Thematic Network

LIFETIME

Lifetime Engineering of Buildings and Civil Infrastructures

Deliverable 4.1

Assessing exting lifetime data and systematics for presenting lifetime data

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1. Introduction

1.1 Background

Lifetime Engineering is becoming and increasingly common feature in the procurement of built assets. Governments are demanding better value rather than lowest capital costs and require that tenders include not only the cost of building but also the expected lifetime costs for planned preventative maintenance, replacement and repairs. Such developments form part of the UK government's initiative on improving the performance of Construction Industry in response to the reports 'Constructing the Team' by Latham [1] and 'Rethinking Construction' - the Egan Report [2].

Furthermore, procurement methods such as Private Finance Initiative (PFI), Public Private Partnership (PPP) and Build, Own, Operate, Transfer (BOOT) are also becoming more popular. Such projects require that the developer maintains responsibility for the asset for a defined contract period (typically 25-30 years) and during that time has contractual responsibility for ensuring that the asset continues to meet its functional requirements by maintaining acceptable serviceability levels. At the end of the contract period the asset is then handed over to the client in a condition that meets the client's requirements for a defined residual life.

These significant changes in the method of procurement, together with an increasing awareness of the need for sustainable development [3,4], have meant that developers are finding it increasingly difficult to avoid the process of lifetime engineering.

Enlightened clients are also increasingly recognising the benefit of sustainable construction, not only in relation to their own strategic development but also with regard to public opinion, branding and benefits associated with planning applications. The importance of this has been reflected in the UK by the introduction of a new British Standard, BS8900, Guidance for Managing Sustainable Development. This is currently (at July 2005) in Draft for comment stage [5]. The document is not prescriptive, but offers guidance "*to help organisations develop an approach to sustainable development that will continue to grow and adapt to meet new and continuing challenges and demands*". The guide defines sustainable development as *"an enduring balanced approach to economic activity, social progress and environmental responsibility".*

In order that competitive bids may be fairly assessed it is necessary that there is transparency in the data that has been used, in the processes that have been employed and in the underlying assumptions. These requirements are also essential when comparing the impact of different options within the design process. In an ideal world, a complete database of life cycle and cost information would be available for all of the available building materials and components, and an internationally accepted (and possibly standardised) method for applying these data would be available. In the real world however the data are fragmented, if available at all, and various processes are used to establish the performance, cost and societal and environmental impacts over the life of a built asset.

1.2 Whole Life Costing

Currently the most commonly used aspect of Lifetime Engineering is Whole Life Costing [6]. This involves the estimating of the costs of constructing, operating, maintaining and, possibly, demolishing an asset. The real skill in WLC lays not so much in the mechanics of the process. The availability of spreadsheets has made it possible for almost anyone with basic mathematical skills and computer literacy to produce a WLC model at a simplistic level and WLC calculators and comparators abound. The required output is usually a prediction of annual costs and a cost profile over the life of the asset (Figures 1a and 1b).

The real difficulty with WLC is in knowing ‘when to spend’ and ‘how much’. When are interventions necessary? How much will be spent on PPM and at what rate? And how much will be spent replacing elements when they cease to fulfil the function for which they were designed? The first step in the process of Whole Cycle Costing (WLC) is, therefore, to predict when events or interventions occur. Costs are then attached to these interventions and a WLC profile may be estimated.

A particular issue here is the definition of loss of serviceability, particularly for those items for which such decisions may contain a large element of subjectivity. This is most apparent when aesthetics is a priority. Hence, without being able to estimate the Service Life, SL, i.e. the time at which the serviceability level drop below that required, the process of Whole Life Costing cannot begin with any degree of reliability.

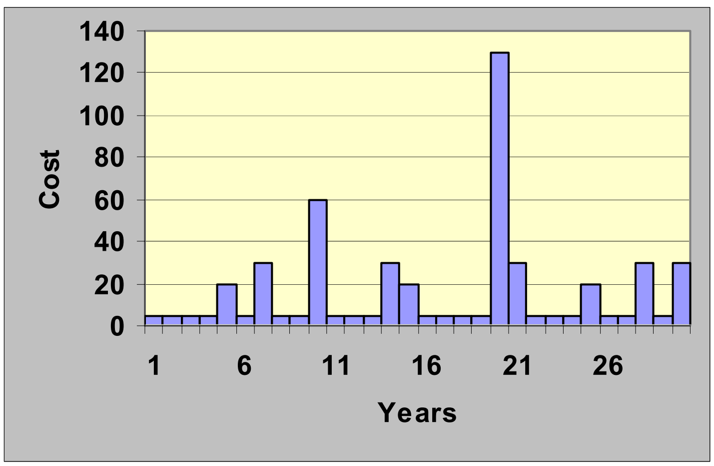

Figure 1.1a *Predicted annual cost*

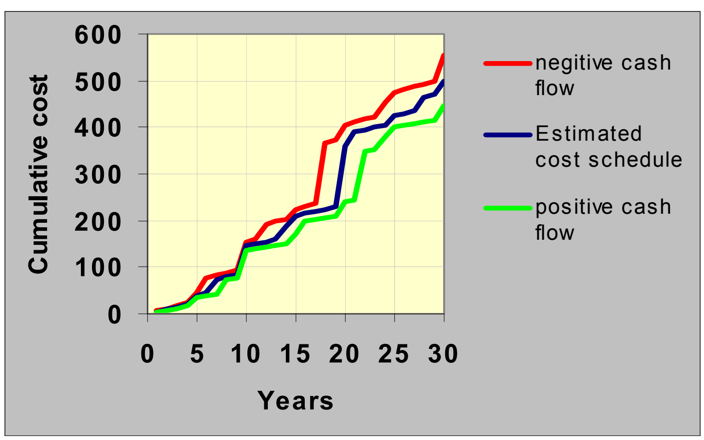

Figure 1.1b *Cumulative cost profile*

When dealing with an abundance of data, much of which is fraught with uncertainty, the only sure thing is that the predicted cost profile will not be matched in reality. In order to make reasoned decisions about how the financial risk should be managed we need to know by how much the real costs may vary from the estimate. Hence the decision making process must necessarily include an acknowledgement of the uncertainties in both the predictive process and the input data. This in turn leads to the need for a risk based approach.

1.3 Life Cycle Analysis

Life Cycle Analysis (or life cycle assessment) is an integrated "cradle to grave" approach to assess the environmental performance of products and services, including built assets. However, it is not only environmental factors that contribute to value and societal impacts are also increasingly being recognised within the design process as shown in Table 1.1

Table 1.1 *Environmental and societal issues*

Environmental	Societal
Land use	Transport
Natural resources	Utility infrastructure
Climate change	Access/accessibility
Acidification	Safety and Security
Eutrophication	Health and Wellbeing
Waste	Community
Ozone depletion	Human Capacity
Ecology	Management
Pollution	Internal conditions
Biodiversity	External conditions
Processes	Cultural Heritage
Energy	
Water	
Recyclability	

1.4 Lifetime 'Balanced Value'

It is clear that the design process has become much more complex with the need to consider issues beyond the capital cost of the asset and its ability to meet specific functional requirements. The designer is required to balance the requirements not only of his client but also of society at large. In order to achieve 'Balanced Value' guidance is required on what issues must be considered (Table 1.2), what tools are available to inform and assist the decision process, and how these tools may be applied within a rigorous and transparent process.

Table 1.2 *Economic and performance issues*

Economic	Performance
Purchase Costs	Usability
Building Costs	Materials
Production Costs	Service Life
Life-Cycle Costs	Durability
Finance	Adaptability
Management	
Water Consumption	
Energy Consumption	
Maintenance	

In the UK a project has been undertaken (with support of the UK government) to address this issue. The 'Balanced Value' project offers 'A framework to assist the selection of materials, components and systems for long-term value – balancing functional performance and sustainability'. It has two principal aims;

1. The development of a toolbox which provides information on the numerous tools, models and systems available for use in the design process

2. The development of a framework within which to apply the tools that enables the designer to balance the varying, and often contradictory requirements, to provide best lifetime value.

Information may be found at www.balancedvalue.com

1.5 Aims and Objectives

The principal aim of this Lifetime work package is to provide recommendations to enable the establishment of both a database and a process which would form the basis of an internationally acceptable approach for Lifetime Engineering. Objectives are

- The identification of current sources of cost and performance data and how it is collected and stored
- The identification of how lifetime data is currently used to optimise lifetime costs and performance of assets

In order to meet these objectives the work packager was broken down into 5 tasks as follows

Task 1: Analysis and benchmarking of lifetime cost data

Task 2: Analysis and benchmarking of service life data

Task 3: Analysis and benchmarking of data on technical performance

Task 4: Analysis and benchmarking of data on environmental performance

Task 5: Support for establishing a lifetime database on cost, service and environmental impact.

As seen above, Work Package 4 of the Lifetime Network programme has involved the collection and review of information on the sources of lifetime data that are available and on how these sources store, structure and present their data. It must be stressed that is not the intent to collect specific lifetime data, but to establish the current sources of information and how they are used to optimise lifetime costs and performance. Information has been collected principally by questionnaire from the network members and other organisations recommended by the members. However, a parallel study in the UK achieved a greater response with feedback, at various levels, from 70 respondents and the results from both the Lifetime survey and the UK survey are included. A comparison of the results from the two surveys has led to some interesting observations.

1.6 European Directives

Another reason for the need for this study has been that many producers have been reticent to give specific figures for service or working life of their products, not only because of technical difficulties associated with predicting long term performance and deterioration but also because they have been concerned about the liability attached to

2.5 Survey Results

2.5.1 Definition of Service Life

Respondents were asked to place the options in order of preference, 1 being the best and 6 being the worst. The results are given in Table 2.1 shown in the order of preference expressed by the Lifetime partners.

Table 2.1 *Order of preferred method of definition of service life (Scores on a scale from 1 to 6 with lower values indicating higher preference)*

Definition of service life	UK	Lifetime
Single characteristic value, e.g. 95% exceeding 15 years	3.58	2.22
Single minimum value, e.g. at least 15 years	2.42	2.83
Distribution, e.g. mean of 20 years with SD of 3 years	3.73	3.23
Range, e.g. 15 to 25 years	3.28	3.35
Single value (unqualified), e.g. 20 years	2.96	4.11
Single maximum value, e.g. not more than 25 years	4.54	5.06

Of the six methods for defining service life it is clear that the Lifetime members preferred a single characteristic or single minimum value. Least preferred were the single unqualified or single maximum value. A distribution or range of values fell between the two extremes. The Lifetime results differed from the UK results in that UK study respondents preferred the simpler single figure options (either minimum or unqualified) over the statistical definitions, opting for simplicity over rigour. This may reflect the fact that the respondents in the UK were largely practitioners seeking simpler answers, while the Lifetime members are primarily researchers and academics and recognised the real complexity of Lifetime Engineering and the need for rigour and an understanding of risk in order to achieve a reliable solution.

A more detailed analysis of the responses from the Lifetime partners is shown in Figure 2.1. Respondents were asked to place the six options in order of preference, 1 being the best and 6 being the worst. It can be seen that the use of a statistical value (characteristic or distribution) represented about 75% of the first choices. Using a single maximum value was the least preferred option. This is not surprising as adoption of such a value in service life design would assure failure before the defined service life had been achieved.

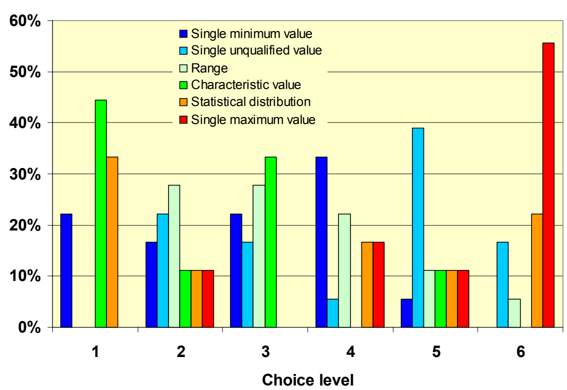

Figure 2.1 *Analysis of responses related to preferred definitions of service life*

2. The Survey

2.1 The issues covered

To obtain a view of current practice and to identify priority issues in the use of Lifetime data and the process of Lifetime Engineering a survey was undertaken involving both the Lifetime partners and UK practitioners. Of the Lifetime partners 18 responded, while 76 responses received from UK practitioners. Many people found it difficult to answer a number of the questions this, in itself, being an indication of the extent to which Lifetime design is not yet fully integrated into the design process.

The questions addressed general issues about lifetime data and how it is collected, presented and used. The following questions were asked.

2.2 General questions relating to service life

The first series of questions addressed general issues about lifetime data and how it is collected, presented and used. The following questions were asked.

- How do you believe Service or Design Life should be defined?
- What factors should be used to qualify value of service life?
- What lifetime data is available?
- Where do you get information relating to the service life of specific elements, components, materials etc?
- Presentation of lifetime data
- How is the data applied?
- What do you consider to be the greatest limitations with lifetime data currently available?

2.3 Questions related to specific materials, components or systems

Following these general questions, the respondent was requested to offer information on specific materials components or systems

- Type of material/component/system
- What is the condition/performance requirement in design?
- What is the condition/performance level that defines the need for intervention?
- Is condition/performance measured to determine when the service life has ended, or to predict when it will end? [with examples]
- Are there benchmarks against which to make comparisons of performance?

2.4 Environmental Impact

These questions sought to determine which environmental issues are currently used in lifetime assessment?

- What environmental issues are most important?
- Where do you get information relating to the environmental impact of specific elements, components and materials?
- How are data on environmental impacts presented

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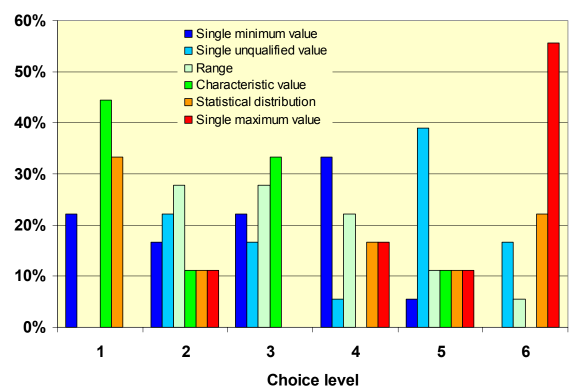

Figure 2.1 *Analysis of responses related to preferred definitions of service life*

While the use of a single value is appealing, it must be appreciated that there is a degree of variability and uncertainty attached to the long-term performance and deterioration of building products and any value of SL that is applied will similarly be subject to uncertainty. Applying a single minimum value of SL (i.e. a value with a very low likelihood of being exceeded) in the process of WLC will be very conservative as all of the components, by definition would be expected to achieve a longer life than predicted. This will also be the most expensive option in terms of the forecast expenditure and perhaps, therefore, the least competitive.

Applying a range of SL values would be an advance by recognising that every element of a particular type will not have to be replaced at the same time. Replacement cost can be spread over a period of time, enabling a more reliable estimate of the life cycle costs. This is illustrated by an example in Figure 2.2. If there are 20 items to be replaced and a minimum SL value is used in the WLC calculations, then all of the cost of replacement is incurred in year 25. If a range of values is specified, say 25 to 35 years, and it is assumed that there is a linear rate of failure, then the calculation assumes that only 2 items are replaced in each year between 25 and 35 years and the estimated cost is spread accordingly. This has a significant benefit with regard to estimated cash flow and if the contract period happened to be 30 years, it would also impact upon the total WLC.

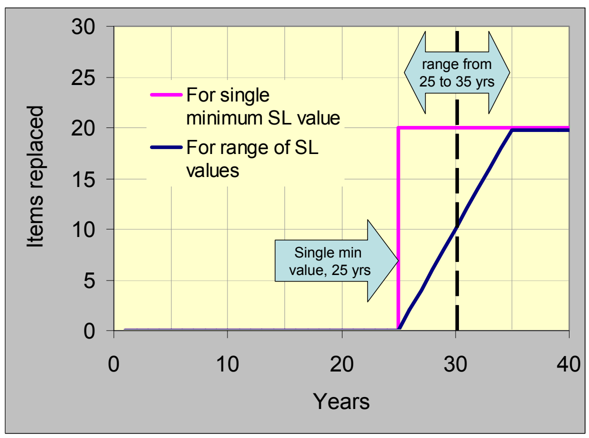

Figure 2.2 *Comparison of the implications of assuming a single minimum SL value and a range of SL values.*

Adopting a range of SL values in WLC is clearly beneficial over the application of a single value, but this approach is still limited inasmuch as the rate of replacement between the limiting values is not defined. In the above example a linear rate of replacement was assumed but this may not apply. To provide a higher degree of rigour, a statistical representation of the rate of replacement may be used provided that there is data to support it. Such an approach enables the rate of replacement to be modelled more accurately and is therefore likely to provide a more reliable estimate of the WLC.

2.5.2 Factors used to qualify service life

A value of service life is of little value without qualification. On the one hand suppliers may provide similar values of service life but based on very different conditions, while on the other hand very different values of SL may be given for products with similar performance because they have been derived under different conditions. Values of SL must, therefore, be qualified and normalised to a standard set of conditions if they are to be used for comparative purposes. Table 2.2 gives the factors considered to be of importance for qualifying service life listed in order of preference. Interviewees were asked to rank each 'qualification' on a scale from 1 – essential, to 4, unnecessary. The results have been processed to present an average percentage score. [100 would represent all interviewees considering the item 'essential' and zero would represent all of the interviewees considering the item to be unnecessary].

Table 2.2 *Factors for qualifying service life*

Qualification of service life	UK	Lifetime
The period	95	92
The condition (limit state), CLS, that defines the end of service life	67	90
The exposure conditions	67	88
The operating condition	71	69
The deterioration mechanism(s) leading to the CLS	53	65
The maintenance regime	73	63
The probability of the CLS being achieved within the service life	48	60
The consequences of achieving the CLS	48	58

The period may seem obvious as the first choice, but service life is not always defined by a time period; it may be defined by a duty level. The condition limit state and the exposure conditions were also considered to be very important by the Lifetime members. The remaining factors were all given lower importance. Again the results from the Lifetime survey and the UK survey differed. First of all, the Lifetime members attached greater importance to all qualifying factors. In particular, the UK respondents attached much more importance to the maintenance regime, indicating their more practical involvement than the Lifetime members.

The sources of information most often used by the respondents are shown in Table 5 together with a reliability score. Product suppliers are most commonly used to obtain SL data, with previous experience of the organisation or the individual following closely with codes and standards.

2.5.3 Current sources of information

The sources of information most often used by the respondents are shown in Table 2.3 together with a reliability score. Interviewees were asked to score each option by frequency of use (from 1, frequently to 4, never) and by their perception of the reliability of the information (from 1, best, to 4 worst). Again the results have been processed to show percentage scores. [For 'use', 100% would represent a situation in which all of the respondents used the source frequently while 0 would represent a situation in which the source was never used by any of the respondents. For 'reliability', 100% would indicate that all of the respondents considered the source to be 'best' and 0 would indicate that all of the respondents considered the source to be 'worst'].

Perhaps not surprisingly, product suppliers are most commonly used to obtain SL data. This would fall in line with current CPD requirements. Previous experience (from projects, in-house or personal experience) was also heavily relied upon as were codes and standards and consultants

Table 2.3 *Currently used sources of information and their perceived reliability*

	UK		Lifetime	
Information sources	Use	Reliability	Use	Reliability
In-house expertise	80	70	88	78
Previous projects	80	74	84	87
Personal experience	71	65	78	78
Research Institutes	62	71	71	85
Product suppliers	82	49	64	46
National Guidance Documents	71	57	62	60
Universities	32	52	49	77
Codes and standards	73	67	45	67
Professional Institutions	56	65	45	67
Commercial databases	43	48	36	48
Trade Associations	51	43	31	37
	Mean	60	Mean	66

It might be expected that the preferred sources would be considered to be the most reliable and that there would therefore be a relationship between use and reliability. The observed relationship is shown in Figure 2.3. As expected, the use of most information sources is related to their perceived reliability. It is apparent however that in both surveys both product suppliers and trade associations were perceived to offer the least reliable information (as indicated by the highlighted points in Figure 2.3).

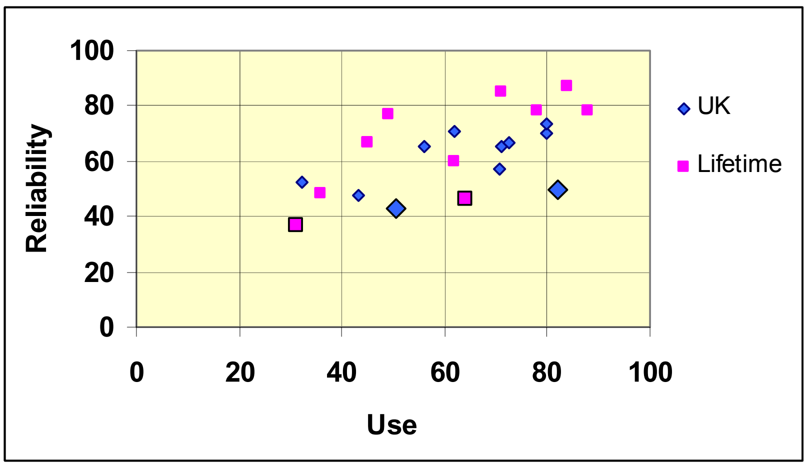

Figure 2.3 *The relationship between Use and perceived Reliability of data sources*

This is at first surprising, as it might be expected that suppliers and trade associations would have the greatest understanding of the performance of their products. An issue here is trust, and the belief that suppliers may oversell their products. This view is supported by the fact that suppliers are rarely willing to offer guarantees which match SL values. But in the support of the suppliers, the performance of many products is determined by the installation process and the suppliers may have little or no control over this.

It is also interesting to note that the Lifetime members generally considered data to be more reliable than the UK respondents, the only exceptions being product suppliers and Trade Associations. In both surveys, in-house knowledge, personal experience and previous project information were all rated as being among the most reliable and most used sources.

Another issue that has been raised by several respondents is that it may not be possible to develop a standard database format. However, guidelines may be developed to ensure that, whatever the format, the information is presented such that it may be used in the process of Lifetime Engineering in such a way that the risks may be understood and managed.

2.5.4 Other issues arising from the interviews

During the UK interviews (both full and short) a number of recurring themes emerged as follows, but in no particular order of priority.

As built quality – there are still considerable problems arising during construction and installation that have a major impact on service life. While manufacturers may issue detailed instructions for the correct installation and use of the products, instances are all too common of these being disregarded because of ignorance or expediency.

Changes in specification or supply - these cannot always be predicted and may result in marked changes in performance and service life. One respondent sadly commented: "Most people who put up buildings don't give a s*it". Excellent products could last for the life of buildings but installers use the cheapest." In some cases substitution of materials takes place under pressure of time because the correct items are not immediately available. Such changes may go unrecorded, so that subsequent assessment of performance may not be a true reflection of the original design capability. When equipment becomes obsolescent, difficulty in obtaining spare parts may result in the need for replacement rather than repair.

The contractual/commercial set up - the low (capital) bid culture makes standardisation of components and suppliers difficult. Partnering in the supply chain, where the supplier has an interest in whole life costs for a number of contracts over a long time, may help to encourage standardisation rather than allowing a proliferation of suppliers each supplying different products for the lowest initial cost at the time.

The impact of exposure conditions - there is a lack of appreciation of the impact of different environments. Where suppliers are asked for information on the performance of the products, they will normally give details of performance under 'standard' conditions (which will be relatively benign) and supply information regarding 'difficult' or 'aggressive' environments only when specifically asked. Insufficient attention is given to both the initial environment and that following a change of use.

Definitions are not rigorous - while it is desirable to keep things simple, e.g. a single figure for service life, this prohibits realistic design and fails to acknowledge variations that occur in practice. There is still little thought given, in some cases, to what condition limit states are and in particular how they are quantified and measured. Without quantification, deterioration cannot be predicted, and without measurement the need for intervention cannot be established. . There was a variety of responses to the question of how service life should be defined, with people tending to prefer a single value (unqualified, minimum, or characteristic).

FM input at the design stage is missing – whole life performance is therefore not optimized. Access/down-time for maintenance and standardisation of components and fittings are two particular areas where an early FM input can result in considerable whole-life cost savings. Maintenance costs can be minimized by placing machinery where it can be serviced in situ or readily exchanged with minimum disruption to the operational use of the building (e.g. heavy plant positioned on the roof with crane access). One respondent cited the case of an architect specifying 20 different varieties of luminaire, reduced to four or five after the FM had explained the prohibitive cost of supporting so many types.

Expectations may be too high for new components - often early maintenance is not properly implemented and we bother less with what cannot be seen, e.g. roofs. This can lead to loss of warranty and premature deterioration. Typically a roof may require inspection every 6 or 12 months to comply with insurance or warranty requirements. Any defects such as wind damage, ponding, corrosion or blocked gutters would have to be rectified, or the subsequent deterioration would not be covered. There may also be a requirement for cleaning. However, the design of the roof may be such that access is difficult so that inspection and cleaning are discouraged by the expense of erecting scaffolding, etc.

Building fabric is much more difficult to deal with than services - the latter tend to have shorter lives and more historical data which can be used to predict performance. While a large database may exist to help assign servicing intervals and schedule replacements for plant and machinery, many of the fixed parts of buildings may have limited comparators. A design life of 30 or 60 years will have to rely on accelerated ageing tests and extrapolation calculations where the materials used have not been in service that long.

2.5.5 Summary of survey results

Integrated lifetime engineering involves the development and use of technical performance parameters to provide some assurance that an asset will continue to fulfil the user requirements, and will meets the broader needs of cultural, social and ecological considerations, throughout its life cycle. The design process thus aims to balance these objectives is as cost-effective manner as possible. Hence Whole Life Costing is an integral part of lifetime engineering.

By definition, lifetime engineering involves making future predictions about performance. In an ideal world we would fully understand the way in which building components and materials deteriorate and be able to model these processes to be able to predict precisely when interventions are needed by way of maintenance, repair or replacement. We would also know exactly how much these interventions cost and thus be able to develop life cycle cost profiles that would be close to reality. But in the real world the one thing that is certain is that any predictions that we make will not be achieved in practice. The real skill, and need, of lifetime engineering is not in predicting exactly what will happen in the future, but in understanding the extent to which we may be wrong, and managing the risk accordingly. Any prediction must therefore be presented with a level of qualification and confidence and to do this we have to use statistics and a probabilistic, or risk based approach. This necessarily leads to the requirement for data that is expressed statistically.

Accepting this approach leads to a better understanding of what data is required and how it has to be presented in order to undertake lifetime design in a rigorous way.

3 Typical Sources of Service Life Data

As discussed previously, the ability to estimate the SL of materials and components is essential in the process of Lifetime Engineering. While there is not an abundance of publicly available service life data, some sources do exist in the UK from which service life data may be derived as follows.

3.1 HAPM (Housing Association Provident Mutual) Manual

HAPM [8] offers insurance on Housing Association developments in the UK. The manual provides 'insured' life values for insurance purposes and covers all of the components of domestic dwellings as follows

- Flooring components
- Walling and cladding components
- Roofing components
- Doors, windows and joinery
- Mechanical equipment components
- Electrical equipment components
- External works and outbuildings

HAPM reviews the specification, the design and the construction process and if all requirements are met the declared insurance period is offered. The way in which cover is provided is shown in Figure 3.1 which gives an example for a 30-year insured life.

For the first half of the period, full replacement costs are covered, hence it may be assumed that HAPM have judged that there is a very low probability of failure within this period. For the second half of the period the amount of insurance cover reduces linearly such that at the end of the period no further cover is offered. From this it may be assumed that the probability of failure increases over the second half of the period and that at the end of the period the probability of failure is high.

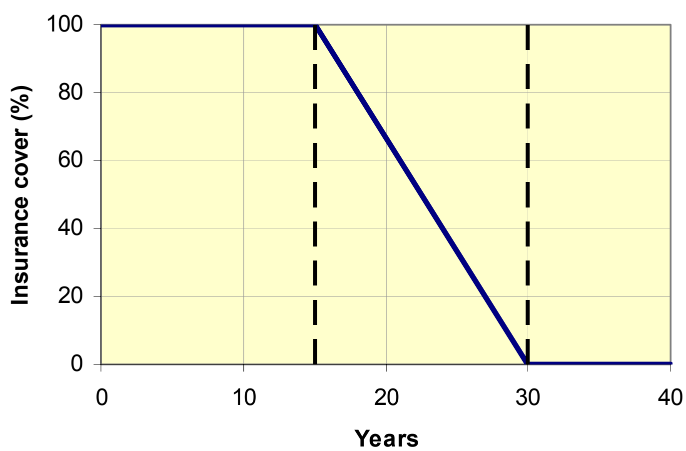

Figure 3.1 *Level of insurance cover provided by HAPM as a percentage of the full replacement cost for an element with a 30-year insured life*

Hence the level of the insurance that is provided may be interpreted in relation to the probability of failure that HAPM have predicted, as shown in Figure 3.2. Also shown is the cumulative probability curve for a component with a mean service life of 22.5 years and a Standard Distribution of 5 years. This provides a very close fit with the linear HAPM curve over most of the period.

This provides a useful demonstration of the need to define precisely what the declared SL means. For HAPM, the declared value, in this example, of 30 years is the MAXIMUM period over which they are willing to offer insurance, This may also be interpreted as being equivalent to a component with;

- a minimum insured life of 15 years
- an insured life in the range from 15 to 30 years
- a mean insured life of 22.5 years (with an SD of 5 years)
- a characteristic insured life (at a 5% probability level) of 14.3 years (mean – 1.64 x SD)

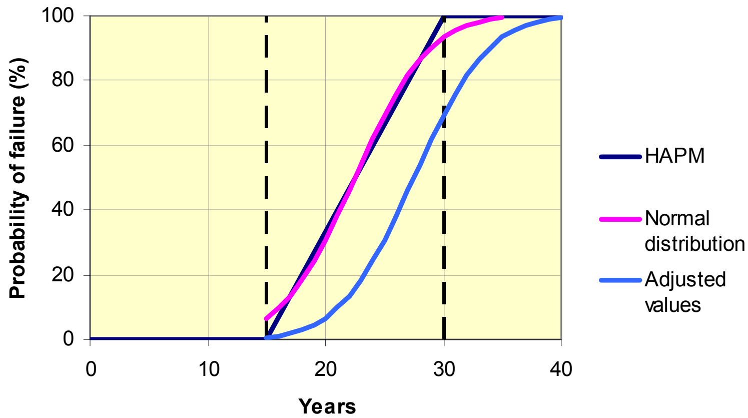

Figure 3.2 *Interpretation of the HAPM insurance cover in terms of the probability of failure*

The HAPM Manual was first published in 1992 and the advantage of this system is regular feedback from insurance claims and the ability to adjust the SL values to reflect real performance. Because the HAPM Manual provides 'insured lives', the lives quoted are acknowledged as being conservative. Where the information is to be used for other purposes, such as maintenance scheduling and life cycle costing it is recommended that users apply there own adjustment factors. For example, the SL could be assumed to be increased by, say 5 years, as shown in the example in Figure 3.2.

3.2 BPG Building Fabric Component life Manual

Following the success of the HAPM manual, BPG prepared a Building Fabric Component Life Manual [9] under the sponsorship of the Defence Estates Organisation of the UL Ministry of Defence. It covers 'building components, materials and assemblies used in typical commercial, industrial and public building types' and was published in 1999. It covers the following,

- Flooring components
- Walling and cladding components
- Roofing components
- Doors, windows and joinery
- Stairs and balustrades
- Internal fixtures and fittings

3.3 Building LifePlans – Building Services Component Life Manual

In 2001 BPG followed the Building Fabric Component Life Manual with a manual specific to building services, also commissioned by Defence Estates [10]. This covers the following components.

- Piped supply systems
- Mechanical heating/cooling/ refrigeration systems
- Ventilation/air conditioning systems
- Electrical and lighting systems
- Controls and security systems
- Transport systems

The concept of 'insured' lives was maintained but the introduction of BS ISO 15686: Part 1 led to the addition of the adjustment of service life values based on the seven factors affecting plant longevity. This approach is described in more detail in Section 4.

3.4 Life Expectancy of Building Components

In 2001, the RICS (Royal Institute of Chartered Surveyors) undertook a survey of 80 building surveyors to collect information on the service life of components [11]. Information was collected as minimum, most likely and maximum SL values for a wide range of building components.

The report also highlights the factors that may affect the deterioration or failure of the components. The life expectancies in the BMI report are based on the assumptions that the components a) were installed in accordance with manufacturer's instructions and other recognised methods, b) were in compliance with all relevant regulations governing installation and use, c) were subject to moderate exposure and d) were maintained in accordance with manufacturer's guidelines.

Although most common building components are identified, the BMI guide is not exhaustive and only refers to buildings and not civil engineering. Furthermore, the results do not take into account specific design, construction, location, positioning, local ground conditions, air quality, loading or misuse that may occur. Hence the ranges of values are very wide. However, with a general understanding of the range of conditions that prevail in the UK, and knowledge of the conditions pertaining to a specific project, the range of values may reduce to more practical levels.

The results are presented in - Life Expectancy of Building Components, Experiences of buildings in use [11]. This information has been used to provide benchmark data within the EuroLifeForm database and is presented as Minimum, Most Likely and Maximum values.

3.5 The nature of service life data

It is clear from the above review that service life data is tending to be presented not as a single value (even if that is the initial impression) but as a range of values with some statistical significance. This clearly makes sense as in reality the time to failure for essentially similar elements does vary significantly (consider the simple and obvious example of light bulbs).

4. Adjusting Service Life data for project specific conditions

When SL data is provided it should be related to reference conditions under which the stated value applies. Where the project conditions differ from the reference conditions the SL value must be adjusted to reflect the se differences. A difficulty with service life prediction has been that there has been no standard approach. BS 7543 [12] offered some guidance on how to specify for durability but fell short of offering a specific method for deriving service life. However, guidance on Service Life Planning is now available through ISO 15686 [13] and while this approach is not yet accepted universally and has attracted some criticism, it does at least offer a standardised approach for dealing with Service Life. In particular it highlights the critical factors, many of which were identified as part of the industry survey, and encourages the designer/specifier at least to consider how these factors will impact upon performance over the long term (Figure 4.1).

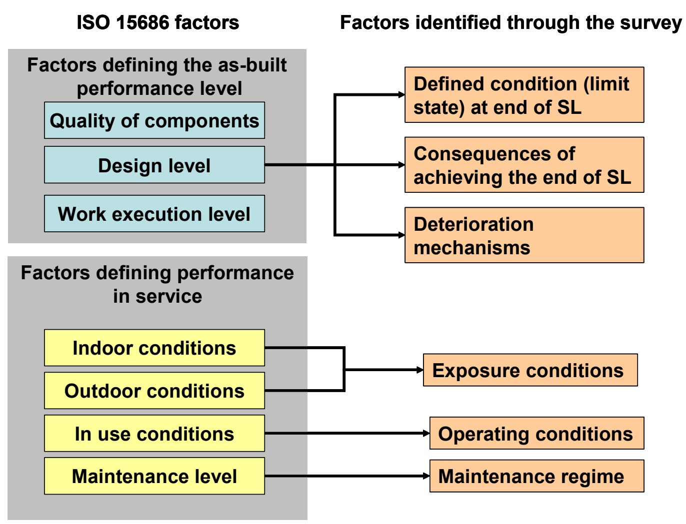

Figure 4.1 *A comparison between the ISO factors and factors identified in the survey*

The ISO factor method provides a way of deriving an estimated service life (ESL) for a particular construction component or assembly in specific conditions. It is based on a reference service life (RSL), which is normally taken as the service life (SL) or durability of a component or assembly in a well-defined set of in-use conditions, and a series of modifying factors that relate to the specific conditions of a project. The SL is the period of time after installation during which a building or its components meets or exceeds the required performance.

The factor approach for service life planning need not be applied to all components – for example those that are lifelong and do not need maintenance. However it is important that those components or sub-components whose performance is critical to the performance of the building or main component are considered, along with those that may have been selected because they are costly to install. A roof leak over a computer suite may be a disaster and requires immediate attention, whereas a leak to bike shelter may be tolerated. A sub-component such as a glazing gasket may fail before the window frame, and so on.

The modifying factors are described in more detail in the Table 4.1 and a more detailed explanation of this approach is given in ref [14].

Table 4.1 *The ISO 15686 factors*

Agents and factors		Relevant Conditions (examples)	
Agent related to the inherent quality characteristics	A	Quality of components	Manufacture, storage, transport, materials, protective coatings (factory-applied)
	B	Design Level	Incorporation, sheltering by rest of structure
	C	Work execution level	Site management, level of workmanship, climatic conditions during the execution work
Environment	D	Indoor environment	Aggressiveness of environment, ventilation, condensation
	E	Outdoor environment	Elevation of the building, micro-environment conditions, traffic emissions, weathering factors
Operation Conditions	F	In use conditions	Mechanical impact, category of users, wear and tear
	G	Maintenance level	Quality and frequency of maintenance, accessibility for maintenance

Any one or any combination of these variables can affect the service life. The factor method is expressed as a formula:

ESLC = RSL(of the component) x factor A x factor B x factor C x factor D x factor E x factor F x factor G

The starting point for calculating the ESL is the reference service life (RSL). This is the period that the component or assembly can be expected to last in a reference case under certain well-defined service conditions. The RSL is based on the following, as appropriate:

- data provided by a manufacturer, a test house or an assessment regime - for innovative components it will normally be based on the manufacturer's or supplier's exposure results and may be a single figure or a distribution of typical performance;
- previous experience or observation of similar construction or materials or in similar conditions;
- Boards of Agreement in the EC state assessments of durability in their certificates or reports of national product evaluation services;
- some reference books which include typical service lives;
- building standards or codes which give typical service lives for components.

Any reference case from which the reference service life is taken should be as similar as possible to the specific project in terms of service conditions. The factors are applied to represent deviation from the assumed conditions in the reference service life. In this way, values of the factors will be as close to unity as possible, to minimise the uncertainty inherent in the methodology.

To obtain a reasonable indication of the magnitude of each of the adjustment factors, the specifier must be able to define the project specific conditions that apply and the supply must be able to define under what conditions the RSL data will apply.

Factors of less than 1 reduce the estimated service life; factors of more than 1 increase it. The reliability of the reference service life figure is critical, as it will affect the estimate proportionally.

The estimated service life is the result of the application of factors to the reference service life a shown in the example in Table 4.2

Table 4.2 *Sheet steel roofing – reference service life 30 years*

Factor	Project	Reference	Difference	Adjustment
Quality of components	Galvanised mild steel 275g/m^2 zinc, organic coating	Galvanised mild steel 275g/m^2 zinc, organic coating	None	1
Design Level	Light steel frame, insulation, vapour barrier, plasterboard	Light steel frame, insulation, vapour barrier, plasterboard	None	1
Work execution level	No repair of damaged coatings	Damaged coatings repaired	Construction damage not repaired	0.9
Indoor environment	Heated, warm frame	Heated, warm frame	None	1
Outdoor environment	Industrial pollution	Science Park, low pollution	More aggressive environment	0.9
In use conditions	Appropriate use only	Appropriate use only	None	1
Maintenance level	none	Manufacturers recommendations	No regular maintenance	0.8
Adjustment to Reference Service Life = 1 x 1 x 0.9 x 1 x 0.9 x 1 x 0.8 =				**0.65**

Calculation of estimated service life

ESL = 30 x 1 x 1 x 0.9 x 1 x 0.9 x 1 x 0.8 = 19.4 years

ESL = RSL(of the component) x factor A x factor B x factor C x factor D x factor E x factor F x factor G

The factor approach will not provide an assurance of service life and is subject to a degree of subjectivity, particularly in the selection of the magnitude of the adjustment factors. Nevertheless, adopting the principles embodied in all three parts of ISO 15686 does provide a pragmatic methodology for considering the key issues that affect the performance of building components and materials and providing 'trigger' service life data and intervention events for whole life costing.

5. Cost Data

5.1 Data Requirements

Extensive cost data are required to enable Whole Life Costing (WLC). The principal cost items include;

- Costs associated with the procurement of the built asset
  - Concept and detailed design
  - Construction
  - Commissioning
- Costs associated with the operation of the built asset
  - Planned preventative maintenance
  - Replacement costs
  - Repair costs
  - Soft FM (e.g. cleaning)
- Utilities
  - Power
  - Water
  - Waste management
- Costs for decommissioning
  - Demolition
  - Refurbishment
  - Residual value (if reused or recycled)

Consequential costs, for example, as a result of the business process being disrupted during maintenance, repair or replacement activities, must also be taken into account. For this reason it is important to work very closely with the client to understand how the business operates.

Hence, to undertake a rigorous WLC analysis, data are required for each of the above items. Publicly available data for WLC are scarce, however. The principal reasons for this are as follows;

- Costs are very contract specific and may be determined by particular commercial agreements or strategic alliances within a supply chain
- Contractors consider such data to be their commercial differentiator and are generally unwilling to share this information with competitors

Furthermore, costs are made up of several components, principally, materials, equipment and labour. Both the absolute and the relative values of these cost components will vary around Europe and any attempt to develop a cost database that is applicable across Europe is likely to end up as a series of National databases. It is important, however, that all databases include the same basic information that is needed to estimated the costs as follows

- Materials and components – with a clear description of what is (and what isn’t) included
- Equipment (required for installation, maintenance and removal, including access)
- Labour (expressed as man-hours or man-days) required for installation, maintenance and removal.

Appropriate costs relevant to the location of the structure may then be attached to these items.

5.2 Recording cost data

Because of the lack of publically available cost data and the commercial sensitivity of that which is available, it is very important to obtain feedback from existing built assets and to maintain an up-to-date in-house database. In the UK, the Whole Life Cost forum has established a web-based tool for the confidential collection of project specific cost data. This is a subscriber service, with each user being allocated a protected area for storage of data and is available at www.wlcf.org.uk . The confidential data can then be loaded into a general database anonymously to enable comparison with other information and to establish general cost indicators.

As part of the EuroLifeForm programme a much more comprehensive, electronic project 'Log-Book' has been developed to enable information to be recorded at each stage of the design, construction, commissioning and de-commissioning process. www.eurolifeform.com. The Log-Book structure is shown in Figure 5.1. It is set up at client brief stage and updated through design, construction, commissioning, operation and decommissioning.

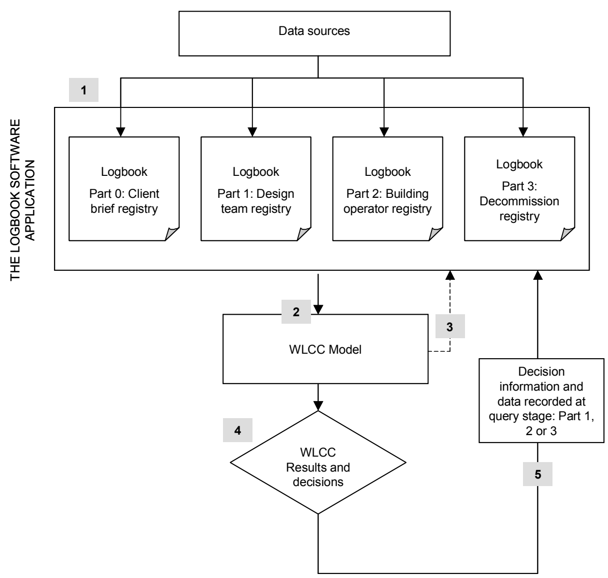

Figure 5.1 *Eurolifeform Log-book structure*

5.3 Future costs

A critical aspect of WLC is the use of Present Value or Discounted Cost. This takes account of investment costs (interest rates) and inflation rates and this requires that judgements must be made about future cost. While interest rates will be determined by the financial markets, the same general inflation figure may not apply to every cost component. For example, it is very likely that energy costs will increase faster than the general rate of inflation, while the real cost of electronic components may decrease. When collecting WLC data, estimates of likely future cost should, therefore, be component specific.

The influence of using Present Value is shown in Figure 5.2. It can be seen that using a discount rate of only 6%, the Present Value is halved in about 12 years.

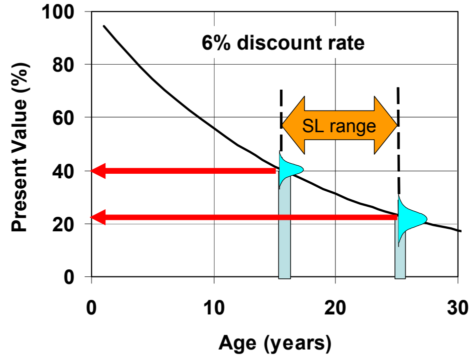

Figure 5.2 *Present value at 6% discount rate*

While specific cost data may be hard to come by, for a particular component, in a defined environment, the performance will be predetermined, if not entirely predictable and SL itself has a significant impact on cost. Improving the as-built quality to extend service life delays the time to intervention. This has two significant consequences

1. The number of replacement cycles is reduced
2. The present (discounted) value of each intervention is reduced

Furthermore, recognising that an asset may have a SL of 25 years or more, it must be appreciated that the operating costs may be considerably higher than the capital costs. On this basis, additional capital expenditure may be WLC effective when costs are discounted. An example is shown in Figure 5.3. In this case it is assumed that the capital cost is doubled to increase the SL by 50%. At 6% discount rate, the WLC of the more expensive option is the most cost effective if the asset has a SL beyond 25 years.

	Option 1	Option 2
Capital Cost	100	200
Replacement cycle	8	13
Maintenance p a	2	2

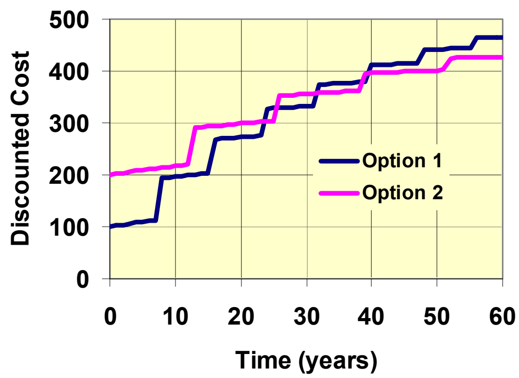

Figure 5.3 *A comparison of options with differing capital cost and SL values*

It is clear, therefore, that in order to undertake WLC, data is required not only on the specific cost of components and the costs associated with their replacement, but also how these costs are likely to change with time.

6. An approach to Service Life prediction.

6.1 Defining Service Life

The way in which service life is defined will depend to a large extent on the use to which the value is being put. In practice, SL values are used to enable maintenance and life cycle replacements schedules to be prepared and from this information whole life costs and cash flow to be derived. To prepare a maintenance and replacement programme, specific SL values are required, but it is clear that SL values are not discrete. Similar components will not all fail at the same time.

A way to deal with is dilemma is to define SL as the time at which the likelihood of failure reaches an unacceptably high level. An example is shown in Figure 6.1, for which the SL is the time at which the probability of failure exceeds 10%. Of course the acceptable likelihood of failure will vary according to the consequences of failure and it would be expected that if the consequences are severe then intervention must take place when the likelihood of failure is very low. Conversely if the consequences of failure are mild then a higher probability of failure may be acceptable.

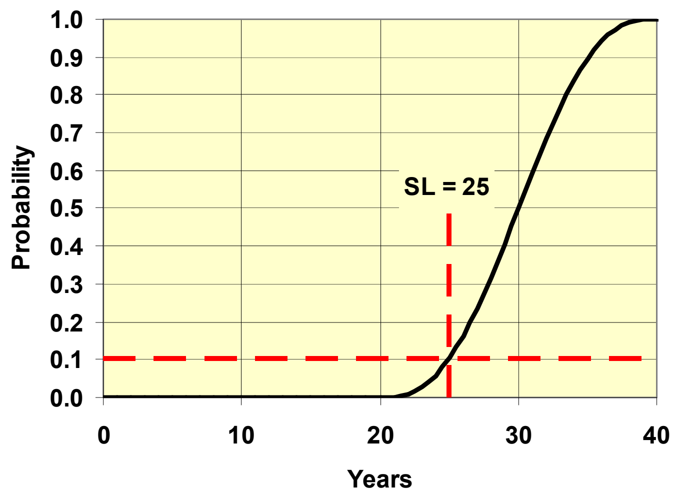

Figure 6.1 *Defining Service Life in relation to the probability of failure*

While it is not declared explicitly, this approach to SL definition is already used in practice. When a 'Minimum' value of SL is provided it is, in fact, a value below which the supplier believes that the likelihood of failure will be acceptably low. What is 'acceptably low' will be determined primarily on commercial grounds, including not only the costs but also customer relations. The period of warrantee will have been established on the same basis and is not a guarantee that failure will not occur, only that the supplier is taking the financial risk during that period. In terms of WLC however, it may be reasonable to assume that the warrantee period represents a minimum SL value.

An example of where a SL value is clearly statistically based is the HAPM approach (section 3.1). In this case it is the maximum insured life that is presented, but the linearly reducing cover between half insured life and full insured life indicates the increasing probability of failure.

A particular benefit in using this approach to defining SL is that a quantitative assessment of the impact of assuming different SL values may be established. As an example, consider the process of developing a replacement life cycle plan as shown in Figure 1a. Because SL values are often quoted in multiples of 5 years, it is common that there will be years within which the replacement of several components is coincident, resulting in very high expenditure and excessive disruption. To avoid this, the interventions may be spread over several years, bringing some replacement cycle forward and moving other back. With knowledge of the probability of failure and the consequential risks, the spreading process may be undertaken on a rational basis, bringing forward the high risk items, but moving back those items for which the increasing risk is considered to be acceptable.

6.2 Generating Statistical SL data

It is very rare to find extensive statistical data on the performance of building components. The BMI data is presented as minimum, most likely and maximum values, but covers a variety of exposure and in-use conditions, hence the spread is very wide.

HAPM uses a statistical approach, the linear reduction in insurance cover reflecting a linear increase in the probability of failure (section 3.1). More commonly, no statistical data are available but an estimate of the distribution of service life may be obtained by interrogation of the product supplier. By obtaining a range of likely values of SL (lower, most likely and upper bound values) a triangular distribution may be established. A cumulative probability curve for a triangular distribution with minimum, most likely and maximum SL values of 10, 20 and 30 years is shown in Figure 6.2. This is almost exactly the same as a normal distribution with a mean of 20 years and a SD of 4.3 years, or a Beta distribution with the same range and Alpha and Beta coefficients of 3, also shown.

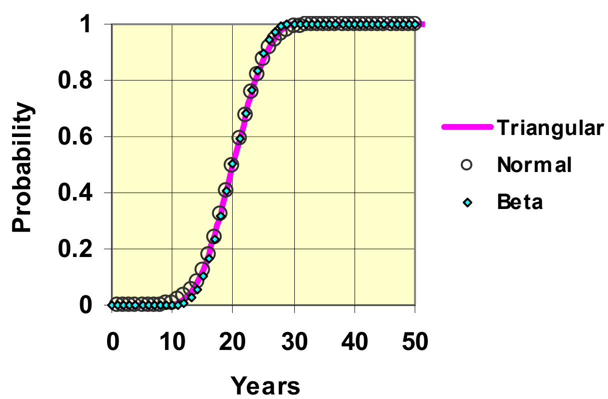

Figure 6.2 *Probability curve based on a triangular distribution with minimum, most likely and maximum SL values of 10, 20 and 30 years and comparison with Normal and Beta distributions...*

A more flexible statistical distribution, however, is the Beta distribution. This enables a wide variety of distributions to be accommodated. It is similar to a normal distribution, with the main exception that it has upper and lower limits (a normal distribution has limits that very from –infinity to +infinity). The Beta distribution is defined by Alpha and Beta values and the lower and upper bound values. The Alpha and Beta coefficients change the shape of the distribution curve as follows (see Figures 6.3)

1. When Alpha and Beta are equal, the distribution is symmetrical
2. When Alpha and Beta both equal 1, the distribution is linear
3. When Alpha and Beta are greater than 1 the curve is a typical S-curve and is very similar to a normal distribution curve
4. When Alpha and Beta are less than 1 the distribution is a reflected S-curve about the linear distribution

5. When Alpha and Beta are high the distribution is compressed towards the most likely value
6. When Alpha is higher than Beta the distribution is skewed towards the maximum value
7. When Beta is higher than Alpha the distribution is skewed towards the minimum value

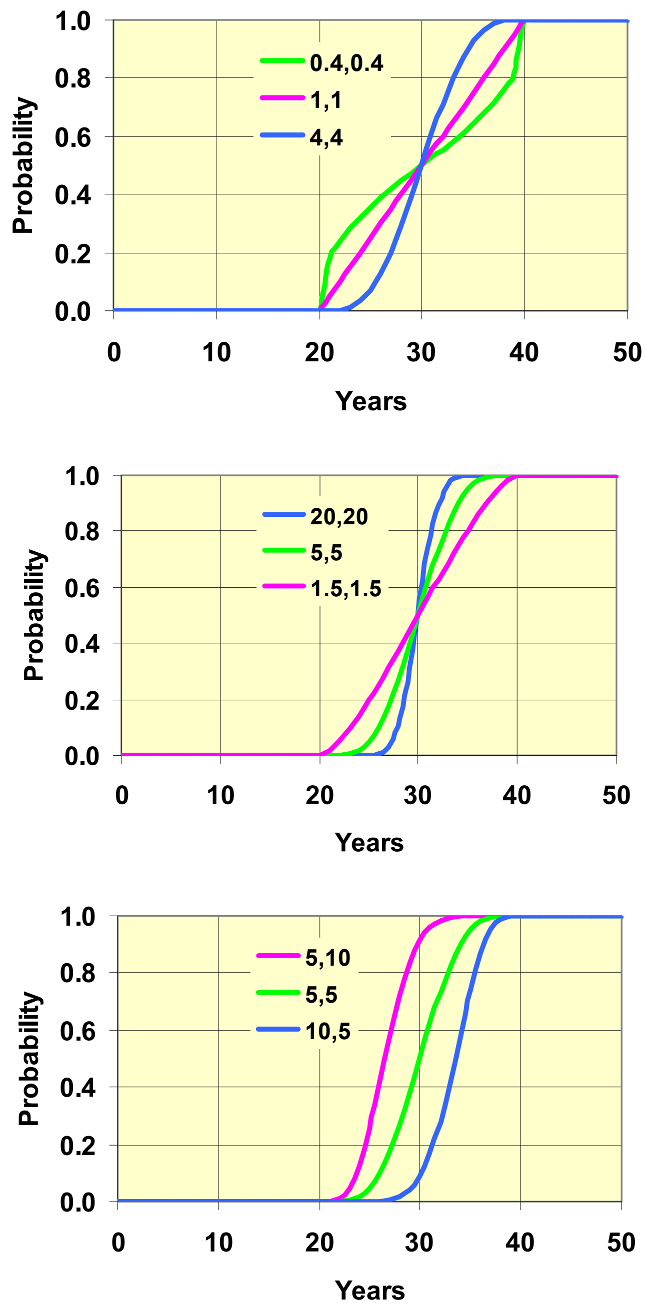

Figure 6.3 *Beta distributions with varying Alpha and Beta coefficients for a distribution within the range 20 to 40 years [The legends show Alpha, Beta]*

As an example, the HAPM approach implies a linear cumulative probability distribution. This can be can be represented by a Beta distribution, where Alpha and Beta both equal 1, the minimum value is half the insured life and the maximum value is the full insured life.

Thus, when collecting SL data the following questions should be asked

1. What is the minimum SL?
2. Is this a true minimum value i.e. the probability of failure before this time is zero or the risk is entirely covered by the supplier?
3. If the quoted minimum value is not a true minimum, then what is the probability of failure at this time?
4. What is the maximum SL?
5. Is this a true maximum value i.e. the probability of failure beyond this time is zero?
6. If the quoted maximum value is not a true maximum, then what is the probability of failure at this time?
7. What is the most likely SL?
8. If the most likely SL cannot be quantified then is it likely to be closer to the minimum value or the maximum value.

With the answers to these questions a probability curve may be derived. An example is shown below in Figure 6.4

1. What is the minimum SL?	**20**
2. Is this a true minimum value i.e. the probability of failure before this time is zero or the risk is entirely covered by the supplier?	**NO**
3. If the quoted minimum value is not a true minimum, then what is the probability of failure at this time?	**0.05**
4. What is the maximum SL?	**40**
5. Is this a true maximum value i.e. the probability of failure beyond this time is zero?	**NO**
6. If the quoted maximum value is not a true maximum, then what is the probability of failure at this time?	**0.95**
7. What is the most likely SL? I.e the value at which trhe probability of failure is 50%	**28**
8. If the most likely SL cannot be quantified then is it likely to be closer to the minimum value or the maximum value.	

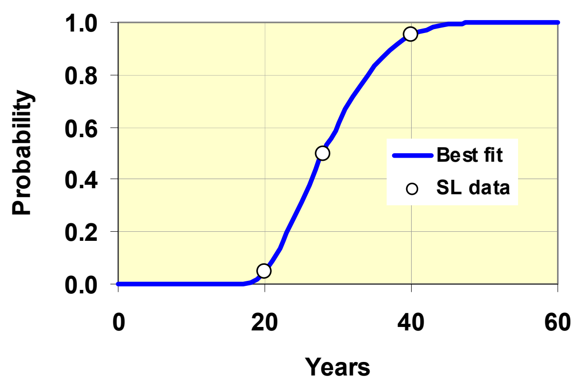

Figure 6.4 *Beta distribution derived from SL data [Minimum = 17.2, Maximum = 55.1, Alpha = 2.13, Beta = 4.89]*

7. Environmental and Societal Impacts

Rigorous data on impact on the environment and society was difficult to come by. Much of the available information has been used to develop life cycle assessment tools for which the output is a score or rating. The specific information and assumptions upon which these scores and ratings are developed are not always declared and the processes themselves are not always transparent. In providing recommendations for data collection and presentation, therefore, guidance is only possible in relation to those factors that need to be considered. The way in which they are then dealt with will be very project specific, with different clients having different priorities

7.1 Environmental Impacts

While environmental assessments are presented and undertaken in a variety of ways, all generally involve three principal items

- Resources
- Energy
- Pollution

Water usage is also very important and is often considered separately, although this does fall within the general heading of resources.

These four principal areas cover a range of issues as follows.

7.1.1 Use of resources

The principal concern here is the conservation of primary material sources and this may be dealt with in several ways. In terms of Lifetime Engineering, assessments should be based on the following factors

- Efficiency of the use of primary sources – not denial of use
- Good husbandry of primary material supplies
- Waste reduction, during construction, operation and decommissioning
- Re-use and re-cycling of materials and components
- Protection of renewable sources

In addition to the broad aim of achieving sustainable construction, there are often financial incentives to avoid the use of primary materials (e.g. the UK primary aggregate levy) and to avoid waste (avoidance of landfill tax). Having a ‘Green’ image may also be a differentiator with more enlightened clients and in particular Government contracts.

With regards to waste there is a hierarchy as follows

- REDUCE waste
- REUSE materials
- RECYCLE waste materials
- RECOVER ENERGY from waste
- REDUCE landfill

7.1.2 Use of energy

Energy is used at all stages of the life of an a built asset, including winning of raw materials, manufacture of materials and products, the construction process, operation and maintenance and decommissioning. The construction sector and the operation of buildings accounts for over 60% of the energy usage in the UK (Figure 7.1), hence there is considerable scope for savings. It is also apparent that the cost of energy is likely to rise substantially over the life of structures being currently built, as natural resources (oil, gas and coal) diminish.

Much of the energy in use is required for environmental conditioning and in this area alone considerable advances are being made. For example, passive ventilation – reducing reliance on M&E – offers financial gain not only through reduction in energy but also on maintenance. Coupled with design for energy efficiency – Air tightness and thermal mass, insulation etc – building may be designed to be much more energy efficient than they are currently. The fact that, in the UK, the energy costs for operating a building are more than 5 times the energy used in producing and transporting construction materials indicates that in design the focus, in relation to energy saving, should be on reducing operational energy consumption, rather than the embodied energy in the construction process.

The use of micro energy generation plants on buildings and structures is a possible trend for the future to offset energy costs – Micro wind, solar panels. In this respect there are also advantages in terms of security of supply.

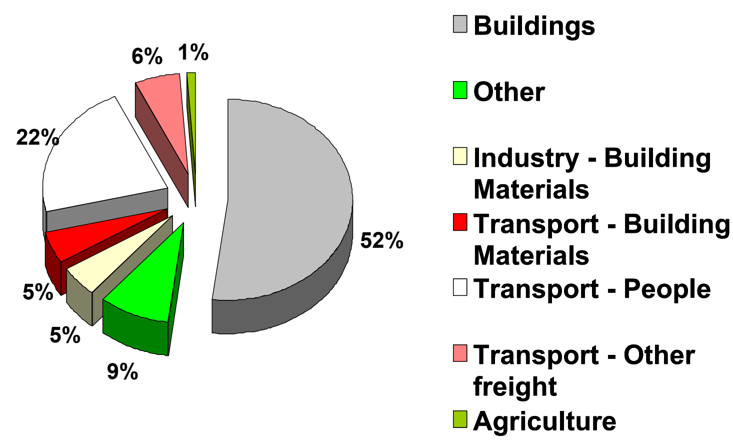

Figure 7.1 *Energy consumption in the UK*

Transport is a particular issue as, in the UK, CO_2 emissions have been increasing in recent years, while emissions form both domestic dwellings and commercial buildings have been reducing.

7.1.3 Use of water

Water is currently viewed as plentiful and cheap but water use is currently increasing quickly. Much of the UK has no further capacity to increase extraction (particularly during summer). With increasing usage it is likely that taxation and legislation may be introduced to penalise excessive use and waste of water. Hence in assessing lifetime requirements and costs, the use of current prices at normal inflation rates is likely to result in a gross underestimate of lifetime costs.

Water efficient appliances are being developed and rainwater harvesting is being introduced (albeit very slowly) to support the landscape, grey water schemes etc.
The value in Sustainable Urban Drainage Systems (SUDS) is also being recognised.
CIRIA http://www.ciria.org.uk/suds

7.1.4 Pollution

Pollution may occur during all stages of the construction and operation of a built asset. Considerable legislation already exists in relation to limits on emissions to the air, the ground and to groundwater and as a minimum requirement, lifetime design should ensure that the appropriate limits are met.

In the UK the government are developing policies which will 'make the polluter pay' hence any costs associated with pollution are only likely to rise in the future.

7.1.5 Life Cycle Analysis

Life Cycle Analysis is a method to measure and evaluate the environmental burdens associated with a product system or activity, by describing and assessing the energy and materials used and released to the environment over the life cycle. Many tools exist and LCA is useful in many respects. For example,

- To measure existing performance and monitor improvements
- To assess benefits of innovative processes
- To compare materials which offer the similar functions, e.g. external wall constructions
- To compare building designs over their expected lifetimes

Based on the above review it is clear that in collecting data the focus should be on the four principal areas of resources, energy, pollution and water.

The following questions are therefore appropriate

General

1. IS the project covered by an environmental management scheme?

Resources

1. To what extent are primary sources of raw materials used?
2. Are these primary sources renewable?
3. If YES to 3, how is the project contributing to these renewable processes?
4. What proportion of the materials/components is reused or recycled?
5. What proportion of the materials/components may be reused or recycled at the end of the asset life?
6. Is there a waste management system?
7. Are materials procured in such a way as to minimise waste?
8. Are materials chosen to be long lasting, i.e. to minimise replacement frequency?

Energy

- for components

1. What is the embodied energy of the material/component?
2. To what extent will the material/component contribute to energy saving in the structure?

- for the structure

3. Is there an Energy management scheme in place?
4. Is the heating/ventilation active or passive?
5. To what extent are renewable energy sources being used (e.g. solar, wind, hydro)

Pollution

1. Are materials chosen to be environmentally friendly?
2. To what extent do project requirements exceed those of the minimum legislative requirements

Water

1. Is water consumption monitored?
2. Are water installations designed to minimize water consumption (e.g. low flush toilets)?
3. Is rainwater collected to supplement the water supply?

7.2 Societal Impact

A UK Government strategy paper in 2004 (Taking it on – Developing UK sustainable development strategy ***together***) presented a set of 10 guiding principles to sustainable development as follows;

- Putting people at the centre
- Taking a long term perspective
- Taking account of costs and benefits
- Creating an open and supportive economic system
- Combating poverty and social exclusion
- Respecting environmental limits
- The precautionary principle (not using lack of full scientific certainty to postpone action)
- Using scientific knowledge
- Transparency, information, participation and access to justice
- Making the polluter pay

The fact that the first of these principles is focused on people, and that many deal with societal issues, stresses the need to include an assessment of societal impact of a project and that this will become an increasingly significant component of the assessment of future projects. Furthermore, in describing sustainable development the strategy paper defines four objectives

- Social progress which recognizes the needs of everyone
- Effective protection of the environment
- Prudent use of natural resources
- Maintenance of high and stable levels of economic growth and employment

Again, the social impact is the first objective, stressing further its importance.

Essentially societal impacts consider the way in which a project will affect individuals and communities and many of the impacts are difficult to quantify. They include the following;

- Health and Safety – Construction
- Health in Operation - Quality of life – Aesthetics - Occupancy satisfaction
- Social inclusion – employment, education, training
- Security
- Business efficiency

7.2.1 Health and Safety

H&S law applies to companies, employees and the self employed and can result in criminal prosecution if the law is broken. It applies to the operation of a built asset as well as its construction. For example, how windows will be washed in operation or how access will be gained to plant etc are all part of design and of CDM requirements.

Managing H&S in construction and in facility management is a requirement of effective business management. Aside from moral considerations, days lost due to accidents can be a substantial burden on a business.

Occupancy satisfaction is also an important issue. It has been suggested that the relative costs to build as asset, to maintain and operate the asset and to run the business within the asset are in the order of 1: 5 : >25. Hence a loss of productivity of, say 4%, which may result from cost cutting during construction to save even as much as 20%, would not be cost effective. Conversely, a capital cost increase of 20% would only have to result in an increase in productivity of 0.8% to be cost effective to the business.

Development should enhance the lives of occupants and the community – not make them sick! (Sick building syndrome). The design should therefore be sympathetic to its surroundings and aesthetically pleasing, and should remain so for the duration of its life, e.g. avoiding rain water staining and adverse weathering. It should also be maintainable In a safe way.

7.2.2 Social inclusion

Everyone has a right to participate fully in society, and to have the opportunity to reach their full potential. A new project may impact on individuals in many ways, both positively and negatively. On the positive side there will be an increase in local employment and this in turn may result in knock on effects for other local businesses. Education and training though employment will also give to a community the ability to improve their lives.

It has also been shown that an increase in the wealth of an area can improve the quality of the local environment and reduce health problems.

Conversely, if these issues are not considered at the design stage there may be a detrimental effect on a local community, for example, if a new building is considered to be an eye-sore, or if due consideration is not given to local transport resulting in an increase in traffic.

7.2.3 Security

Security covers a variety of factors, but most people consider this firstly in relation to personal safety in the community and the security of their homes.

Enhancing security may be achieved through the design process by, for example,

- Providing environmental quality & a sense of ownership
- Natural surveillance
- Access and footpaths – planting.
- Provision of open space and lighting

Security of the supply of utilities and services is also an increasingly critical issue with the increase in the occurrence and severity of both human and natural events.

7.2.4 Business Efficiency

As stated above, the cost of running a business is significantly greater than the cost of building and operating an asset. Providing a sympathetic environment for working can increase both morale and performance. Design to promote efficiency in the end users business can, therefore, be very cost effective. However, this requires close interaction with the client in order to understanding the business processes and operatives needs.

Recognising that energy cost are also a major component of the operating costs of a building, and hence a cost to the business, energy efficiency measures can also improve business efficiency. Designing for a reduction in M&E maintenance and replacement, hence minimising disruption, can also improve occupancy satisfaction.
Occupant's satisfaction linked to business efficiency.

8 Developing the Decision support tool for Service Life design

8.1 Background

The industry survey had indicated that there are many issues to be addressed before it will be possible to undertake service life design with adequate reliability. In particular,

- We need a better understanding what is meant by 'service life' in relation to the function of a component
- Performance modelling is still not sufficiently advanced and more information is needed on real performance
- The relative impact on the various factors that influence service life need to be better understood
- Uncertainties must be acknowledged and the risk managed in a more rigorous way

The ISO15686 approach provides some advancement in dealing with the factors that affect the SL and the proposed probabilistic approach to defining SL enables uncertainties and variability to be taken into account. Combining the two approaches may therefore provide considerable advantage and enable a rational approach to SL design to be developed.

8.2 Selection of components for detailed Lifetime Design

It is unnecessary and impractical to include every element of the structure in the Lifetime Engineering process. Information from the risk register and the application of the 80:20-rule (which states that 80% of the cost can be attributed to 20% of the building elements) will help to reduce the level of detail with the least impact on the overall outcome. Supply chain issues should also be considered at this stage and, of course, components with a life that is longer than the asset life will not need life cycle replacement. This screening process will lead to a selection of elements to be evaluated in detail.

The 80:20-rule is particularly helpful in deciding which components to investigate The rule states that, in general, 80% of the cost will be taken up by 20% of the components. Focusing on this 20% of components will therefore have the greatest impact on the overall cost.

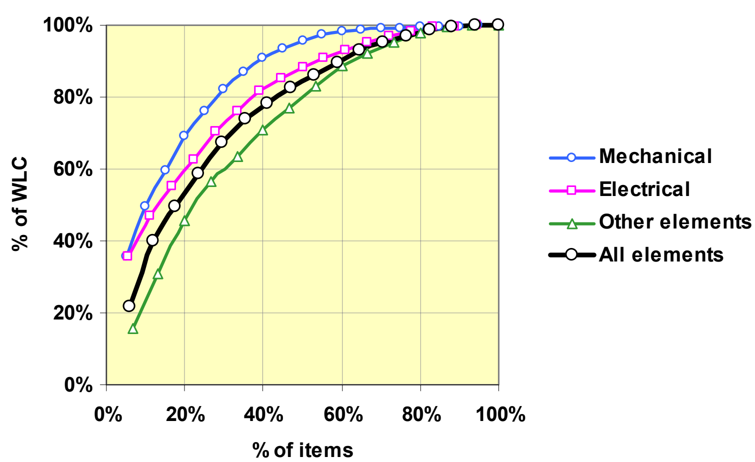

Figure 8.1 *The relationship between percentage cost and percentage of components*

In a Taylor Woodrow study of the tender costs for a PFI hospital, the 80:20-rule appeared to be closer to 70:30, as shown in Figure 8.1. Nevertheless, the principle that a majority of the cost is attributed to a minority of expensive components applies. The ratio varied for different systems, e.g. mechanical, electrical, but the principle was consistent. It should also be noted that the analysis used to provide the relationships in Figure 6.1 did not break down the systems into all of the individual components. The greater the level of breakdown, i.e. the greater the number of components, the closer the ratio is likely to move towards 80:20.

The next stage is to begin the process of defining the service life of specific components and undertaking scenario analysis to select the most cost effective options. It is at this stage that it is necessary to define the specific performance requirement and the level that defines when interventions will be needed (Figure 8.2). A reference service life (RSL) may be obtained from historical data or by performance modelling and the process requires that a distribution of values be provided. This reflects reality inasmuch as it acknowledges that there will be progressive deterioration within a population of similar components. In the example shown in Figure 8.2 it is assumed, for simplicity, that the cumulative probability curve for failure is linear with zero probability of failure below the minimum value of RSL and 100% probability of failure above the maximum value of RSL. [In this context, 'failure' represents the performance level reaching its acceptable limit state]. The linear distribution is a Beta distribution with both Alpha and Beta coefficients being equal to 1.

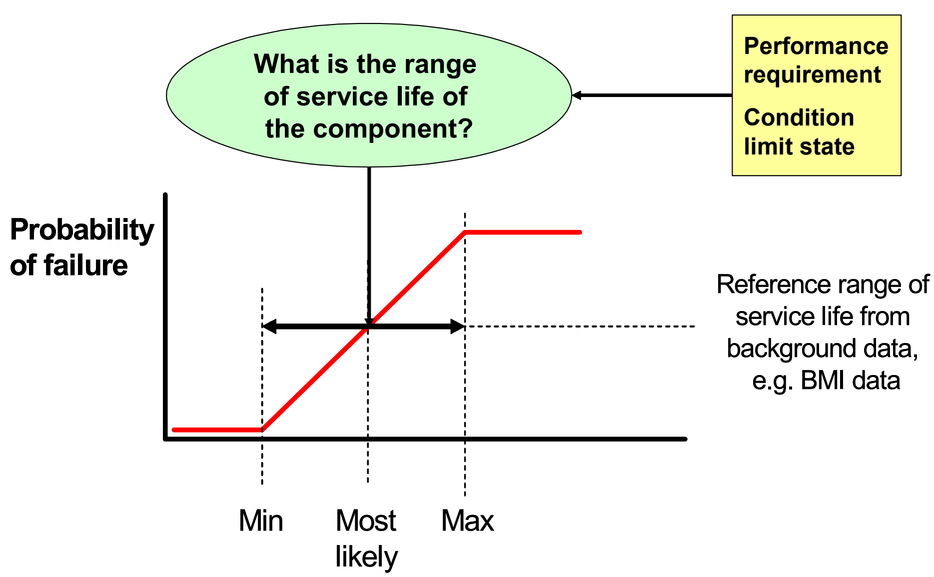

Figure 8.2 *Service life related to performance requirement and trigger levels*

The designer should select reference information that most closely reflects the conditions that apply to the particular project. Adjustments using the ISO modification factors will therefore be minimised.

Having derived a Reference Service Life range, this is adjusted using the ISO factorial method to generate an Estimated Service Life range as described in Section 5.

Within the proposed approach to SL design, the ISO factors are applied not to a single ESL but to the range of values, reflecting the fact that in reality there will be progressive deterioration. This is shown in Figure 8.3. In the next stage of the process, the lower and upper values are assumed to represent respectively the levels below which no failures occur and above which failure is certain. This should be taken into account in the selection and determination of these values.

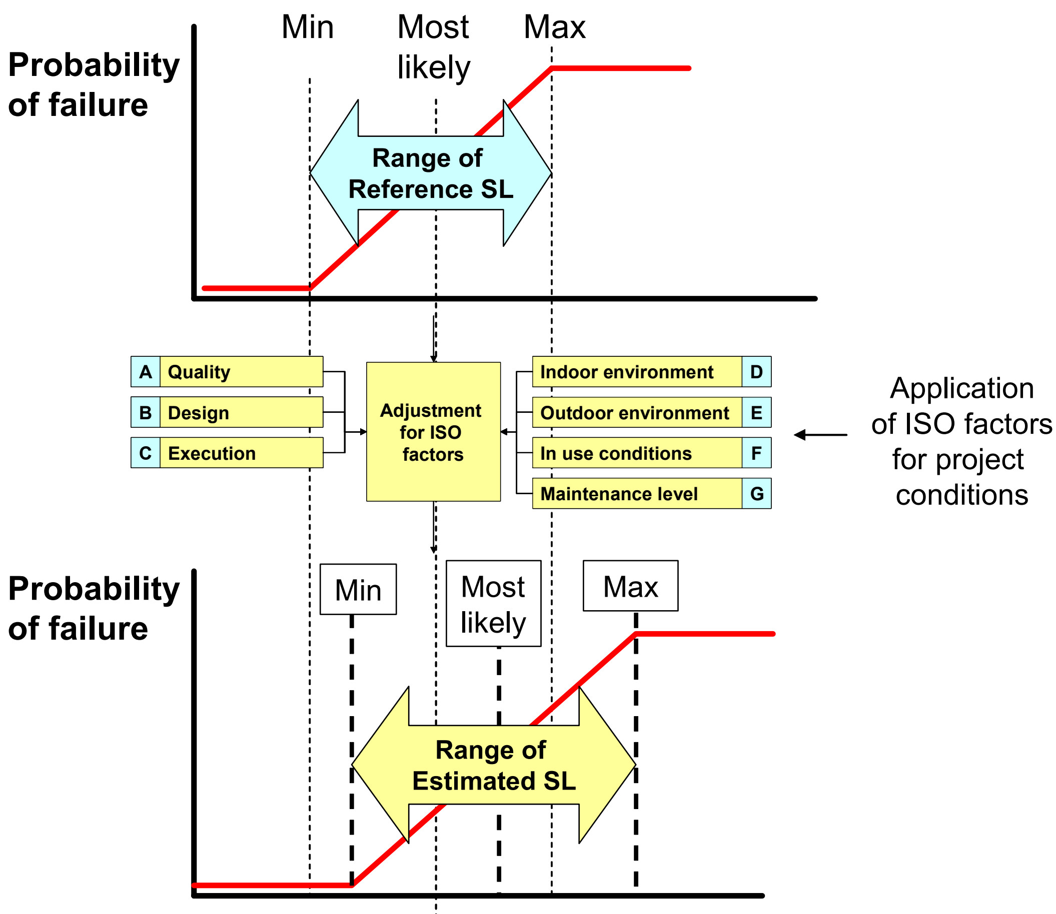

Figure 8.3 - *The application of ISO modification factors to determine the range of estimated service life*

This final stage in the SL design process introduces an approach to Service Life Design based on assessment of risk. It is assumed that the more severe the consequences of 'failure' (failure being defined as the limiting condition being reached) the lower the likelihood of this occurring must be.

The consequences of failure (for the appropriate condition limit state) may be ranked on a scale of 1-5. This may be done intuitively or more rigorously using a multi-criteria decision analysis or similar approach. Factors such as H&S, cost, client satisfaction etc may be considered. A weighting and ranking system may be established to achieve this.

Depending on the severity of the integrated consequence, the design service life is then set at a level that minimises risk. Assuming that RISK = PROBABILITY X CONSEQUENCES, then the more severe the consequences of failure the lower the probability of failure must be as shown in Figure 8.4

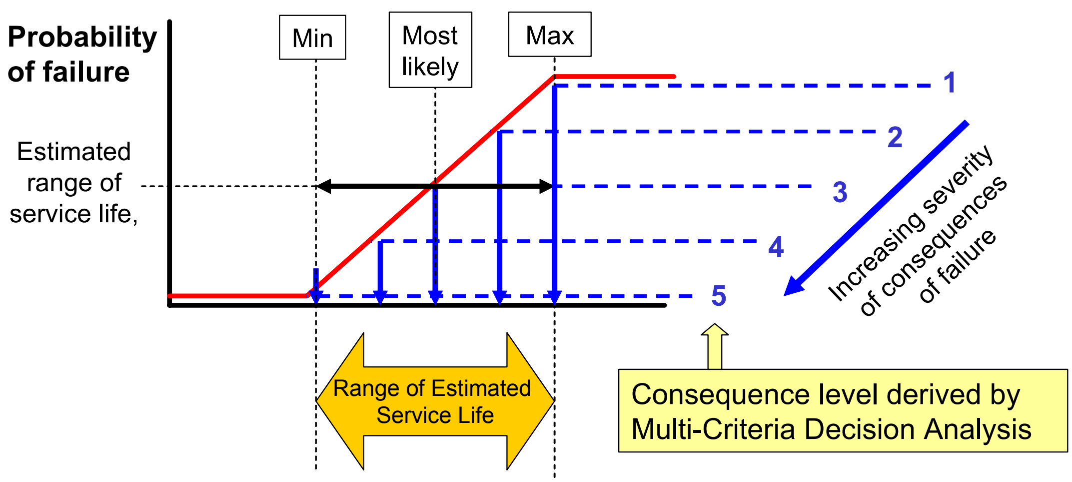

Figure 8.4 *Relating the value of service life used in LCC to the consequence of failure*

At level 5 (most severe consequence), the minimum value of ESL will be used in the design process and at level 1 (the lowest severity of consequence) the maximum ESL will be used. Interim values will be at quarter points. Thus if the range of ESL is, say, 20-40 years, design SL values will be 20, 25, 30, 35 and 40 for level of severity of 5, 4, 3, 2 and 1 respectively.

The ability to relate the probability of an event with its consequences provides a rational means for prioritisation of action and financial resource.

To adopt this approach it is necessary to record the implications of loss of serviceability of a particular component or system and any consequential impacts that this will have on the performance of the asset.

8.3 Taking advantage of a risk based approach

There are considerable advantages in presenting outputs on a probabilistic basis. For example, the tender price for a new project can be selected in a more transparent and rigorous manner, as shown in Figure 8.5. In this example the most likely cost is €20m, but the cost could be as low as €15m or as high as €25m. Before margins are added, the most likely figure is one for which there is a 50% chance of it being exceeded. This may be an unacceptably high risk. Increasing the bid price to €22.5m reduces the likelihood of it being exceeded to only 10%. Using this information the bid manager can select a tender price based on an acceptable and declared level of risk.

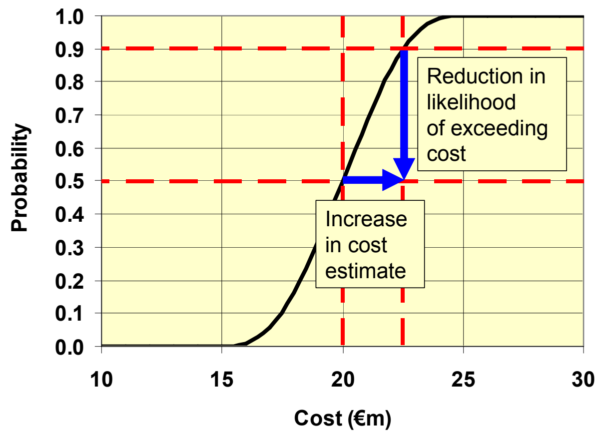

Figure 8.4 *Probabilistic presentation of WLC*

Probabilistic SL data can also be beneficial in planning of replacement cycle. It is common for SL values to be quoted in multiples of 5 years and this often results in 'spikes' of activity occurring (see Figure 1a). If it is required that these spikes be avoided, perhaps to more evenly distribute replacement costs, it may be most effective to extend the replacement cycle of some items and to reduce the replacement cycle of others. In order to do this it is useful to know those items for which the replacement cycle may be extended with the lowest risk.

9. Conclusions

This study has reviewed the availability of Lifetime data and given some guidance on how it may be applied. Recommendations are given for the type of data that will be helpful in Lifetime Engineering, and how it should be presented and qualified.

Lifetime Engineering requires three categories of input data,

- Service Life
- Cost (short and long term)
- Environmental and Societal Impacts

Hence a database should be structured to record any relevant information within these three categories.

9.1 Service Life

With regard to Service Life, while practitioners require that data to be presented in the simplest way, i.e. a minimum value, some form of statistical representation is required to enable the management of financial risk. A probability curve can be established relatively simply by asking the supplier the following questions;

1. What is the minimum SL?
2. Is this a true minimum value i.e. the probability of failure before this time is zero or the risk is entirely covered by the supplier?
3. If the quoted minimum value is not a true minimum, then what is the probability of failure at this time?
4. What is the maximum SL?
5. Is this a true maximum value i.e. the probability of failure beyond this time is zero?
6. If the quoted maximum value is not a true maximum, then what is the probability of failure at this time?
7. What is the most likely SL?
8. If the most likely SL cannot be quantified then is it likely to be closer to the minimum value or the maximum value.

The simplest form of presentation is a Beta distribution with the Alpha and Beta factors both being 1. This results in a linear probability curve (see Figure 8.2). Having established a reference range for service life, the factor approach described in ISO 15686 may be used to derive a range that applies to conditions that are project specific. These factors deal with changes in service life that may result from the following;

A. Quality of components
B. Design Level
C. Work execution level
D. Indoor environment
E. Outdoor environment
F. In use conditions
G. Maintenance level

In particular, it is important to note where the project specific conditions differ from the conditions that apply to the reference data. If these differences are very large it is likely that the reference data is not appropriate.

With this data a design SL value may be derived based on an acceptable likelihood of loss of serviceability, this in turn being based on the consequences of failure (in this context defined as loss of serviceability). Where the consequences are severe, the likelihood of failure must be very low, hence early intervention, within the defined SL range will be required. When the consequences are less severe, a greater likelihood of failure may be accepted, thus extending the time to intervention.

It is acknowledged that the proposed approach has limitations. However, the value of the decision tool is not only in providing more rigour in predicting service life. It also educates the user by demanding attention to various issues concerned with both the factors which influence failure and the consequences of loss of serviceability. It also provides a basis for data collection by identifying those factors which impact on performance.

9.2 Costs

Cost data are required to enable Whole Life Costing (WLC). The principal cost items include;

- Costs associated with the procurement of the built asset
- Costs associated with the operation of the built asset
- Utilities
- Costs for decommissioning

Consequential costs must also be taken into account. Publicly available data for WLC are scarce because they are generally very contract specific and commercially sensitive. In addition, both the absolute and the relative values of the major cost components - materials, equipment and labour - will vary around Europe. With regard to a European database it would be of more value to record those items which contribute to cost, rather than the costs themselves.

9.3 Environmental and Societal Issues

While environmental assessments are presented and undertaken in a variety of ways, all generally involve three principal items

- Resources
- Energy
- Pollution

Water usage is also very important and is often considered separately, although this does fall within the general heading of resources.

Societal impacts consider the way in which a project will affect individuals and communities and many of the impacts are difficult to quantify. They include the following;

- Health and Safety – Construction
- Health in Operation - Quality of life – Aesthetics - Occupancy satisfaction
- Social inclusion – employment, education, training
- Security
- Business efficiency

Environmental impacts are becoming increasingly regulated, with minimum requirements being demanded. However, quantifying the value of many of the environmental and societal impacts may be difficult, if not impossible. Regulation in this area is still in its infancy. Techniques are available to provide some degree of qualitative assessment but many of the issues are still very subjective.

10. References

1. Latham, Sir Michael, Constructing the Team (The Latham Report) Final Report of the Government/Industry Review of Procurement and Contractual Arrangements in the UK Construction Industry, HMSO Department of the Environment (1994).

2. Rethinking Construction, The report of the Construction Task Force to the Deputy Prime Minister, John Prescott, on the scope for improving the quality and efficiency of UK construction, Egan Report, HMSO, July 1998.

3. DEFRA, Taking it on – developing UK sustainable development together, A Consultation Paper, Department of Environment, Food and Rural Affairs, 2004

4. Institution of Civil Engineers, Society, Sustainability and civil engineering, A strategy and action plan, 2002-3.

5. British Standards Institution, Guidance for Managing Sustainable Development, BS8900, Draft for public comment, 2005.

6. Bamforth, P B, Issues in design for whole life performance and cost. International Conference on Façade design and procurement, Bath University, 10/11 April 2003.

7. CPD (1988) The Construction Products Directive (Council Directive 89/106/CE).

8. HAPM (1999). “Component Life Manual.” SPON.

9. BPG (1999). “Building Fabric Component Life Manual.” Building Performance Group.

10. BLP (2001).) “Building Services Component Life Manual.” Building Lifeplans.

11. Life Expectancy of Building Components – surveyors’ experiences of buildings in use – a practical guide compiled by Nigel Harvey published by the Building Cost Information Service Ltd (RICS 2001)

12. BS 7543: 1992, Guide to durability of buildings and building elements, products and components, BSI, 389 Chiswick High Road, London, W4 4AL.

13. BS ISO 15686, Buildings and constructed assets – Service life planning – Part 1: General principles (2000), Part 2: Service life prediction procedures (2001) BSI, 389 Chiswick High Road, London, W4 4AL.

14. Marteinsson, B, Assessment of service lives in the design of buildings – Development of the factor method, Licentiate Thesis, KTH’s Research School, Centre of Built Environement, University of Gavle, Sept 2003.