12 Further Research

12.1 General

Following publication of the 1st Edition of the Natural Stone Surfacing-Good Practice Guide in October 2000, some areas for further research were identified.

The SCOTS working group have directly commissioned consultants or assisted individual local authorities with some research. Some authorities have investigated particular issues as part of the process of developing projects.

Work commissioned by the group included: -

- An evaluation of the technical, economic and aesthetic performance of a selection of completed natural stone streetscape projects around the country. The main objectives of the evaluation were to obtain an independent view of technical performance and to gather information on problems that had been or were being experienced by the various authorities along with solutions to those problems where possible (I.D. Consultants).

- Development of a robust Whole Life Cost model for natural stone streetscapes, using basic accounting principles, including discounted cash flows (I.D. Consultants).

- Investigate current street-cleansing practice around Scotland and report on how those practices impact on the quality and durability of natural stone streetscapes. Wherever possible give practical recommendations for cleansing practioners (I.D. Consultants).

Research by Local authorities includes: -

- Insitu Re Texturing Of Sett Surfaces By Shot Preening Trials - Renfrewshire Council And Glasgow City Council.
- Insitu Reinstatement Of Joints And Laying Courses - Dundee City Council With Modus Ltd.

Project Developments include: -

- Specification for Shallow Stone Units in Rigid Construction under Very High Traffic Load - Dundee City Council.

The results of this further research are briefly summarized below and the full text can be found on the SCOTS web site (www.scotsnet.org.uk):

12.2 Technical Evaluation of Natural Stone Surfacing in Streetscape Schemes in Scotland

To inform the research a selection of 24 completed streetscape projects in various locations around the country were evaluated with regard to their technical, economic and aesthetic characteristics.

The evaluations considered each project from inception through to maintenance and were based on responses to questionnaires, site visits and meetings with local operational managers. During site visits a checklist of standard characteristics was used to ensure, as far as possible, that each scheme was objectively assessed on a common basis. To maintain confidentiality all information is given in generic rather than site specific form.

The main conclusion was that while the majority of the completed streetscapes functioned reasonably well with only minor faults occurring a few others have suffered fairly dramatic failure and have required continuous maintenance or in some cases reconstruction.

Minor faults included occasional loose joints, rocking slabs and/or cracking around interfaces with channels and street furniture. The initial SCOTS research has established that unless such minor defects are attended to at the earliest opportunity they can cause progressive serious failure. Identified causes of actual failure included: -

- Inappropriate trafficking of slabbed surfaces by heavy vehicles
- Natural stone surfaces being used in unsuitable locations.
- The joint-loosening effect of suction sweeping and cleaning vehicles causing progressive failure.

Where failure had occurred it was noted that some schemes behaved better than others probably due to a combination of location, specification and workmanship. The original SCOTS research has now established that not all locations are suitable for stone surfacing and so care must be taken when deciding whether or not to use stone as the final finished surface. Additionally it has been established that the structural performance of flags and slabs is solely dependent upon the laying course while that of cubes and setts is dependent upon wall shear at the joints with the laying course being of less structural importance. Of paramount importance is the need to ensure that contractors use only skilled and properly trained personnel in streetscape projects.

Design of most of the streetscapes that have been evaluated in this study was carried out prior to publication of the SCOTS Natural Stone Surfacing - Good Practice Guide in October 2000. General practice prior to this time was to give prescriptive sand/cement ratios for bedding and jointing materials rather than target strengths as recommended in the Guide.

There was evidence that in some instances site controls had been too lenient with regard to ensuring compliance with the design and specification and in controlling and testing bedding and grouting materials. Particularly in older schemes (pre-2000) there are instances where there seem to have been ad-hoc changes to bedding and jointing specifications either because they appeared to be inadequate or the contractors had their own preferred methods.

There seemed to be a general perception that natural stone streetscape schemes should not require maintenance because of the ‘infinite life’ of the stone and the high cost of the works. This is not the case; stone streetscape schemes need regular maintenance and aftercare to maintain the integrity of the jointing system, and to retain aesthetic standards that meet public expectation.

Some Maintenance Engineers and Cleansing Managers have made the valid point that their views have not been sought at the design stage resulting in an unsustainable maintenance burden due to, for example, street furniture that is not functional and is difficult to replace.

It is recommended that maintenance manuals, agreements and maintenance funding should be discussed at the design stage rather than be addressed by ad hoc or reactive maintenance procedures

Appropriate levels of inspection need to be set along with maintenance regimes that allow for the special nature and status of streetscape schemes.
Roads authorities must ensure that public utilities carry out reinstatements to the same quality and standard as the original work. This may be achieved by using term contractors specialising in streetscape works or through Maintenance Agreements with the utilities themselves. Maintenance Manuals should be prepared to ensure consistency in the maintenance and aftercare of streetscapes

Aesthetically, amongst the biggest concerns are residual cement stains deposited during the construction stage and, after commissioning, the difficulties associated with discarded chewing gum.

Recommended topics for further research and development are: -

- Grouting specifications
- Slab laying techniques
- How to replace depleted joints
- Damage to joints caused by suction sweeping or pressure washing equipment
- Cement stain removal
- Chewing gum removal.

The full report by ID consultants is available on the SCOTS web page.

12.3 Whole Life Costing for Natural Stone Streetscape Works

This area of the research examined the theory behind Whole Life Costing with a view to developing a model, which could be used for comparison purposes.

Whole Life Costing (WLC) is a means of transferring the value of future years costs or payments into the present. All transactions are taken back to a base year by adjusting for the amount of interest these monies would have earned if invested in a bank or similar financial institution. The rate of interest assumed is referred to as the discount rate and the total value or cost of a transaction transferred back to the base year is called the Net Present Value (NPV). The Whole Life Cost of a scheme is the total value of all transactions over the whole life of the scheme.

The model that has been developed allows comparison between competing projects as well as comparisons of different alternatives for individual schemes. While there is no direct income from a streetscape project these high quality schemes are generally intended to bring positive values in the form of increased economic activity; stopping or reducing shop closures; increasing tourism and creating a ‘feel good’ factor by providing an aesthetically pleasing environment

To quantify the benefits to retail, business, tourism and the feel good factor, the model allows the designer to include positive contributions for these factors. It is calibrated to give an overall positive WLC for justified schemes and results in negative values if the use of natural stone is not justifiable. In order to establish the sensitivity of the various cost assumptions the model has been tested for both high and low costs of asphalt, man made and natural stone schemes.

This section of the report concludes that: -

- The Whole Life Cost of an asphalt scheme will always be cheaper initially than a natural stone scheme when considering only construction and maintenance costs

- If Whole Life Costs include benefits to the local community, natural stone schemes may well offer better value than asphalt schemes

- For natural stone schemes to be economically justifiable the designer must ensure that future maintenance burdens are minimized and that a robust maintenance system is in place to safeguard the investments made.

In the model Whole Life Costing is dominated by the discounting rate used but the relative comparison between asphalt, man made and natural stone products remains fairly stable. The main consequence is that a high interest rate will reduce the value of future costs or payments much more rapidly than lower rates.

In practical terms Whole Life Costs do not change after about 50 years with high interest rates and after about 100 years with low interest rates. In global terms stone has a low Whole Life Cost being a natural material that requires relatively few secondary processes before being used.

The Whole Life Costing Model spreadsheet is shown at the end of this section and has the following key: -

***Co** - is the total cost of procurement and installation at time zero*

***M** – is the annual recurring maintenance cost per sq metre.*

***R** – is the cost of non-continuous work such as refurbishment work*

***N1**- is the assumed interval over which R occurs (i.e. once in 5 years or once in 10 years would give values for N1 of 5 and 10 respectively)*

***V** – is the value of the asset at the end of its service life at disposal, allowing for all costs of the disposal*

***r** – is the standard industry discount rate and should be determined through reference to the Bank of England current rate.*

***E, T and A** – the research has demonstrated that economic regeneration or prevention of economic decline play an important part in the overall WLC of a street. Increases in tourism and visitor numbers will add increased economic value to the local economy and a pleasant high quality environment carries an aesthetic value and feel good factor that may act as a catalyst for other more tangible benefits. While this type of benefit is difficult to quantify the following matrix had been developed to create a rational for comparing the importance of individual schemes.*

	Economic (E)	***Tourism (T)***	***Aesthetic (A)***
Very Important	*15*	*2.5*	*5*
Important	*10*	*1.5*	*3.5*
Some Value	*5*	*0.5*	*1.75*
No Value	*0*	*0*	*0*

***N2, N3 and N4** – are assumed benefit intervals. These intervals are an objective assessment but should be based on influencing factors such as the anticipated life of the scheme, future developments etc.*

Guidance on the determination of appropriate figures for use in the model is given in the full report obtainable from the SCOTS web site.

12.4 Cleansing Practice in Natural Stone Streetscape Areas in Scotland

The competition between town and city centres with out of town malls is increasing and levels of cleansing and facilities are fundamental in the public's decision making on where to shop. There is a need for an integrated approach to all aspects of street cleansing which should employ cultural along with mechanical and chemical controls. Whilst chewing gum may be the biggest problem at the moment, all cleansing issues must be treated equally to avoid investment for single issues reducing the impact of others. Single-issue campaigns tend to be generally short term and quickly forgotten unless regularly revived. Local authorities and communities each have a part to play and must work together. Prevention will always be better than the cure, and there is a need for strong partnership working both between Council departments and with all other local public agencies, for example the Police, along with the whole community. Success will only be achieved with everyone working together, treating the symptoms as well as tackling the cause of the problems through education and enforcement if necessary, followed by well-organised and effective action on the ground.

12.4.1 Maintenance Manual

Each authority must develop specific cleansing strategies, which are appropriate for the effective and safe care of their high quality assets. These should be included in a Maintenance and Management Manual for the area.

12.4.2 Costs

Adequate funding, ideally ring fenced, must be provided to allow services to be developed based on community need. Investment in specialist equipment and the training of staff is vital, and will be beneficial in the long term. In Scotland in 2003 about £55M was being spent annually on the direct costs of street cleaning and litter clearance. It can cost between £6 and £19 per kilometre to sweep streets.

These figures exclude indirect costs, for example the relationship between public / tourist attraction and cleanliness. The economic benefits of being renowned as a clean location are immense, conversely the cost of being seen as a dirty location are equally high.

12.4.3 Operatives and Machinery

Specialist training of operatives and staff involved in the care of natural stone surfacings is needed, only a few local authorities currently carry out their own in-house staff training. A national approach to this is required, with recognised qualifications being used to ensure that only qualified staff are permitted to operate in high quality areas. Only in this way will the services provided be of the highest possible quality.

Manufacturers of specialist equipment must work together with local authorities to develop a range of machines that are practical, cost effective and affordable, and most importantly which do not damage

the surface being cleaned. Through a further research programme, these issues should be developed to produce definitive procedures and guidelines for cleaning of stone streetscape areas.

12.4.4 Best Practice Guidance

From a detailed literature search, general generic advice for street cleansing operations has been developed. Following this, a detailed examination of street cleansing management and practice in the schemes studied has been carried out to reveal the various elements of both good and, where appropriate, less effective practice.

These findings were discussed in detail with Keep Scotland Beautiful (KSB) [a.k.a. ENCAMS (Scotland)] who have provided detailed information from their considerable experience to give a national perspective on the research.

The report brings together 'theory' and the actual practice. It concludes with general and specific recommendations in the form of best practice guidelines for the full range of street cleansing operations, which it is hoped will provide a catalyst for Roads and Cleansing staff to improve the execution of their services, either individually or in partnership.

12.5 Best Practice Guidelines for Cleansing Practice in Natural Stone Streetscape Areas in Scotland

12.5.1 Litter

For high quality public spaces, performance targets should be set well above those used for other areas, to reflect the considerable value of good street appearance and ever increasing public expectations. Many people use out of town malls for the simple fact that the walking surfaces are swept and cleaned regularly thus creating an attractive environment in which to shop.
There is a need to concentrate resources to achieve a standard well above the legal minimum or the standard applied to other nearby areas. This could be achieved using some of the following recommendations:

- Provide enough litter bins, preferably covered ones, located in most convenient places. They should be available for use at all times and the frequency of emptying will be critical in preventing overflow. Ensure bins provide sufficient storage volume and are emptied on a regular basis. For most major public areas these should have an individual capacity of at least 100 litres, and the actual location of bins will depend on the geometry of the street, lines of travel (especially away from take away shops) and servicing frequency. The need for emptying

may vary throughout the day, but with experience an optimum cycle of servicing should be achieved.

- Establish a system for secure storage of retail waste (inside or outside premises) and time this appropriately to the schedule of uplift, by both public and private operators.
- Consider cyclical service provision rather than ad hoc treatments.
- Establish written guidelines and performance targets for litter issues, and keep these under review.
- Take precautions to prevent spillage from refuse bags, and protect bags from wind when placed outside. This is an issue really for the person putting the bags out on the street, targeted direct personal contact and education in problem areas might assist in prevention.
- Take-away shops should have bins located outside them, although too many bins close together will prevent cleaning of the paving surface between them.
- Have well trained cleansing staff who are committed to providing a good service.
- Encourage a litter conscious attitude by all users of the street through public education programmes and campaigns.
- Identify ‘hot spots’ and target action appropriately.
- If possible appoint litter wardens who can work closely with Police on enforcement.
- Ensure that all service providers and the local community appreciate the importance of maintaining the quality appearance of the street.

12.5.2 Street Cleaning - Stains

- Establish written guidelines for all stain types.
- Use appropriate equipment based on trials of alternative types
- Recognise the possible detrimental effects of operations on the quality of the stone surface and its joints.
- Consider cyclical treatment instead of / as well as, ad hoc programmes of work.
- Recognise the need to give staining some degree of priority to ensure action is taken.
- Treat with appropriate equipment and materials as quickly as possible. Have appropriately trained staff and specialist equipment.
- Identify sources of staining and try to prevent recurrence.
- In new surfacing, try to incorporate polished surfaces against walls and around street furniture to allow more successful cleaning

12.5.3 Chewing gum

- Determine the most appropriate system for your needs both technically and financially through trials, or on peer group recommendation.
- Regularly treat 'hot spots' around entrances and bus stops for instance.

- Establish a treatment programme, which will cover the whole street surface. Gum dropping is indiscriminate and affects the entire street, even though certain areas are more affected than others. Regularly target ‘hot spots’.
- Encourage a gum conscious attitude by all users of the street through public education programmes.
- Secure the required additional funding to adequately tackle the problem.

12.5.4 Fly posting

Fly posting will occur almost anywhere and whether the property is publicly or privately owned, the detrimental affects on a public space can be considerable. Local authorities should work with building owners to seek partnerships to jointly tackle the problem.
Local Authorities have a number of approaches to try to tackle the problem on their property (which could equally apply to private owners)*:* -

- Prosecution of offenders (if enforcement resources are available)
- Removal under legislative authority
- Prevention through surface treatment of furniture etc. (generally of limited use)
- Use of dedicated or approved sites for placing of advertisements
- Prevention through education and campaigns.

12.5.5 Dog Fouling

Whilst the most cost-effective solution to much of the problem would be to encourage dog owners to take responsibility for fouling and to clean up after their pet, some other actions a local authority can implement include: -

- Employ dog wardens
- Have a complaints procedure
- Carry out educational and promotional work within the community
- Enforce legislation
- Provide adequate quantity and locations of dog-waste bins

12.5.6 Graffiti

This is very much a social problem and involves only a small number of people, even though the effects of their actions are considerable. It is essential that local authorities and private owners are pro-active and that: -

- There is a system in place to identify areas of graffiti through regular inspections, and to take reports from external parties who have reported graffiti.
- There is a mechanism for getting an appropriate experienced contractor on site as quickly as possible, and that they have the correct equipment and materials for the work. Experience shows that prompt removal is a very good deterrent to further problems.
- There is sufficient funding put in place to pay for inspections, removal and prevention.
- Consideration is given to the use of protective coatings for areas regularly damaged. Unfortunately, the more experienced graffiti artist will be able to use a range of painting media to ensure maximum difficulty in removal.
- There is an education programme through local schools to prevent graffiti.
- There is direct Police action towards known regular offenders (e.g. through exclusion).

12.6 Insitu Re Texturing Of Sett Surfaces By Shot Peening Trials - Renfrewshire Council And Glasgow City Council.

It is well known that old setts generally have worn top surfaces that have poor skid/slip resistance. Such setts are increasingly being used in busy public streets and in particular in bus/hgv trafficked areas. To meet modern road safety requirements, these surfaces must be able to provide an appropriate level of skid resistance for vehicles, and slip resistance for pedestrians.

Re-texturing of stone surfaces which have become slippery due to vehicular or heavy pedestrian traffic can be undertaken by various methods including scabbling, sand or shot blasting, high pressure water jetting or application of a weak acid.

Scabbling is slow but can be used successfully on flags, especially where there is some form of surface growth. Debris is likely to be a hazard to passing vehicles and pedestrians. Sand blasting can be successful but results in a lot of fine particles and debris, which have to be removed separately, and again are a hazard to vehicles and pedestrians. Both methods would probably be best used in small areas where suitable working areas can be cordoned off.

On stone setts, flame texturing and bush hammering can be carried out insitu but are again slow and hazardous to the public. The process has been trialled and slip/skid resistance improvement of up to 40 % can be achieved. Either method would be suitable for small working areas where the public can be temporarily excluded.

Shot blasting (peening) with steel shot involves the use of specialised machinery, which sucks up the debris and shot by vacuum. The steel shot is separated magnetically in the return loop for continuous reuse. Waste material is disposed of safely and at no risk to the public. This is a very successful process that tends to form a lightly exposed aggregate surface on flags and setts, giving a pleasing appearance free from staining and detritus. The machinery comes in various shapes and sizes with large vehicle mounted units most suited to fast treatment of large areas. However, retexturing areas around street furniture and in irregular shaped areas can be difficult. The machinery is currently expensive to hire and would not be cost effective for small areas. In time, if this method becomes more widely used, the hire costs should reduce considerably.

Trials carried out in Paisley in October 2001 have shown that increases in slip/skid resistance of up to 60% can be achieved through shot peening, depending on stone type. Rigid (bound) joints, if stable prior to the retexturing, should not be damaged by the process although the top few millimetres may be removed. It is not certain what would happen to flexible (unbound) joints but it can be reasonably assumed that there would be some degree of joint loss requiring resealing after treatment.

The detailed results of the tests (carried out by Glasgow City Council, Land Services) are shown below

Appendix A

Test Results of Shot Peening Trials

Location: St. Mirren Street, Paisley – Bus-bay **Date:** 29 October 2001
Direction of test: Longitudinal **Time:** 9:50 & 11:30
Weather: Bright/Damp **Operator:** Tom Adams

Test no.	1	2	3	4	5	Ave	Temp	Corr	Result
1a	52	52	51	51	52	51.4	13.4	-2	**49**
1b	68	68	69	68	67	68	14.1	-1.7	**66**
2a	42	42	42	42	42	42	13.6	-2	**40**
2b	60	60	60	60	60	60	13.8	-1.8	**58**
3a	48	48	48	49	50	48.6	13.4	-2	**47**
3b	77	75	75	75	74	75.2	13.7	-1.8	**73**
4a	47	46	45	46	45	45.8	13.4	-2	**44**
4b	76	76	75	75	74	75.2	13.3	-2	**73**

Remarks:

1. Trial shot-peening of setts in bus bay.

1. Tests carried out orthogonal to directional flow of traffic due to narrow width of setts.

2. Tests 1a &1b – brown coloured granitic sett, tests 2a & 2b – light brown/red granitic sett, tests 3a & 3b – grey/red granitic sett, tests 4a & 4b – grey/black coloured basaltic sett.

3. Tests carried out before (a) and after (b) shot-peening.

In addition, setts from another area were tested before shot peening, but were subsequently not included in the trial:

Location: High Street, Paisley – Bus-bay (south) **Date:** 29 October 2001
Direction of test: Longitudinal **Time:** 10:30
Weather: Bright/Damp **Operator:** Tom Adams

Test no.	1	2	3	4	5	Ave	Temp	Corr	Result
5	45	44	44	44	44	44.2	14.2	-1.7	**43**
6	42	40	40	40	39	40.2	15.1	-1.3	**39**
7	59	56	57	57	58	57.4	15.1	-1.3	**56**
8	33	30	31	31	31	31.2	14.6	-1.5	**30**

Remarks

1. All tests carried out on untreated setts.

2. Tests 5 & 6 - grey granitic setts, test 7 – reddish granitic sett, test 8 – grey/black basaltic sett.

3. Tests carried out orthogonal to directional flow of traffic due to narrow width of setts.

12.7 Insitu Reinstatement of Joints and Laying Courses

Since 1988 Dundee has constructed extensive areas of stone surfaces in its programme to improve the city centre environs, including pedetrianised areas, areas subject to moderate traffic and areas subject to heavy traffic.

In several areas problems have been encountered with the loss of materials from joints and laying courses. The initial intervention had been to lift areas to inspect the defect and understand the root of the problem. The areas were then subsequently re-laid

It became apparent that in many instances the defects was confined to the stone surface and occurred for a variety of reasons. For example, overload of the pavement leading to crushing of the laying course, insufficient control of the mix of the concrete allied to compaction of the materials leading to failure of materials, wash out of joint materials by vacuum sweepers. The results were similar in that the pavement exhibited local deformations and loss of materials from the joint. Lifting and relaying the surface was time consuming and expensive and therefore tended to be instructed when larger areas became affected.

An alternative form of early intervention was suggested in which the materials could be replaced or stabilised using thixotropic grouts injected into the surface. These treatments would not require the surfaces to be lifted and might be cost effective on small areas. A specialist consultant was engaged to advise on the plant and specification for grouts for several trials areas within the City Centre

The trials used a combination of plant and grout in areas of different specification of stone surfaces The site work was undertaken in the autumn of 2003 and a report on the performance is expected shortly.

12.8 Specification for Shallow Stone Units in Rigid Construction under Very High Traffic Load - Dundee City Council.

The junction of the Murraygate, High street and Commercial Street forms and important focal point of the pedestrian precinct in Dundee. The pedestrian traffic on Murraygate –High Street crosses the bus route on Commercial Street. The design intention requires the stone surfaces of the pedestrian area to flow across the bus route. Achieving the performance required of the stone surface subject to high volumes of bus movements in channelised running lanes proved to be problematic and a number of repairs were required. When the programme of improvements reached the north section of Commercial Street, the junction was again showing signs of distress and a decision was taken to review the construction specification for the junction area.

The new knowledge gained in the research for the good practice guide indicated that deeper stone units, with good face texture and with high strength joint and laying course materials would be required even then the design life would be a maximum of 15 years. However the depth of the stone unit was constrained by the exiting foundation concrete and by the very tight constraints for the finished surface levels that could not be relaxed.

Obviously to achieve the design requirements a specialised construction was required. A specialist pavement consultant was appointed to undertake the design of the pavement using a fully analytical approach. The specification was for units made to tight tolerances with all faces well textured. This would ensure compliant joint widths and face texture. The laying course and joint materials were well designed to provide specific performance characteristics.

There remained a high risk of failure of this surface and it was decided to limit the stone surface to a smaller area than in the original scheme with a view to trialing the construction. This trial panel was installed in Autumn 2003 and is currently being monitored.

SCHEME **Model Spreadsheet**

MAIN SURFACING ELEMENT:

ASPHALT
MAN MADE
STONE

BASE YEAR COSTS PER SQ M OF SURFACING:	PLANNING,DESIGN & SUPERVISION		£
	ROAD CONSTRUCTION TO BASE COURSE LEVEL		£
	SURFACING MATERIAL		£
	ADDITIONAL COST OF LAYING SURFACING		£
	EXTENDED CONTRACT PERIOD COSTS		£
	STREET LIGHTING AND FURNITURE COSTS		£
	ART WORK COSTS		£
	ANY OTHER SCHEME COST		£
	TOTAL CONSTRUCTION COST:	C0	£
ANNUAL MAINTENANCE COSTS PER SQ M OF SURFACING:		M	£
REFURBISHMENT COST PER SQ M		R	£
	ASSUMED INTERVAL	N1	YEARS
RESIDUAL VALUE OF NATURAL STONE PER SQ M		V	£
DISCOUNT INTEREST RATE		r	%
ANNUAL BENEFIT TO BUSINESS RELATIVE TO DO NOTHING PER SQ M OF SURFACING		B	£
	ASSUMED BENEFIT INTERVAL	N2	YEARS
ANNUAL BENEFIT TO TOURISM RELATIVE TO DO NOTHING PER SQ M OF SURFACING		T	£
	ASSUMED BENEFIT INTERVAL	N3	YEARS
ANNUAL AESTHETIC IMPROVEMENT RELATIVE TO DO NOTHING PER SQ M OF SURFACING		A	£
	ASSUMED BENEFIT INTERVAL	N4	YEARS
WHOLE LIFE COST INTERVAL		N	YEARS

YEAR	Construction	Maintenance	Refurbuishm.	Residual	Bus. Benefit	Tour. Benefit	Aesth. Benefit	
N	C0	M	R	V	B	T	A	
1		M/(1+r)^1			B/(1+r)^1	T/(1+r)^1	A/(1+r)^1	Sum
2		M/(1+r)^2			B/(1+r)^2	T/(1+r)^2	A/(1+r)^2	Sum
3		M/(1+r)^3			B/(1+r)^3	T/(1+r)^3	A/(1+r)^3	Sum
4		M/(1+r)^4			B/(1+r)^4	T/(1+r)^4	A/(1+r)^4	Sum
5		M/(1+r)^5			B/(1+r)^5	T/(1+r)^5	A/(1+r)^5	Sum
6		M/(1+r)^6			B/(1+r)^6	T/(1+r)^6	A/(1+r)^6	Sum
7		M/(1+r)^7			B/(1+r)^7	T/(1+r)^7	A/(1+r)^7	Sum
8		M/(1+r)^8			B/(1+r)^8	T/(1+r)^8	A/(1+r)^8	Sum
9		M/(1+r)^9			B/(1+r)^9	T/(1+r)^9	A/(1+r)^9	Sum
10		M/(1+r)^10			B/(1+r)^10	T/(1+r)^10	A/(1+r)^10	Sum
11		M/(1+r)^11			B/(1+r)^11	T/(1+r)^11	A/(1+r)^11	Sum
12		M/(1+r)^12			B/(1+r)^12	T/(1+r)^12	A/(1+r)^12	Sum
13		M/(1+r)^13			B/(1+r)^13	T/(1+r)^13	A/(1+r)^13	Sum
14		M/(1+r)^14			B/(1+r)^14	T/(1+r)^14	A/(1+r)^14	Sum
15		M/(1+r)^15			B/(1+r)^15	T/(1+r)^15	A/(1+r)^15	Sum
16		M/(1+r)^16			B/(1+r)^16	T/(1+r)^16	A/(1+r)^16	Sum
17		M/(1+r)^17			B/(1+r)^17	T/(1+r)^17	A/(1+r)^17	Sum
18		M/(1+r)^18			B/(1+r)^18	T/(1+r)^18	A/(1+r)^18	Sum
19		M/(1+r)^19			B/(1+r)^19	T/(1+r)^19	A/(1+r)^19	Sum
20		M/(1+r)^20			B/(1+r)^20	T/(1+r)^20	A/(1+r)^20	Sum
N1		M/(1+r)^N1	R/(1+r)^N1		B/(1+r)^N1	T/(1+r)^N1	A/(1+r)^N1	Sum
N2		M/(1+r)^N2			B/(1+r)^N2	T/(1+r)^N2	A/(1+r)^N2	Sum
N3		M/(1+r)^N3				T/(1+r)^N3	A/(1+r)^N3	Sum
N4		M/(1+r)^N4					A/(1+r)^N4	Sum
N		M/(1+r)^N			V			Sum
						WHOLE LIFE COST		SUM