetted vehicles 12 years, age range of vehicles 2 to 8 years

Option	Item: (Service life of pre-wetted vehicle 12 years Age range 2 to 8 years	Increase in sum of present values (m)	Increase in whole life cost (m)
0	Purchase of 'one' vehicle (dry vehicle: £108,000 pre-wetted vehicle: £116,000 retrofit: £10,000) and annual maintenance at £4000/year	238,800	159,506
1		309,800	207,762
3		283,200	183,462
4		275,743	179,579
3	Installation of one saturator at £25,000 with setup costs of £5,000 and running and maintenance costs at £2000/year	79,750	51,299
4		60,250	34,591
3	Setup costs of saturator £10,000 extra	10,000	7,860
4		10,000	6.394
3	Running and maintenance costs on one saturator £500 extra/year	11,500	6,354
4		8,500	4,186
3	100 tonnes of salt (dry salt £23/tonne)	64,000	41,163
4		64,750	41,689
3	100 tonnes of salt (dry salt £26/tonne)	67,000	43,730
4		68,650	44,888
3	100 tonnes of salt (dry salt £30/tonne)	71,000	47,153
4		73,850	49,153

Table D-5 Itemised whole-life costs and sum of present values: difference in cost of dry and pre-wetted vehicle £4000 extra/vehicle (retrofitting £4000 extra/vehicle in parenthesis)

Option	Vehicle details	Increase in sum of present values (m)	Increase in whole life cost (m)
0	Service life of pre-wetted vehicle 12 years Age range 7 to 13 years	0 (0)	0 (0)
1		7,643 (2,857)	5,666 (2,857)
2		7,429 (2,857)	5,403 (2,857)
3		7,500 (0)	5,417 (0)
4		7,329 (0)	5,288 (0)
0	Service life of pre-wetted vehicle 10 years Age range 7 to 13 years	0	0
1		9,486 (2,857)	6,838 (2,857)
2		9,229 (2,857)	6,550 (2,857)
3		9,000 (0)	6,273 (0)
4		8,640 (0)	6,015 (0)
0	Service life of pre-wetted vehicle 15 years Age range 7 to 13 years	0 (0)	0
1		5,726 (2,857)	4,418 (2,857)
2		5,657 (2,857)	4,335 (2,857)
3		6,000 (0)	4,619 (0)
4		6,000 (0)	4,619 (0)
0	Service life of pre-wetted vehicle 12 years Age range 2 to 8years	0 (0)	0 (0)
1		6,200 (4,000)	4,194 (4,000)
3		6,000 (0)	3,965 (0)
4		5,743 (0)	3,831 (0)