CHAPTER 9
MAINTAINABILITY GRADING SYSTEM

9.1. General

The global construction and real estate industries are facing shrinking maintenance budgets, rising construction and maintenance costs and increasing competitive global markets. It is of compelling logic to improve a building's level of maintainability right from the planning and design stages. The rationale of developing a maintainability benchmark is to enable the decision maker to select a more maintainable design option. Yardsticks like grading systems would assist in the selection of highly maintainable building designs.

The objective of grading systems is to promote buildings with high maintainability through a structured risk assessment protocol. It attempts to improve the performance of a building and reduce the life cycle cost (LCC) during its post occupancy period. The broad term "LCC" encompasses initial, future and demolition costs.

9.2. Grading System — State of the Art

Scale and scope of the entire available framework ranges from simple to chronologically complex; prescriptive to performance-based; grading of design-guideline to environmental, impact assessment. Most systems exhibit combination of all these approaches [1].

Mathematically such systems can be classified as:

— first generation: Nominal (pass–fail type certification);
— second generation: Simple additive;

— third generation: Weighed additive;
— others.

Major examples from each category are shown in Table 9.1.

9.2.1. *First Generation: Pass–Fail Systems*

Most of the examples are prescriptive certification programs for conventional building design — Judged against codes, standards or by-laws and with limited focus on energy and indoor environmental quality (IEQ). Few examples are listed in the following section.

9.2.1.1. *R-2000, Canada*

R-2000 [2] jointly developed by CHBA and NRC, started operating in 1981 to promote energy efficiency and reduction of greenhouse gas emissions of residential buildings (R-2000, n.d.). A performance-based energy target for space and water heating was established as per R-2000 standard and calculated for each house, taking into consideration the size, fuel type, lot orientation and climatic location. Upon fulfillment of mandates, certification is issued by the authority.

9.2.1.2. *P-Mark Certification System, Sweden*

The P-mark System [3] of 1989 by SP, Sweden primarily certifies of prefabricated detached houses, but can also be used at project level. It covers products (wooden windows, particleboards and nail plate trusses); quality system (crawl space, concrete slab foundations, basement walls, external walls, kitchen etc); or both against standard test methods or design rules. It involves (1) testing for ventilation, air-tightness of house and ventilation ducts and (2) inspection for HVAC performance, water-tightness of kitchen or toilet. In the long run, P-mark has resulted in a reduction in number of major faults [4].

Table 9.1. A summary of available grading systems.

Type	Year	Grading System	Developed By	Country
First generation	1981	R-2000	Canadian Home Builders' Association (CHBA), Natural Resources Canada (NRC)	Canada
	1989	P-mark	Swedish National Testing and Research Institute (SP)	Sweden
	1997	ELO and EM scheme	Danish Energy Authority	Denmark
	2001	Energy star	Environmental Protection Agency (EPA) and Department of Energy (DOE)	U.S.
Second generation	2000	Leadership in Energy and Environmental Design (LEED)	U.S. Green Building Council (USGBC)	U.S.
	2005	Green Mark	BCA	Singapore
Third generation	1990	Building Research Establishment Environmental Assessment Method (BREEAM)	Building Research Establishment (BRE) Ltd	U.K.
	1993	Building Environment Performance Assessment Criteria (BEPAC)	Environmental Research Group, University of British Columbia	Canada
	1996	Hong Kong Building Environmental Assessment Method (HK-BEAM)	HK-BEAM Society	Hong Kong
	2001	Housing Quality Assurance Law (HQAL)	Japan Government	Japan

(*Continued*)

Table 9.1. (*Continued*)

Type	Year	Grading System	Developed By	Country
	2002	Green Building Tool (GBTool)	International Initiative for a Sustainable Built Environment (iiSBC)	International
	2002	Global Environmental Method (GEM)	Global Alliance for Building Sustainability	UK
	2003	Green Star	Green Building Council of Australia (GBCA)	Australia
	2004	Green Globes	The Green Building Initiative (GBI)	U.S.
	2004	Go Green, Go Green Plus	Building Owners and Manufacturers Association (BOMA)	Canada
	2004	Maintainability Scoring System (MSS)	Department of Building, National University of Singapore (NUS)	Singapore
	2005	National Australian Built Environment Rating System (NABERS)	Department of the Environment and Heritage (DEH), Commercialized by Department of Energy, Utilities and Sustainability (DEUS)	Australia
Others	2004	Comprehensive Assessment System for Building Environmental Efficiency	Japan Sustainable Building Consortium (JSBC)	Japan

9.2.1.3. *ELO and EM Schemes, Denmark*

In 1997 Danish Energy Authority developed ELO and EM schemes as energy labeling program for existing large buildings (total floor area >1500 m^2) and small buildings, respectively, to cover various building types catering to residential, trade, private service and public uses. Both schemes consist of two parts, namely, an energy label and an energy plan. For energy label, three individual values for electricity, heat and water consumption are measured in a scale of A to M and compared with calculated values based on performance of similar buildings. In case of significant difference between these two values, recommendations are made as energy plan. Mandatory annual renewal of the label is exempted for two years if a project earns "A" for heating and electricity consumption.

9.2.1.4. *Energy Star, USA*

Energy Star [5] is a joint venture of U.S. EPA and DOE. Certified new homes must meet EPA guidelines and are at least 15% more energy efficient as per prescriptive and performance-based criteria set by 2006 International Energy Conservation Code (IECC). It includes effective insulation; high-performance windows; tight construction and ducts; efficient heating or cooling equipment; and Energy Star qualified lighting and appliances.

9.2.2. *Second Generation: Simple Additive Systems*

A set of second-generation, simple additive systems appeared to have gained popularity in a short while due to support from various government agencies. However, there is a very little scope for user modification to reflect regional differences or individual preferences, hence amendments are realized for such systems (ASMI, 2002b). For example, few logical drawbacks of LEED for new construction are rectified in LEED for home, which is under pilot stage. Similarly Green Mark has few more environmental proposals to complement its present form [6].

9.2.2.1. *LEED, USA*

In 2000, the United States Green Building Council (USGBC) proposed LEED and it presently includes various types of buildings, namely, new construction and major renovation (NC); existing buildings (EB); commercial interior (CI); core and shell (CS); homes (H); and neighborhood development (ND).

For LEED-NC [7], a total score of 69 is distributed among five major assessment areas namely, (1) sustainable sites; (2) water efficiency; (3) atmosphere; (4) materials and resources; (5) IEQ (Indoor Environmental Quality) and in addition a bonus for innovation and design. Among 69 points, seven are prerequisites or mandatory, 57 are core credits and additional five points are allocated for innovative design. LEED follows a simple additive system, where total score is calculated by adding each credit earned upon fulfilling one or more criteria or their alternative(s). The building is rated as Certified, Silver, Gold or Platinum based on a minimum score of 26, 33, 39 and 52, respectively, out of the total score of 69.

Unlike LEED-NC, LEED-H for homes can be customized for different climatic zones such as dry, wet or normal region, by allocating different points to (1) irrigation; (2) landscaping and surface water management; and (3) material durability. Critical issues are mandatory and provided with higher grades and intricate details. This pilot scheme is expected to undergo further refinements [7]. Though the total score for any building irrespective of its geographic location cannot exceed the maximum of 108 points, individual scoring of few criteria can be confusing, for example, a building in dry zone may earn 26 out of 24 for material and resources.

9.2.3. *Third Generation: Weighed Additive Systems*

Currently the highest-end tools recognize the different impacts of various parameters and therefore have adopted additive weighing systems. Determination of weightage mostly involves judgmental or conscious-based values due to inherent complexity and lack of objective basis. Expert opinion is sought to rank the parameters and then weighings are allocated by analyzing such data through various methods such as, analytic hierarchy process, statistical correlation, artificial neural networks, etc. Horvat and Fazio [8] classified the weighing into two major categories, namely, (1) pre-weighed credits such as HQAL or BREEAM and (2) weighing after scoring such as BEPAC or SBTool.

9.2.3.1. *BREEAM, UK*

BREEAM [9–12] was initiated by Building Research Establishment (BRE) of UK in 1990 and is applicable to residential houses (known as EcoHomes), industrial buildings, offices, prisons, retail facilities, schools and minor refurbishments. For any unconventional or multi-tenancy building, a "Bespoke BREEAM" is carried out with project specific assessment criteria and functions. Eight assessment categories that are evaluated include management, energy use, health and well-being, pollution, transport, land use, ecology, materials and water. EcoHomes cover all of them except management. Each category has sub-categories allocated with pre-weighed points that are either cumulative or otherwise, depending on performance against certain specified standards such as SAP 2005. The awarded credits add up to a final overall score, rated on a scale of Fail, Pass, Good, Very Good and Excellent. The benchmarking procedure and minimum requirement varies with building types and stages. For pre-weighed credits, integers (as in EcoHomes) can be more user-friendly than fractions (as in BREEAM office) or percentage scores of EcoHomes XB.

EcoHomes XB deals with minor refurbishments during routine planned maintenance as their effect cannot be captured solely by EcoHomes. It has a scoring system of 1–100 split into breaks of three without any rating. The smaller breaks reflect the effects of small works. A property once assessed, any further improvement can be monitored and the score is adjusted appropriately. The rating is limited to housing stocks as the management section for the stockholder's company policies is not applicable to individual ownership. Score for a whole development with different types of new houses is given by Eq. (9.1), while the same for existing buildings as mentioned in EcoHomes XB is derived by Eq. (9.2).

$$\text{Average score} = \frac{\sum_1^n [(\text{Individual score for house type } N) \times (\text{No. of units type } N)]}{\text{Total number of house units}}, \quad (9.1)$$

where,
n = the total number of house types,
N = each individual house type.
Note: Only identical homes can be classed as a "house type".

$$\text{Average Score} = \frac{\sum_1^n [(\text{Score for batch } N) \times (\text{No. of units type } N)]}{\text{Total number of units of all types that have been assessed}}, \quad (9.2)$$

where,
n = the total number of house types covered in all assessments to date,
N = number of dwellings of each individual house type.

In 1999, ECD (Energy Citation Database) Energy and Environment worked with TerraChoice to develop BREEAM Green Leaf eco-rating program for offices, multi-residential, industrial and recreational buildings. This question-based tool with percentage scoring is aimed to be more streamlined than BREEAM and easily harmonized with LEED-Canada.

9.2.3.2. *BEPAC, Canada*

BEPAC was developed in 1993 by the Environment Research Group at the University of British Columbia. The method is based on BREEAM and considers new or existing offices or commercial buildings for grading. Design and management criteria for both base building and tenancies are formulated as four modules, with five topic areas namely, (1) ozone layer protection; (2) environmental impact of energy use; (3) IEQ; (4) resource conservation; and (5) site and transportation. Although no hierarchy of importance is implied, the first two topic areas are observed to have profound implications [13]. For these two "performance-oriented" topics, points are awarded over a continuum for assessed performance. By contrast, rest of the topics are "feature-specific" and points are typically given if the feature is present. These criteria are ranked as essential, important and supplementary.

Each topic area constitutes of relevant criteria graded in a scale of 0–10 and few of them may have sub-criteria. Weighing on the points is based on its significance, its priority relative to other criteria within the same topic area, or the effort required to meet the criteria. The point scores are multiplied by the weighing factors to obtain individual credits for the five topic areas. Due to fundamental difference between the topic areas, the credits are not added but together they represent the building profile [8].

9.2.3.3. *Green Globes Rating System, USA*

This system was marketed by The Green Building Initiative (GBI) in 2004. It is based on BREEAM, UK and is the only grading system recognized by American National Standard Institute (ANSI). Its management tool includes an assessment protocol, rating system and guide for environment-friendly design of commercial and institutional buildings. Thirty-one parameters are grouped into seven categories namely, (1) project management — Policies and practices; (2) site; (3) energy; (4) water resources; (5) building materials and solid waste; (6) emissions and effluents; and (7) indoor environment. The checklist is in a questionnaire format with data to be filled in and points vary from 0 to 100 depending on significance and performance summing up to 1000. After obtaining a self assessment score of a minimum 35% in two stages of schematic design and construction document, a formal rating of one, two, three, or four Green Globes is awarded for a minimum total score of 35%, 55%, 70% and 85%, respectively [15].

9.2.3.4. *GEM, UK*

In 2002, Green Globes for existing buildings was introduced in the United Kingdom as the Global Environmental Method (GEM) under the control of GABS and RICS foundation. GEM's six sections namely, energy, water, resources, environmental management, indoor environment and emissions have 19-subsections summing up to 1020 points.

GEM weighing is the mean of weighing recommended by BREEAM, the Harvard Scale and the EPA. Comparing with buildings of similar age, type or geographical zone, two kinds of ratings are provided: (1) scores that give the percentage of possible points that have been awarded for implementing best practices; and (2) quintile ratings to show performance relative to other benchmarked buildings [16].

9.2.3.5. *Go Green and Go Green Plus, Canada*

In 2004, Green Globes for existing commercial buildings was adopted by the Building Owners and Manufacturers Association (BOMA) of Canada and presently known as Go Green which addresses 10 management and operation requirements under five environmental areas namely, (1) resource consumption; (2) waste reduction and recycling; (3) building materials; (4) interior environment; and (5) tenant awareness. A three-year valid certificate is issued upon meeting its "best practices" requirements [17].

Green Globes Plus is a more in-depth benchmarking tool that can be considered as superset of Go Green. Based on "yes/no" type questionnaire regarding 19 parameters grouped into six major criteria, such as energy, water, waste reduction, emission, indoor environment and environment management [18]. After individual assessment is done for each category, a minimum total score of 70% out of 1010 points earns a certification.

9.2.3.6. *HQAL, Japan*

Housing Quality Assurance Law (HQAL) of Japan Government came into effect in 2001 to improve quality and performance of residential buildings of various types namely, detached, apartment, pre-fabricated, built-on-site, timber, reinforced concrete or steel structure. Though it deals in detail with certification of manufacturers of wooden building material and also with dispute solving, HQAL deserves a special mention as it is the only program directly addressing durability in terms of reduced deterioration and enhanced service life [14]. Among four objectives, the third one sets "Housing Performance Indication Standards" based on recommendation of Japanese standards. These standards cover architectural design, construction process for foundation, structural framing process and interior finishing. The specific types of performance characteristics include: (1) structural performance; (2) fire safety; (3) durability; (4) ease of maintenance and management; (5) energy efficiency; (6) air quality; (7) ratio of exterior openings to total wall area; (8) noise transmission; and (9) barrier free design. A prescriptive and detailed “Judgment Standards for Defects” is proposed [19] against which dwelling units are ranked as 1 for fulfillment of requirement to 3 or 4 for better quality.

9.2.3.7. *MSS, Singapore*

Maintainability Scoring System (MSS) is developed by National University of Singapore to mitigate the higher LCC comprising of repair, replacement and cleaning cost due to harsher nature of tropical climate. A higher score indicates easier maintenance [20,21]. MSS defines building as combination of five major components namely, façade, basement, internal wet area, roof and M&E system. The system relies on a comprehensive database of “Material Manual” and “Defect Library” (http://www.hpbc.bdg.nus.edu.sg). Data collected from a detailed study of 450 buildings were modeled into MSS using back-propagation method of artificial neural network. Replacement and cleaning costs can be predicted for each sub-component based on the data fed in.

9.2.3.8. *Green Star Rating, Australia*

The Green Building Council of Australia (GBCA) developed the Green Star environmental rating system in 2003 for whole life cycle assessment of office buildings and extended the scope to pilot assessment for shopping centers, healthcare and educational facilities. Multi-unit residential buildings and convention facilities are scheduled to be launched by the end of 2007. The program rates a building in relation to eight environmental impact categories namely, management, IEQ, energy, transport, water, materials, land use and economy and pollution. Each category has various sub-categories and one or more points are allocated as per Green Star technical manual [22].

The single (overall) score of a project is determined by: (1) calculating each category score; (2) applying an environmental weighing to each category; (3) adding all weighed category scores together; and (4) adding any innovation points that may have been achieved. The calculation is as follows:

$$\text{Category score (\%)} = \text{No. of points achieved/No. of points available} \times 100\%, \tag{9.3}$$

$$\text{Weighed category score} = \frac{\sum \text{Category score (\%)} \times \text{Weighing factor (\%)}}{100}, \tag{9.4}$$

$$\text{Total score} = \text{Weighed category score} + \text{Points for innovation}. \tag{9.5}$$

For a particular project, nonapplicable credits are excluded from "points available". For example, use of recycled content of structural concrete is excluded for a refurbishment project. The category weighing was derived from variety of scientific and stakeholder inputs, as well as considering geographical location, to reflect issues of importance in each territory. For energy calculations, computer software tool Australian Building Greenhouse Rating (ABGR) is used to measure environmental impact of office building. ABGR evaluation for new and existing buildings in a scale of 1–5 is implemented through "commitment agreement" and "performance rating", respectively.

The maximum possible score for Green Star rating is 100 for the weighed categories with an additional 5 points for innovation. A grade of 1–6 stars is determined for overall minimum score of 10, 20, 30, 45, 60 and 75, respectively. GBCA certifies only the last three, i.e. 4 star or "Best Practice", 5 star or "Australian Excellence" and 6 star or "World Leader". The grading is simple and logical by excluding nonapplicable points, but unsuitable to use on a global basis as input for zones is denoted by Australian provinces rather than the climatic data.

9.2.3.9. *NABERS, Australia*

The National Australian Built Environment Rating System (NABERS) is a performance-based rating system in its developing stage designed by

DEUS of New South Wales, Australia for evaluation of existing buildings including home, office building or office tenancy during operation and is based on energy data of last 12 months [23]. Both existing ratings for office and the proposed program for home, utilize ABGR and Energy Smart Home Rating or ESHR [24] complemented by Green Star of GBCA and various software programs such as BASIX [25], NatHERS (Nationwide House Energy Rating Scheme) and FirstRate.

This benchmarking tool comprises of six environmental aspects namely, energy, transport, toxic materials, waste, indoor air quality (IAQ) and occupant satisfaction. Among those, the key impact categories identified by DEUS are energy use and greenhouse emissions, refrigerant use, water use, storm water runoff, storm water pollution, sewage outfall volume, landscape diversity, toxic material and IAQ. For each category relevance, realism and practicality are illustrated to measure them in a scale of 1–5 and finally combined into three scores as follows:

- Overall greenhouse score — Average of energy/greenhouse and refrigerant use.
- Overall water score — Average of water use, storm water runoff and sewage outfall volume.
- Site management score — Average of storm water pollution, landscape diversity, toxic materials, refrigerant ozone depletion and IAQ.

The final score is set at the lowest of these three “overall” scores, with a slight prioritization given to the first two. Refinement of benchmarks and simplification of overall scoring principle are major recommendations made in the first trial of NABERS.

9.2.3.10. *HK-BEAM, Hong Kong*

HK-BEAM or Hong Kong Building Environmental Assessment Method came into existence in 1996 through HK-BEAM Society. This BREEAM-based tool can be regarded as predecessor of SBTool and provides certification of new construction, major refurbishment and existing buildings of various types such as residential, commercial, industrial and institutional projects. Environmental issues are assessed in terms of local, global and indoor impacts grouped into five major areas including site aspect, material aspect, energy use, water use and IEQ. The final score depends on 72 parameters each carrying 1–10 performance-based credits and bonus points. Additionally, the framework includes 24 other parameters, five points for innovation and guidelines for annual energy use. Any nonstereotype building is judged on a case-by-case basis and any nonapplicable point, for example, inferior performance due to externality beyond the control of the client such as source of power supply, are excluded from "credits available".

Weighing of credits is based on expert opinion and other similar systems especially referring to the local standards. Few topics, for example, impact noise, for which local standards are not available, national or international codes are used. In case of conflicting rules, client can select either. For subjective issues, a checklist is used for equitable assessment. Alternative methods can be submitted along with method statement [26,27].

The award classification framework uses assessment benchmark as zero credit level. Overall assessment grade is based on % of applicable credits gained and it is mandatory to obtain a minimum % of credits for IEQ as it is given higher importance. For estate development, common features like site aspect, transport, water use undergo group assessment while IEQ and energy use are multiplied by ratio of floor area and summed up.

9.2.3.11. *GBTool 2005, International*

Based on BEPAC, an International Framework Committee (IFC) comprising of 13 countries proposed the Green Building Assessment (GBA) as an environmental performance assessment framework at international level. It resulted in the Green Building Challenge'98 (*GBC '98*) conference held in Vancouver, Canada [28] and Green Building Tool software (GBTool). GBC 2005 or SB05 is a continuation of the GBC '98 — 2002 presently involving 25 countries. *International Initiative for a Sustainable Built Environment* [29] is the official promoter of SBTool. Both new and renovation projects of residential, office, retail, hotel, motel, hospital, industrial, assembly, institutional and school can be graded along with a combination of any two, three or four different types of building occupancy.

In an Excel environment, GBTool is structured hierarchically in four levels, with the higher levels logically derived from the weighed aggregation of the lower ones as 1 goal, 7 issues, 29 categories and 109 criteria. Few criteria, for example, IEQ has sub-criteria. Issue and categories reflecting regional or city scale forms module-A. Its benchmarks and weights are fixed by national teams using diverse methods such as AHP or analytic hierarchy process [30], Pearson's product–moment correlation [31], etc. Criteria and sub-criteria contained in module-B are project specific and used as self-assessment as set by module-A. In both cases, default values can be used. Nonapplicable parameters such as HVAC in a naturally ventilated building, weigh zero. Weighings at the sub-criteria and criteria level are fixed and are evenly weighed, unless in exceptional cases. Pre-defined weighings of category are selected as per Table 9.5. The values range between –2 and +5, where,

- −1 = unsatisfactory,
- 0 = minimum acceptable performance,
- 5 = considerably advanced of current practice,
- 1–4 = intermediate performance levels and
- 2 = normal default or null value (except for mandatory parameters ranging from 3 to 5).

All issues have individual score of 100 and totals up to 100%. These values are auto-generated within SBTool in any of the following ways [32]:

- Explicitly defined target value: difference between "best" performance target and the benchmark divided by 5.
- Fixed interval: The subsequent values for scores are calculated as difference with the benchmarked value.
- Percentage scale: For criteria measured as % of resource saved or used compared to fixed % value of benchmark. The scale intervals can be set to determine the full range.

9.2.4. *Other Examples*

9.2.4.1. *CASBEE, Japan*

CASBEE (Comprehensive Assessment System for Building Environmental Efficiency), developed by Japan Sustainable Building Consortium (JSBC) differs from other assessment system by BEE (Building Environmental Efficiency) — A quotient to measure environmental performance of building. For both residential and nonresidential buildings, four grading tools for building life cycle are (1) Tool-0: CASBEE-PD for pre-design; (2) Tool-1: CASBEE-NC for new construction; (3) Tool-2: CASBEE-EB for existing building; and (4) Tool-3: CASBEE-RN for renovation [33].

The basic structure of CASBEE has four major aspects with 80 items re-grouped into (1) Q or Quality: the environmental quality and performance of the building and (2) L or Loadings: the building's environmental loading with three sub-groups each. A scale of 1–5 is used with 3 as standard grade or ordinary level for each assessment item. Grades are tabulated on score sheet, weighed using pre-defined co-efficient for each to get overall scores $S_{Q1\sim Q3}$ or $S_{LR1\sim LR3}$. Next overall scores S_Q and S_{LR} are calculated to compute BEE as:

$$\text{BEE} = \frac{Q\ \text{(Building environmental quality and performance)}}{L\ \text{(Building environmental loadings)}} = \frac{25\times(S_Q - 1)}{25\times(5 - S_{LR})}, \tag{9.6}$$

$$\text{Building complex score} = \Sigma\ (\text{Score for each building type} \times \text{Corresponding floor ratio}). \tag{9.7}$$

The same logic applies for a building with multiple use. Weighing coefficient for each assessment field for different kinds of building are based on the outcome of a questionnaire survey of designers, building owners and operators, related officials and others users. The responses were analyzed by analytic hierarchy process (AHP). For example, Level 1 is awarded for noise level >50 dB for office, hospital, hotel, apartment but for school a much lower value of 45 dB is recommended. Similarly, multiple scoring is provided for points with variations such as the criteria to reflect special regional characteristics. Examples of such customizations are regional versions developed in Nagoya and Osaka [34].

CASBEE calculations are done in excel environment and graphical representation in assessment sheet includes BEE, radar chart and bar graph. For BEE, points are plotted with Q values on the Y axis and L values on the X axis to determine the BEE position, in a scale of class C (poor), class B^-, class B^+, class A and class S (excellent), in order of increasing BEE value.

9.3. Maintainability and Management

In maintenance management, maintainability is a critical decision making process which involves the optimum selection of building elements that require minimum cleaning, repair and replacement. In general, this is not a straightforward task, given (1) the large number of materials and variety of systems and designs, (2) variation of performance and (3) difference in the risk of failures associated with different systems and components.

Building maintainability is hence a composition of many factors. It could be modeled in various forms, one of which is LCC [35]. In such case, optimum maintainability, i.e. the optimum LCC is set at the minimum level of risk. Defining the minimum level of risk involves a series of decision-making process known in the construction industry as “risk management”.

The most common method for contemporary risk management, the “five-tiered” model might be used for maintainability management. This might be expressed as [36]:

(1) risk identification,
(2) risk estimation,
(3) risk evaluation,
(4) risk response and
(5) risk monitoring.

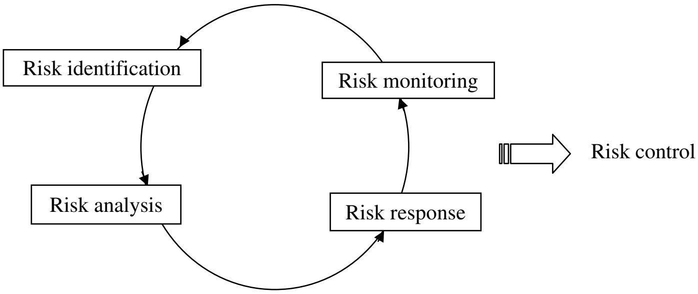

Fig. 9.1. Risk management cycle.

Of the five steps, risk estimation and evaluation are closely related and thus are collectively referred to as risk analysis. Similarly, risk response and risk monitoring could also be combined into a single broader category such as risk control (Fig. 9.1).

9.3.1. *Risk Identification and Primary Risk Factors*

The number of risk factors that describe a typical risk environment of maintainability could often run into hundreds. However, not all of them are significant when considering the local conditions of the user. For example, risk of snowfall in affecting the maintainability of façades is unlikely to be experienced by buildings located along the tropical belt. Hence, in identifying risks to maintainability, historical maintenance data from a large pool of buildings would be most useful.

Risk factors that determine the level of LCC and hence maintainability of housing stocks were reported [37–41]. The significance of quality of constructional components at the time of completion, technical aspects of the aging process, maintenance methods and practices and level maintenance as preliminary factors of LCC was identified.

The following sections look at the following risk factors

(1) design (water-tightness, stress accommodation, water flow control, accessibility, downtime and material performance) risk,
(2) construction (quality) risk,
(3) maintenance (quality) risk,

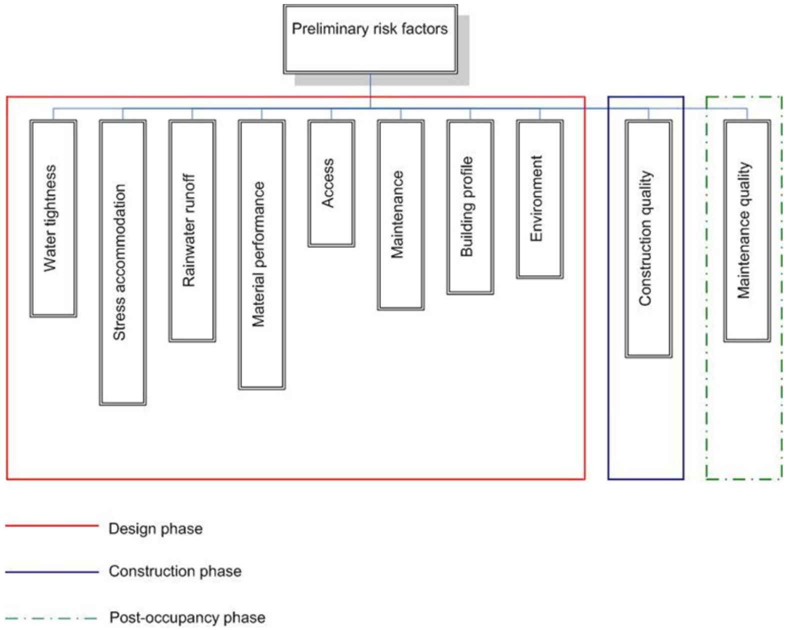

Fig. 9.2. Façade preliminary risk factors.

(4) risk from environment and usage, and
(5) risk from building's profile.

Façade as an element is used as an example in the following sections. Figure 9.2 illustrates primary risk factors related to façade.

From a detailed survey [35], 22 risk factors that were significant to a façade's maintainability were identified. These factors were further grouped into 14 clusters (Table 9.2).

Details of the risk factors of other components are described in the Maintainability Website (http://www.hpbc.bdg.nus.edu.sg/) under the topic "Maintainability Scoring System".

9.3.2. *Risk Analysis*

Once significant risk factors have been identified, they could be analyzed in depth. Such risk analysis was concerned with the severity of each risk attribute to LCC. Over the past years, several formal techniques have

Table 9.2. Façade risk factors.

Risk Clusters	Risk Factors	Elements
Wall selection	1. First line defense	1. Type of finishes and joints
	2. Second line defense	2. Type of wall system
Wall detail	3. Shape	3. Proper detail to drain away the water and prevent staining
	4. Grid	4. Size, detailing
	5. Joint	5. Type, spacing, size and detailing and exposure
Wall maintainability	6. Accessibility	6. Building shape, provision for access and coverage
	7. Flexibility	7. Wall complexity, removability (panel), down time and access system
Window selection	8. Fixing method	8. Exposure
	9. Panel detail	9. Panel, frame and drainage system
Window detail	10. Fixing details	10. Protection detail, drainage detail and louver detail
Window maintainability	11. Accessibility for cleaning	11. Method of opening
Material selection	12. Durability	12. Lifespan
Material detail	13. Performance	13. Resistance to tropical conditions and interface compatibility
Material maintainability	14. Cleanability	14. Cleaning requirement such as methods, frequencies, etc.
	15. Inspection	15. Maintenance requirements such as inspections, frequencies, etc.
Construction	16. Workmanship quality	16. Construction quality assessment score (CONQUAS)
Maintenance practice	17. Method	17. Maintenance inspections, equipments and chemical used for cleaning
	18. Efficiency	18. Frequencies of inspection and cleaning cycles
Environmental	19. Topography	19. Pollution level
	20. Orientation	20. Parks, expressways, major roads, light traffic roads and cost line
Building age	21. Age 1–30 years	
Building height	22. Five groups such that height less than 5, 5–12, 13–40, 41–60 and more than 60 stories	

been developed to facilitate risk analysis. They ranged from simple techniques such as elementary risk analysis to more sophisticated techniques that involved modern concepts such as application of expert systems and neural networks.

To carry out a risk analysis, it is necessary to estimate and quantify each of the risk. Probabilistic techniques and discrete interval methods were few of the techniques that could be used. In practice, various indices that were associated with parameters describing risk factors were specified in their own dimension and units. For instance, risk of water penetration was well-described by depth of penetration while accessibility was considered as area of coverage. However, from an analytical point of view, using a homogeneous set of inputs was much more computationally feasible than a set of heterogeneous inputs.

9.4. Maintainability Prediction and Integration

Maintainability is a design parameter and hence should be addressed right from the design phase. In previous chapters, the major elements of a facility is discussed in the form of risk analysis and subsequently converted to sets of checklist. The relevant chapters and tables for each of the elements are summarized in Table 9.3.

This section discusses work conducted in NUS of which the elements of a facility were graded in terms of cause and criticality. Guidelines in

Table 9.3. Summary of checklists for elements.

	Element	Chapter	Table
Civil and Architecture	Wet area	2	2.7, 9.6
	Façade	3	3.3, 9.5
	Basement	4	4.3, 9.4
	Roof	5	5.1, 9.7
Mechanical and Electrical	Sanitary-Plumbing	6	4.1, 9.8
	HVAC	6	4.2, 9.9
	Elevators and Lifts	6	4.3, 9.10
	Electrical	6	4.4, 9.11
	Fire protection	6	4.5, 9.12

the form of maintainability checklist were developed. The relevant factors, their significance and relative weights were evaluated. The result may be used, with relevant adjustment to the different needs of the user, as a benchmark for good design, construction and maintenance practices and provides guidelines for optimum selection of maintenance strategies.

The work focused on major building systems and services maintained by central facility management. The elements or subsystems were grouped under two main systems, civil- architectural (C&A — Basement, façade, wet area and roof) and mechanical–electrical (M&E — Sanitary-plumbing, HVAC, elevator, electrical and fire protection). The work was conducted in three phases:

- defect analysis;
- benchmarking for design, construction and maintenance;
- integration of subsystems based on maintainability parameters.

9.4.1. *Defect Analysis*

As per FMECA rules, the nine subsystems were divided into components. List of associated defects, their causes and effects were noted from literature, site investigation, discussion with building professionals and facility managers (FM) and past maintenance records. The causes were divided into: (1) design/specification; (2) construction/installation; (3) maintenance; and (4) external factors, e.g. age, vandalism, etc. Criticality was expressed through defect frequency and severity given by impact on (1) economy; (2) system performance; and (3) health, safety and comfort. Severity Index (Sv) and Criticality Index (Cr) were proposed as:

$$\mathrm{Sv} = \frac{\bar{X}_{EC} + \bar{X}_{SP} + \bar{X}_{HS}}{3} \quad \text{and} \quad \mathrm{Cr} = \frac{\bar{X}_{FR}}{5} \times \frac{\mathrm{Sv}}{5},$$

where $\bar{X}_{EC}$, $\bar{X}_{SP}$, $\bar{X}_{HS}$ and $\bar{X}_{FR}$ are the mean rating (out of 5) or weighted average for economic impact, system performance impact, health–safety–comfort impact and defect frequency, respectively.

The grading scale for frequency and severity depends on the situation. Here a five-point scale was selected to suit the five-point Likert scale of questionnaire. Such structured data collection strategy ensures unbiased and unambiguous response. For frequency, 1 = very rare (once in 10 years. or rarer); 2 = rare (once in 5 years); 3 = occasional (yearly); 4 = frequent (quarterly); 5 = very frequent (monthly or more frequent). For severity, 1 = negligible; 2 = slight; 3 = moderate; 4 = serious; 5 = very serious, hazardous or fatal. In a questionnaire survey, experienced FMs graded the defects in terms of frequency and three severity parameters. A critical defect has ≥1 of these four factors found significant in statistical *t*-test with 95% confidence interval. The null hypothesis ($H_{0:}$ $\mu \leq \mu_0$) was tested against the alternative hypothesis (H_1: $\mu > \mu_0$), where μ is the population mean and μ_0(=3) is critical rating above which a factor was called significant.

9.4.2. *Benchmarking for Design, Construction and Maintenance*

For each subsystem, guidelines to achieve higher maintainability were developed in the form of defect-mitigating checklist factors based on literature and DL (Defect Library). These factors were grouped under design–construction–maintenance aspects and further sub-grouped under components of the subsystem. Factors' relative weights (RW) are their ability to mitigate both critical and noncritical defects and scores was set as 5 = full compliance with the requirements; 1 = violation of the same and 0 = factors not applicable. Weighted sum of the MS of each factors indicate MS for individual subsystem. The ideal score ≈ 100%. Using 80–20 rule, RW of *i*-th factor RW_i is:

$$\mathrm{RW_i} = W_i \Big/ \sum\nolimits_{i=1}^{N} W_i \quad \text{for} \quad W_i = \left(0.8 \times \sum\nolimits_{p=i}^{p} \mathrm{Cr}_p\right) + \left(0.2 \times \sum\nolimits_{q=i}^{Q} \mathrm{Cr}_q\right),$$

where W_i = weight of a factor, N = no. of factors for a subsystem, P, Q = no. of critical and noncritical defects respectively, Cr = criticality index for a defect. This generic formula is applicable to any component or any building phase. In that case RWs of only relevant factors are to be renormalized to obtain a new set of RWs.

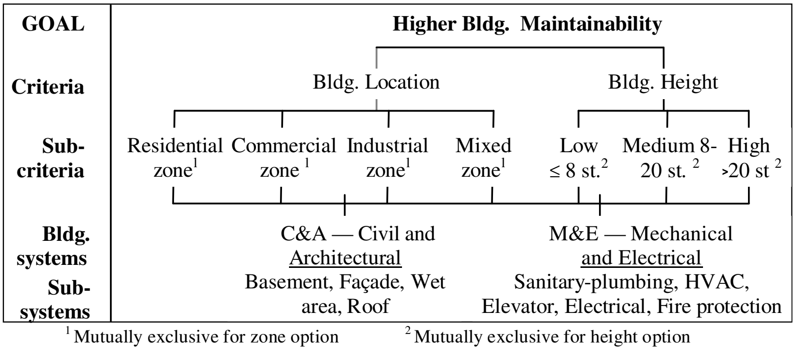

Fig. 9.3. The AHP model to integrate building subsystems into COMASS.

9.4.3. *Integration of Subsystems Based on Maintainability Parameters*

Figure 9.3 shows the AHP model for integration of nine subsystems in terms of maintainability. As per problem definition, higher building maintainability was goal and subsystems were at lowest strata. Expert FMs as respondents considered technical viability of subsystems (objective parameter) and business profile (subjective parameter) rely on height and zone, respectively. Hence these two were criteria and their different options (mutually exclusive) were sub-criteria. From individual responses, group decision for RW of subsystems was derived as per standard method. The numeric values were matched to grading logic and the MS of the building was yielded from weighted sum of MS of subsystems.

Tables 9.4–9.12 show the maintainability factors for various elements with their relative weights for reference only. Users should use the relevant weights according to their own needs for the best performance.

9.4.4. *Overview of Scoring of All Subsystems*

For the entire building a total of 731 guidelines were proposed (Table 9.13). Design related guidelines were undoubtedly the highest in number. Details of the guideline is tabulated in the Maintainability Website (http://www.hpbc.bdg.nus.edu.sg/).

Table 9.4. Maintainability factors for basement and their RWs.

Component		Maintainability Factors	Asso. Critical Defects	Asso. Noncritical Defects	Wt.	RW
Design phase						
W/P system	a1	Usage	A3, A5		0.454	0.021
	a2	Application feasibility	A3, A5		0.454	0.021
	a3	Soil condn.	A3, A5		0.454	0.021
Concrete	a4	System/construction method selection	A20	A12	0.302	0.014
	a5	Design (mix and rebar)	A3, A4. A5	A1, A111, A17	1.117	0.052
	a6	Joint details		A1, A12, A17	0.333	0.016
	a7	Pipe penetrations	A19		0.289	0.014
W/P membrane (in Type A system)	a8	Location	A3		0.258	0.012
	a9	Application	A3		0.258	0.012
	a10	Material selection	A3		0.258	0.012
	a11	Material properties	A3, A4	A8	0.622	0.029
	a12	Joint details		A1	0.283	0.013
	a13	Pipe penetrations	A19		0.289	0.014
Waterstop (in Type B system)	a14	Shape	A20	A1	0.571	0.027
	a15	Material	A2	A1	0.571	0.027
	a16	Detailing	A2	A1	0.571	0.027
Cavity (in Type C system)	a17	Cavity wall design		A6, A11	0.065	0.003
	a18	Masonry block and mortar selection		A6	0.033	0.002
	a19	Cavity floor selection	A20		0.278	0.013
	a20	Cavity floor design	A20	A6	0.311	0.015

(Continued)

Table 9.4. (*Continued*)

Component		Maintainability Factors	Asso. Critical Defects	Asso. Noncritical Defects	Wt.	RW
Drainage system	a21	Pump sump	A20		0.278	0.013
	a22	Catchments	A20		0.278	0.013
Flooring	a23	Screed	A20	A17	0.278	0.013
	a24	Additives	A16		0.229	0.011
	a25	Finishing	A16		0.229	0.011
Wall finishes	a26	Paint selection		A8, A10	0.230	0.011
	a27	Tile selection		A12, A13	0.061	0.003
Ancillary facilities	a28	Coordination among professions		A15	0.244	0.011
					Subtotal	0.450
Construction phase						
RCC	a29	Excavation and formwork	A20	A12	0.278	0.013
	a30	Rebar laying		A1	0.283	0.013
	a31	Material quality	A20	A11, A17	0.057	0.003
	a32	Casting and curing	A3, A4, A5	A1, A12, A17	1.110	0.052
	a33	Check and test		A17	0.025	0.001
W/P install	a34	Substrate and material quality	A3		0.258	0.012
	a35	Application	A3, A19	A1	0.830	0.039
	a36	Inspect and test	A3	A1	0.541	0.025
	a37	Protection	A3		0.258	0.012

(*Continued*)

Table 9.4. (*Continued*)

Component		Maintainability Factors	Asso. Critical Defects	Asso. Noncritical Defects	Wt.	RW
Waterstop	a38	Installation	A2, A4	A1	0.895	0.042
Cavity	a39	Material quality and condition		A12	0.024	0.001
	a40	Laying	A20		0.278	0.013
	a41	Finishing		A14	0.032	0.002
Flooring	a42	Screed	A20		0.278	0.013
	a43	Joints		A17	0.025	0.001
	a44	Checking	A20	A17	0.303	0.014
Paint and plaster	a45	Substrate and material quality		A8, A9	0.219	0.010
	a46	Application	A7		0.212	0.010
Tiling	a47	Screed and tile prep.		A12, A14	0.056	0.003
	a48	Tiling		A13, A14	0.070	0.003
	a49	Protection		A13	0.037	0.002
					Subtotal	0.285
Maintenance phase						
General	a50	Inspection	A4, A5, A15, A19	A2, 18	1.569	0.074
Drainage system	a51	Check	A20		0.278	0.013
	a52	Clean	A20		0.278	0.013
Flooring	a53	Clean	A20		0.360	0.017

(*Continued*)

Table 9.4. (*Continued*)

Component		**Maintainability Factors**	**Asso. Critical Defects**	**Asso. Noncritical Defects**	**Wt.**	**RW**
Tiles	a54	Clean	A16, A20	A17	0.419	0.020
Painted wall	a55	Clean		A10, A18	0.266	0.012
External factors	a56	Soil permeability	A1, A3, A5		0.541	0.025
	a57	Aggressive chemical	A1, A3		0.541	0.025
	a58	Depth	A1, A3		0.541	0.025
	a59	Building age	A1, A3, A4		0.865	0.041
					Subtotal	0.265
					Total	**1.000**

Table 9.5. Maintainability factors for façade and their RWs.

Component		Maintainability Factors	Critical Defects Mitigated	Noncritical Defects Mitigated	Wt.	RW
Design phase						
System selection	b1	Water resistance	B3	B4, B9, B14, B25, B29, B30	0.351	0.016
	b2	Complexity	B49		0.192	0.009
	b3	Removeability	B49		0.192	0.009
	b4	Accessibility		B48	0.060	0.003
	b5	Availability	B49		0.192	0.009
Finishes	b6	Water resistance: Traditional wall	B3	B9, B14, B25, B30	0.298	0.014
	b7	-Do-: Curtain wall/cladding	B43	B40	0.261	0.012
	b8	Cleanability	B5, B13, B21, B43, B49	B10, B24, B31	1.250	0.059
	b9	Inspect. freq.	B49		0.192	0.009
Material	b10	Masonry block	B3, B5	B1, B2, B10, B14, B25	0.560	0.026
	b11	Plaster	B13		0.241	0.011
	b12	Stone		B27 ,B28, B29, B30, B31	0.330	0.015
	b13	Tiles		B23, B24, B26	0.097	0.005
	b14	Paint	B21	B16, B18, B19, B20	0.318	0.015
	b15	Coating		B34, B39	0.069	0.003
	b16	Metal	B33	B32, B35, B36, B38, B41, B42	0.338	0.016
	b17	Glass	B43, B44		0.413	0.019

(*Continued*)

Table 9.5. (*Continued*)

Component	Maintainability Factors		Critical Defects Mitigated	Noncritical Defects Mitigated	Wt.	RW
Wall joint	b18	Water resistance	B3	B9, B14, B25, B30	0.298	0.014
	b19	Grid size		B6, B22, B27, B35	0.074	0.003
	b20	Exposure		B6, B10	0.075	0.004
	b21	Drainage	B43	B40	0.261	0.012
Expansion joint	b22	Location	B3	B1, B11, B27, B28, B35, B36	0.332	0.016
	b23	Spacing		B22, B23, B27, B28, B35, B36	0.127	0.006
	b24	Rigidity	B44	B35, B36, B45	0.273	0.013
Sealant	b25	Type		B6, B42	0.065	0.003
	b26	Geometry	B44	B6, B42	0.243	0.011
	b27	Backer rod	B44	B6, B42	0.243	0.011
	b28	Exposure		B42, B45	0.066	0.003
Building shape	b29	Plan	B13, B21, B31, B49	B48	0.980	0.046
	b30	Massing	B49	B48	0.252	0.012
	b31	Regularity	B5, B13, B21, B31, B33, B43	B9, B10, B24	1.457	0.068
	b32	Projection	B49	B48	0.252	0.012
Access system	b33	Type	B49		0.192	0.009
	b34	Coverage	B49		0.192	0.009
	b35	Number	B49		0.192	0.009

(*Continued*)

Table 9.5. (*Continued*)

Component	Maintainability Factors		Critical Defects Mitigated	Noncritical Defects Mitigated	Wt.	RW
Window	b36	Position	B46		0.213	0.010
	b37	Panel detail	B46		0.213	0.010
	b38	Louvre detail	B5, B13, B21, B33	B9, B10	0.915	0.043
	b39	Shading	B5, B13, B21, B33, B46	B9, B10	1.128	0.053
	b40	Drainage detail	B46		0.213	0.010
	b41	Accessibility	B47		0.219	0.010
Ancillary	b42	Structural	B7, B8, B21	B1, B2, B10, B22, B23, B35	0.640	0.030
					Subtotal	0.677
Construction phase						
Brickwork	b43	Material quality	B3, B5	B1, B2	0.463	0.022
	b44	Laying		B4	0.036	0.002
	b45	Finishing	B3	B4	0.233	0.011
Block masonry	b46	Material quality		B1, B2	0.035	0.002
	b47	Laying		B4	0.036	0.002
	b48	Finishing	B3		0.197	0.009
PC	b49	Preparation	B7		0.030	0.001
	b50	Erection and jointing	B8	B10	0.173	0.008

(*Continued*)

Table 9.5. (*Continued*)

Component	Maintainability Factors	Critical Defects Mitigated	Noncritical Defects Mitigated	Wt.	RW
Plastering	b51 Substrate prep.	B12, B15		0.061	0.003
	b52 Material quality		B11, B12, B14, B15	0.123	0.006
	b53 Application and curing	B13	B11, B12	0.309	0.014
Painting	b54 Substrate prep.		B16, B17	0.069	0.003
	b55 Material quality		B16	0.022	0.001
	b56 Application		B17	0.047	0.002
Tiling (ceramic and stone)	b57 Base prep.		B22, B23, B28	0.049	0.002
	b58 Tile prep.		B23, B26	0.046	0.002
	b59 Tiling		B23, B27, B28, B30	0.079	0.004
	b60 Grouting		B24	0.051	0.002
	b61 Inspection		B22, B23, B24, B26	0.112	0.005
	b62 Protection		B24, B26	0.073	0.003
Metal	b63 Material quality and preparation		B32, B34, B35, B37, B38, B40	0.159	0.007
	b64 Setting fixings	B44	B32, B37, B40	0.275	0.013
	b65 Panel erection	B44	B32, B34, B35, B36, B40, B41	0.318	0.015
Sealant application	b66 Substrate prep.	B44	B6, B42, B45	0.274	0.013
	b67 Material quality		B6, B42, B45	0.096	0.005
	b68 Application	B43	B6, B42, B45	0.331	0.016
				Subtotal	0.173

(*Continued*)

Table 9.5. (*Continued*)

Component	Maintainability Factors	Critical Defects Mitigated	Noncritical Defects Mitigated	Wt.	RW
Maintenance phase					
Clean	b69 Masonry	B5		0.230	0.011
	b70 Conc. and plaster	B8, B13	B9, B10, B14	0.466	0.022
	b71 Painted	B21	B17	0.278	0.013
	b72 Stone cladding	B31		0.257	0.012
	b73 Tile cladding		B23, B24, B25, B26, B30	0.146	0.007
	b74 Glass curtain	B43	B47	0.454	0.021
	b75 Metal cladding	B33	B32, B38, B39	0.274	0.013
External	b76 Building age	B8	B10, B20, B22, B35	0.219	0.010
	b77 Exposure	B5, B7, B8, B31	B2, B10, B19, B20, B39, B42, B45	0.676	0.032
	b78 Height		B49	0.192	0.009
				Subtotal	0.149
				Total	**1.000**

Table 9.6. Maintainability factors for wet area and their RWs.

Component		Maintainability Factors	Asso. Critical Defects	Asso. Noncritical Defects	Wt.	RW
Design phase						
Floor	c1	Zoning	C2	C1, C11	0.163	0.010
	c2	Gradient		C18	0.024	0.002
	c3	Concrete slab	C2, C4	C1, C3, C5, C6, C11	0.350	0.022
	c4	Screed		C1, C5, C6, C11, C18	0.118	0.008
Water proofing	c5	Material select	C2, C4	C1, C11	0.290	0.019
	c6	Material property	C2, C4	C1, C11	0.290	0.019
	c7	Application feasibility	C2, C4	C11	0.259	0.017
	c8	Joint details		C1, C11	0.055	0.004
	c9	Penetration details	C4, C15, C16	C11	0.547	0.035
	c10	Fixture detailing	C2	C11	0.131	0.008
Plumbing	c11	Wet wall or layout	C2	C11, C13	0.428	0.028
	c12	Penetration plan	C2, C4, C15, C16	C11	0.655	0.042
	c13	No of fl./wall penetration	C4, C15	C11	0.340	0.022
	c14	Pipe accessibility	C4, C15	C11, C12, C17	0.385	0.025
	c15	Wall accessibility	C13	C7	0.313	0.020
Fixture and fittings	c16	Gen. quality		C19	0.238	0.015
	c17	Basin selection	C13		0.296	0.019
	c18	Basin layout	C13		0.296	0.019
	c19	WC and urinal selection	C13		0.296	0.019
	c20	WC and urinal layout	C13		0.296	0.019

(Continued)

Table 9.6. (*Continued*)

Component		Maintainability Factors	Asso. Critical Defects	Asso. Noncritical Defects	Wt.	RW
	c21	Bath selection	C13	C18	0.320	0.021
	c22	Shower layout	C13		0.296	0.019
	c23	Bathtub layout		C18	0.024	0.002
	c24	Piping material selection	C19	C12, C17	0.280	0.018
Tiles on floor and wall	c25	Movement joint location		C5, C6, C8	0.076	0.005
	c26	Movement jt. detail		C5, C6	0.040	0.003
	c27	Tiles selection		C5, C6, C7, C8	0.092	0.006
	c28	Bedding material		C6, C8	0.039	0.003
	c29	Grout selection		C6, C7, C9	0.059	0.004
Paints	c30	Paint property	C10, C13	C11	0.432	0.028
	c31	Water resistance	C13	C11	0.320	0.021
Ancillary facilities	c32	Coordination among professions	C13	C14, C16	0.549	0.035
					Subtotal	0.533
Construction phase						
Floor	c33	Slab casting	C2, C4	C1, C3, C6, C11,C12	0.352	0.023
	c34	Embedding of services	C4, C15, C16	C11	0.547	0.035
	c35	Laying the slope		C18	0.024	0.002
Water proofing	c36	Substrate condition	C2, C4	C1, C11	0.290	0.019
	c37	Quality of material	C2, C4	C1, C11	0.290	0.019
	c38	Application	C2, C4, C15, C16	C1, C11	0.686	0.044
	c39	Inspection and testing	C2, C4	C1, C11	0.290	0.019
	c40	Protection	C4, C15, C16	C11	0.547	0.035

(*Continued*)

Table 9.6. (*Continued*)

Component		Maintainability Factors	Asso. Critical Defects	Asso. Noncritical Defects	Wt.	RW
Tiles on floor and wall	c41	Base (substrate and screed) preparation		C6, C8	0.059	0.004
	c42	Preparation of tiles		C6, C8, C9	0.079	0.005
	c43	Tiling		C5, C6, C8, C9	0.096	0.006
	c44	Grouting		C6, C7, C9	0.059	0.004
	c45	Inspect and check		C5, C6, C7, C9	0.076	0.005
	c46	Protection		C5, C6	0.040	0.003
Paints	c47	Substrate prep.	C10	C11	0.135	0.009
	c48	Material quality	C10	C11	0.135	0.009
	c49	Application	C10	C12	0.131	0.008
Fix. and fittings	c50	Fixing and connection	C15, C16	C11, C14	0.282	0.018
					Subtotal	0.265
Maintenance phase						
General	c51	Inspection	C4, C15	C1, C11, C12, C17	0.416	0.027
Tile finish	c52	Cleaning	C13		0.296	0.019
Marble	c53	Cleaning	C13		0.296	0.019
Granite	c54	Cleaning	C13		0.296	0.019
Paints	c55	Cleaning	C13		0.296	0.019
Fix fittings	c56	Cleaning	C19		0.238	0.015
External factors	c57	Building age	C2, C4, C16	C1, C11	0.497	0.032
	c58	level of usage	C19	C7	0.254	0.016
	c59	Vandalism	C13, C19	C7	0.550	0.035
					Subtotal	0.202
					Total	**1.000**

Table 9.7. Maintainability factors for roof and their RWs.

Component		Maintainability Factors	Asso. Critical Defects	Asso. Noncritical Defects	Wt.	RW
Design						
Roofing sys. deck	d1	Selection	D3	D11, D15	0.230	0.014
	d2	Struct. conc.		D1	0.025	0.001
	d3	Bearing capacity	D3, D5, D21	D11	0.679	0.040
	d4	Deflection	D5, D21	D6, D11	0.538	0.032
	d5	Movement jt.	D3	D2, D4, D11, D16	0.280	0.017
	d6	Vapor barrier		D6, D12	0.060	0.004
	d7	Parapet	D5	D4	0.235	0.014
	d8	Pipe and equip.	D3, D25		0.323	0.019
WP membrane	d9	Selection		D6, D10, D11, D12, D13, D14	0.152	0.009
LAM	d10	Jt. detail	D3	D4, D14	0.224	0.013
	d11	Penetration	D3, D22, D25	D4, D14	0.602	0.036
Preformed	d12	Jt. detail/flashing	D3	D2, D4, D14	0.248	0.015
	d13	Penetration	D3, D22, D25	D4, D14	0.602	0.036
	d14	Venting		D6	0.038	0.002
Insulation	d15	Properties		D4, D11	0.045	0.003
	d16	Material	D21	D5	0.477	0.028
Tiles/panels	d17	Properties		D16, D17	0.050	0.003
Sealant	d18	Type		D18	0.043	0.003
	d19	Joint geometry		D18, D20	0.064	0.004
	d20	Bk. rod detail		D18, D20	0.064	0.004

(Continued)

Table 9.7. (*Continued*)

Component		Maintainability Factors	Asso. Critical Defects	Asso. Noncritical Defects	Wt.	RW
Roof drainage	d21	Design rate	D22		0.235	0.014
	d22	Effective runoff	D22		0.235	0.014
	d23	Angle of slope	D22		0.235	0.014
	d24	Uniformity of slope	D4, D21	D5	0.499	0.030
	d25	Ease of construction	D21	D5	0.477	0.028
Outlet	d26	Size and no.	D22		0.235	0.014
	d27	Location	D21	D5	0.477	0.028
	d28	Protection	D22		0.235	0.014
RWDP	d29	RWDP size and material	D22		0.235	0.014
	d30	Slope	D22		0.235	0.014
	d31	Access	D22		0.235	0.014
	d32	Fixing	D22		0.235	0.014
	d33	Jointing	D22	D24	0.268	0.016
	d34	Termination	D23		0.098	0.006
Ancillary facility	d35	Coordination	D3, D27	D14, D24, D26	0.387	0.023
					Subtotal	0.553
Construction phase						
Deck	d36	Concreting	D4	D1	0.047	0.003
	d37	Precast unit		D1	0.025	0.001
	d38	Propping		D1	0.025	0.001

(*Continued*)

Table 9.7. (*Continued*)

Component		Maintainability Factors	Asso. Critical Defects	Asso. Noncritical Defects	Wt.	RW
	d39	Const. joint	D3	D2	0.204	0.012
	d40	Curing		D1, D6	0.063	0.004
	d41	Protection	D2	D3, D9, D11	0.259	0.015
	d42	Finished surface	D2, D4, D21	D3, D5, D6, D9, D11, D12	0.817	0.049
WP-LAM	d43	Storage and prep.		D6, D9, D10, D11	0.117	0.007
	d44	LAM apply		D6, D9, D12, D14, D15	0.141	0.008
	d45	Membrane application	D21	D6, D9, D10, D13, D14, D15	0.429	0.025
	d46	Joint and penetration	D4, D21	D3, D5, D11, D14, D24	0.757	0.045
	d47	Protection		D9, D14	0.054	0.003
	d48	Testing	D21	D5	0.477	0.028
Insulation	d49	Layout		D16	0.031	0.002
Tiles/panels	d50	Base	D21	D17	0.282	0.017
	d51	Tiling		D17	0.019	0.001
Sealant	d52	Substrate		D18	0.043	0.003
	d53	Quality check		D18	0.043	0.003
	d54	Application		D18, D20	0.064	0.004
Drainage	d55	Jointing	D21, D22	D5, D24	0.745	0.044
	d56	Testing	D21, D22	D5, D24	0.745	0.044
					Subtotal	0.320

(*Continued*)

Table 9.7. (*Continued*)

Component		**Maintainability Factors**	**Asso. Critical Defects**	**Asso. Noncritical Defects**	**Wt.**	**RW**
Maintenance phase						
Roof surface	d57	Check	D2, D19	D3, D7, D8, D20	0.425	0.025
	d58	Clean	D19	D5	0.375	0.022
Drainage	d59	Check	D4	D12	0.257	0.015
	d60	Clean		D12	0.235	0.014
Details	d61	Check	D2	D3, D5	0.417	0.025
External factors	d62	Usage		D7, D8, D9, D15	0.097	0.006
	d63	Building age	D2	D3, D18, D20	0.268	0.016
	d64	Exposure		D15, D18	0.071	0.004
					Subtotal	0.127
					Total	**1.000**

Table 9.8. Maintainability factors for sanitary-plumbing system and their RWs.

Component		Maintainability Factors	Critical Defects Mitigated	Noncritical Defects Mitigated	Wt.	RW
Design phase						
Cold water supply piping	e1	Size	E5	E1	0.366	0.009
	e2	Material	E2, E3, E4, E5		0.957	0.025
	e3	Strength		E1	0.064	0.002
	e4	Layout	E3, E4, E5, E6, E14	E7	1.142	0.030
	e5	Safe distance		E1	0.064	0.002
	e6	Cross connection	E3		0.144	0.004
	e7	Protection (u. gr.)		E1	0.064	0.002
	e8	Support (u. gr.)		E1	0.064	0.002
	e9	Protection (ovr. gr.)	E2		0.266	0.007
	e10	Support (ovr. gr.)	E6		0.237	0.006
	e11	Access	E3	E7	0.203	0.005
	e12	Noise prevention	E6		0.237	0.006
	e13	Joints	E3, E4, E5		0.690	0.018
	e14	Penetration	E2	E9	0.320	0.008
	e15	Cleaning facility	E3, E5		0.446	0.012
	e16	Isolation valve	E3	E7	0.203	0.005
	e17	Air valve	E5, E6, E14		0.695	0.018
Hot water supply	e18	Piping design	E11		0.282	0.007
	e19	Material	E12		0.202	0.005
	e20	Temp. control	E3, E11, E12		0.628	0.016

(Continued)

Table 9.8. (*Continued*)

Component	Maintainability Factors		Critical Defects Mitigated	Noncritical Defects Mitigated	Wt.	RW
Storage tank	e21	Capacity		E10	0.029	0.001
	e22	Location	E3		0.144	0.004
	e23	Material	E3, E8	E9	0.523	0.014
	e24	Access	E3	E10	0.173	0.004
	e25	Circulation	E3	E9, E10	0.226	0.006
	e26	Ventilation	E3		0.144	0.004
Pumps	e27	Capacity	E5, E13, E15		0.868	0.022
	e28	Material		E16	0.063	0.002
	e29	Housing	E13		0.302	0.008
Sanitary appliances	e30	Material	E18, E19, E21		0.955	0.025
	e31	Fixing	E19, E21		0.613	0.016
	e32	Supply	E3, E18		0.486	0.013
	e33	Discharge	E19		0.364	0.009
	e34	Floor waste and trap	E19, E20		0.712	0.018
	e35	Access	E19		0.364	0.009
Sanitary pipe	e36	System select and venting	E18, E24, E25		0.735	0.019
	e37	Pipe design E18	E23, E24, E25		0.691	0.018
	e38	layout	E24	E26	0.253	0.007
	e39	Access	E24	E26	0.253	0.007
	e40	Joints	E23		0.298	0.008

(*Continued*)

Table 9.8. (*Continued*)

Component		Maintainability Factors	Critical Defects Mitigated	Noncritical Defects Mitigated	Wt.	RW
Sewage ejector and solid diverter tank	e41	Pit design	E27, E29		0.478	0.012
	e42	Location	E29		0.257	0.007
	e43	Access	E27		0.221	0.006
	e44	Services	E27		0.221	0.006
	e45	Pump and piping	E29		0.257	0.007
Sewer drain	e46	Material	E3	E31	0.207	0.005
	e47	Jointing	E3, E30		0.340	0.009
	e48	Location	E3		0.144	0.004
	e49	Layout	E30		0.196	0.005
					Design subtotal	0.460
Construction phase						
Water supply	e50	Storage and handling	E2, E11, E12		0.728	0.019
	e51	Laying	E3, E5, E6, E14	E7	0.898	0.023
	e52	Joint and penetration	E3, E4, E5	E9	0.744	0.019
	e53	Insulation	E2, E12		0.468	0.012
	e54	Backfill		E1	0.064	0.002
	e55	Testing	E4, E5	E1	0.610	0.016

(*Continued*)

Table 9.8. (*Continued*)

Component		Maintainability Factors	Critical Defects Mitigated	Noncritical Defects Mitigated	Wt.	RW
Storage tank	e56	Achieve water-tightness	E3, E8	E9	0.523	0.014
	e57	Device installation	E3	E10	0.173	0.004
	e58	Commissioning	E3, E8	E9	0.523	0.014
	e59	disinfection	E3		0.144	0.004
Pumps	e60	Mounting	E13, E14		0.458	0.012
	e61	Testing	E13, E15		0.565	0.015
Sanitary appliance	e62	Storage	E18		0.342	0.009
	e63	Fixing	E19, E20, E21		0.961	0.025
	e64	Testing	E19, E20		0.712	0.018
	e65	Protection	E18, E20		0.690	0.018
Sanitary pipe	e66	Storage and handling	E23, E24		0.515	0.013
	e67	Fixing	E24	E26	0.253	0.007
	e68	Jointing	E23, E24	E26	0.551	0.014
	e69	Protection	E23, E24		0.515	0.013
	e70	Test	E23		0.298	0.008
Swg. eject and solid divert	e71	Installation	E29		0.257	0.007
	e72	Testing	E29		0.257	0.007
Sewer	e73	Laying	E30	E31	0.259	0.007
	e74	Testing	E3, E30		0.340	0.009
					Subtotal	0.306

(*Continued*)

Table 9.8. (*Continued*)

Component	Maintainability Factors		Critical Defects Mitigated	Noncritical Defects Mitigated	Wt.	RW
Maintenance phase						
Cold water supply	e75	Check	E2, E3, E4, E5		0.957	0.025
	e76	Clean	E3, E5		0.446	0.012
Hot water supply	e77	Check	E3, E11		0.426	0.011
	e78	Clean	E11, E12		0.484	0.013
Storage	e79	Check	E3, E8		0.470	0.012
	e80	Clean	E3, E8	E10	0.499	0.013
Pumps	e81	Check	E13		0.302	0.008
	e82	Clean	E13, E15	E16	0.628	0.016
	e83	Test	E5	E17	0.327	0.008
Sanitary appliances	e84	Check	E19, E21, E24, E27	E22	1.103	0.028
	e85	Clean	E18, E20		0.690	0.018
	e86	Replace	E20, E27		0.569	0.015
Sanitary pipe	e87	Check	E23, E24		0.515	0.013
	e88	Clean	E24	E26	0.253	0.007
Swg. eject and solid divert	e89	Check	E29		0.257	0.007
	E90	clean	E27		0.221	0.006
Sewer	e91	Check		E31	0.063	0.002
	e92	Clean	E30		0.196	0.005
Ext. factor	e93	Building age	E2, E12, E28	E22	0.659	0.017
					Subtotal	0.234
					Total	1.000

Table 9.9. Maintainability factors for HVAC system and their RWs.

Component	Maintainability Factors		Asso. Critical Defects	Asso. Noncrit. Defects	Wt.	RW
Design phase						
AHU room	f1	Location	F38		0.098	0.004
	f2	Enclosure	F38	F3, F11	0.160	0.006
	f3	Access	F4, F10, F13		0.972	0.038
	f4	Mounting	F2, F38		0.317	0.012
	f5	Isolator	F2, F38		0.317	0.012
	f6	Services	F13		0.412	0.016
Air intake	f7	Location	F10	F37	0.345	0.013
	f8	Protection		F31, F37	0.054	0.002
	f9	Fan and motor	F1	F7	0.359	0.014
Drain pan	f10	Material	F5	F3	0.147	0.006
	f11	Drainage	F8	F31, F37	0.252	0.010
	f12	Drain off pipe	F8	F9	0.229	0.009
Filler	f13	Selection	F10		0.304	0.012
	f14	Layout	F10		0.304	0.012
	f15	Pressure gauge	F10		0.304	0.012
Cooling coil	f16	Material		F3	0.043	0.002
	f17	Coil row	F4	F7	0.292	0.011
FCU	f18	Location	F10	F37	0.345	0.013
	f19	Housing		F3	0.043	0.002
	f20	Access	F13, F39		0.528	0.020

(*Continued*)

Table 9.9. (*Continued*)

Component	Maintainability Factors		Asso. Critical Defects	Asso. Noncrit. Defects	Wt.	RW
	f21	Isolator	F2		0.219	0.008
	f22	Cooling coil	F4	F7	0.292	0.011
	f23	Drain pan material	F5	F3	0.147	0.006
	f24	Drainage	F8		0.198	0.008
	f25	Drain off pipe	F8	F9	0.229	0.009
	f26	Filter type	F10		0.304	0.012
Chiller	f27	Capacity	F19	F18, F27	0.173	0.007
	f28	Refrigerant	F17		0.170	0.007
	f29	Compressor	F19	F35	0.150	0.006
	f30	Condenser	F14	F18	0.359	0.014
	f31	Piping	F22		0.229	0.009
	f32	Purge unit	F17	F18	0.192	0.007
	f33	Mounting	F19		0.110	0.004
	f34	Thermal insulation	F22		0.229	0.009
	f35	Leak detector	F16, F17		0.289	0.011
	f36	Plant room	F19, F20, F23		0.475	0.018
Cooling tower	f37	Design	F24		0.347	0.013
	f38	Type	F14, F18		0.359	0.014
	f39	Material		F25	0.024	0.001
	f40	Location	F39	F27	0.157	0.006

(*Continued*)

Table 9.9. (*Continued*)

Component	Maintainability Factors		Asso. Critical Defects	Asso. Noncrit. Defects	Wt.	RW
	f41	Access		F26	0.028	0.001
	f42	Vibe/noise reduction	F28		0.067	0.003
	f43	Legionella prevention		F26	0.028	0.001
Air distribution	f44	Duct material	F30		0.128	0.005
	f45	Insulation		F29	0.046	0.002
	f46	Return air	F39		0.116	0.004
	f47	Air velocity		F33	0.033	0.001
	f48	Access	F32		0.369	0.014
	f49	Wet exhaust		F31	0.013	0.001
	f50	Terminal location	F34	F29	0.253	0.010
	f51	Terminal type	F34, F39		0.323	0.012
	f52	VAV box access	F39		0.116	0.004
	f53	Damper selection		F33	0.033	0.001
	f54	Controller location	F36		0.248	0.010
					Sub-total	0.475
Construction phase						
AHU/FCU	f55	Housing		F11	0.019	0.001
	f56	Filter	F4, F10, F32	F6	0.977	0.038
	f57	Fan and motor	F1, F2, F38		0.640	0.025

(*Continued*)

Table 9.9. (*Continued*)

Component	Maintainability Factors		Asso. Critical Defects	Asso. Noncrit. Defects	Wt.	RW
	f58	Cooling coil		F6	0.048	0.002
	f59	Drain pan and pipe	F5, F8	F3	0.346	0.013
Chiller	f60	General	F38	F15	0.139	0.005
	f61	Motor and controller	F16, F17		0.289	0.011
	f62	Fluid system	F21, F23	F35	0.406	0.016
Air distribution	f63	Duct quality	F28	F25	0.091	0.004
	f64	Fixing	F30, F32	F29	0.543	0.021
	f65	Testing	F30	F31	0.142	0.005
Cooling tower	f66	Installation		F33	0.033	0.001
					Subtotal	0.142
Maintenance phase						
AHU/FCU housing	f67	Clean	F13		0.412	0.016
	f68	Check	F12, F38	F3, F11	0.312	0.012
Cooling coil	f69	Clean	F4	F3, F6	0.346	0.013
	f70	Check	F4	F6	0.304	0.012
Drain pan	f71	Clean	F8		0.198	0.008
	f72	Check	F8	F9	0.229	0.009
Air intake and fan	f73	Clean	F2, F10, F32		0.893	0.035
	f74	Check	F1, F2, F10, F32		1.216	0.047

(*Continued*)

Table 9.9. *(Continued)*

Component		**Maintainability Factors**	**Asso. Critical Defects**	**Asso. Noncrit. Defects**	**Wt.**	**RW**
Chiller	f75	Check	F16, F20, F22		0.471	0.018
Compressor	f76	Check and test	F19, F21, F38	F35	0.373	0.014
	f77	Clean	F21		0.126	0.005
Condenser	f78	Check		F15	0.041	0.002
	f79	Clean	F14	F15, F18	0.497	0.019
	f80	Test	F19		0.110	0.004
Evaporator	f81	Check		F18	0.021	0.001
	f82	Clean		F3	0.043	0.002
Refrigerant	f83	Check	F16, F17		0.289	0.011
	f84	Purge	F17	F18	0.192	0.007
Control	f85	Check		F33	0.033	0.001
	f86	Clean		F35	0.039	0.002
Cooling tower	f87	Check	F28	F25	0.091	0.004
	f88	Clean and lubricate	F14, F24, F28, F39	F18, F25	0.913	0.035
	f89	Water treatment	F24, F39	F26	0.491	0.019
Air distribution	f90	Check	F34, F36, F39	F29, F33	0.689	0.027
	f91	Clean	F32, F34, F39		0.692	0.027
Ext. factor	f92	Building age	F2, F5, F12, F19, F23	F3	0.870	0.034
					Subtotal	0.383
					Total	**1.000**

Table 9.10. Maintainability factors for elevator and their RWs.

Component	Maintainability Factors		Asso. Critical Defects	Asso. Noncritical Defects	Wt.	RW
Design phase						
General	g1	Goal setting		G1, G4, G59	0.127	0.006
	g2	Performance selection	G6	G1	0.279	0.013
Machine room	g3	Location		G4	0.041	0.002
	g4	Size	G9	G8	0.306	0.014
	g5	Structure	G9	G11	0.243	0.011
	g6	Access	G9		0.217	0.010
	g7	Services	G10	G11	0.161	0.007
Machines in general	g8	Placing	G15	G18, G21	0.240	0.011
	g9	Load calculation		G16, G18	0.093	0.004
	g10	Material for parts	G15	G18, G21	0.240	0.011
	g11	Sheave dimension		G21	0.027	0.001
	g12	Sheave geometry		G21, G41	0.055	0.002
Roping system	g13	Load calculation	G3		0.193	0.009
	g14	Roping method	G3	G40	0.237	0.011
	g15	No. of strand	G22	G16, G40	0.198	0.009
	g16	Rope type	G22	G16, G40, G41	0.226	0.010
	g17	Rope lay	G22	G16	0.154	0.007

(*Continued*)

Table 9.10. (*Continued*)

Component	Maintainability Factors		Asso. Critical Defects	Asso. Noncritical Defects	Wt.	RW
Car	g18	Size and shape	G1, G4		0.092	0.004
	g19	Enclosure		G38	0.031	0.001
	g20	Internal finish	G31	G35	0.227	0.010
	g21	COP button	G6, G32, G42, G43		0.984	0.044
	g22	Services	G30, G31	G33	0.372	0.017
	g23	Car top	G34		0.170	0.008
	g24	Car bottom		G26	0.022	0.001
Hoistway	g25	Space design		G8, G37, G38	0.081	0.004
	g26	Landing opening		G8, G38	0.045	0.002
	g27	Material		G38, G39	0.075	0.003
	g28	Guiderail		G37	0.036	0.002
	g29	Services		G38	0.031	0.001
	g30	Counter weight		G4	0.041	0.002
	g31	Safety gear type		G4	0.041	0.002
	g32	Safety gear location		G25	0.016	0.001
Lobby/car door	g33	Material		G50, G51	0.090	0.004
	g34	Strength		G50, G51	0.090	0.004
	g35	Locks	G7, G52		0.239	0.011
	g36	Operation		G46	0.035	0.002
Landing	g37	Material selection	G54		0.324	0.015
	g38	Fire protection	G55	G56	0.245	0.011

(*Continued*)

Table 9.10. (*Continued*)

Component	Maintainability Factors		Asso. Critical Defects	Asso. Noncritical Defects	Wt.	RW
Pit	g39	Size	G28, G57	G8	0.450	0.020
	g40	Structure	G57	G8	0.327	0.015
	g41	Access	G28, G57		0.436	0.020
	g42	Services	G58	G8	0.147	0.007
	g43	Partitions		G8	0.014	0.001
Ancillary facilities	g44	Coordination	G10, G19, G24, G31	G12, G38, G39	0.704	0.032
					Subtotal	0.379
Construction phase						
Structure	g45	Quality	G57	G11, G37	0.374	0.017
	g46	Protection	G57		0.313	0.014
	g47	Landing opening	G3		0.193	0.009
Equipment	g48	Controller	G6, G14	G2, G17, G46	0.409	0.018
	g49	Traction machine and motor	G15	G18	0.093	0.004
	g50	Brake assembly	G19	G4, G5, G20	0.246	0.011
	g51	Lift car	G27	G23	0.107	0.005
	g52	Rope		G4, G40	0.085	0.004
	g53	Doors		G46, G47, G48	0.087	0.004
	g54	Cable		G26, G29, G59	0.076	0.003
					Subtotal	0.089

(*Continued*)

Table 9.10. (*Continued*)

Component	Maintainability Factors		Asso. Critical Defects	Asso. Noncritical Defects	Wt.	RW
Maintenance phase						
Machine room	g55	Cleaning	G9		0.217	0.010
	g56	Wkg. condn.	G10	G8	0.150	0.007
	g57	Check and record	G9	G11	0.243	0.011
Controller	g58	Clean	G14	G1, G13	0.155	0.007
	g59	Check and record	G6, G7, G14, G42, G49, G52	G2, G12, G13, G46, G47	1.140	0.051
Traction machine and motor	g60	Clean and lubricate	G15, G18	G4, G17	0.286	0.013
	g61	Check and record	G15	G1	0.222	0.010
Brake assembly	g62	Clean and lubricate	G19	G5, G20	0.204	0.009
	g63	Check and record		G5, G20	0.089	0.004
Governor machine	g64	Clean and lubricate	G22	G21	0.129	0.006
	g65	Check and record	G22		0.102	0.005
Lift car body	g66	Clean and lubricate	G27, G28	G25	0.219	0.010
	g67	Check	G3, G27	G23, G29	0.319	0.014
	g68	Safety	G7, G24	G34	0.295	0.013
Car interior	g69	Clean	G6		0.229	0.010
	g70	Checking	G30, G32, G42, G43	G33	0.942	0.042
Hoistway	g71	Clean	G36	G8, G38, G39	0.191	0.009
	g72	Check		G37	0.036	0.002

(*Continued*)

Table 9.10. (*Continued*)

Component	Maintainability Factors		Asso. Critical Defects	Asso. Noncritical Defects	Wt.	RW
Roping system	g73	Lubricate		G16, G37, G41	0.115	0.005
	g74	Check and record		G40	0.044	0.002
Lobby/car door	g75	Clean	G43	G44, G46, G47	0.383	0.017
	g76	Check	G7, G42, G43, G49, G52, G53	G44, G45, G46	1.201	0.054
Lobby	g77	Clean	G55		0.209	0.009
	g78	Check	G55	G56	0.245	0.011
Pit	g79	Clean and lubricate	G57	G8, G59	0.363	0.016
	g80	Check and record	G55, G58	G4, G59	0.599	0.027
	g81	Safety		G8	0.392	0.018
External factors	g82	Age of the building	G19, G22	G2, G18, G40, G46	0.363	0.016
	g83	Level of usage	G6, G30, G32, G42, G43	G46, G50	1.257	0.057
	g84	Vandalism	G6, G7, G30, G32, G42, G43, G53	G47, G50	1.453	0.066
					Subtotal	0.532
					Total	**1.000**

Table 9.11. Maintainability factors for electrical system and their RWs.

Component	Maintainability Factors		Asso. Critical Defect	Asso. Noncritical Defect	Wt.	RW
Design phase						
System in general	h1	Capacity	H2		0.191	0.005
	h2	Phase	H2		0.191	0.005
	h3	Location	H12		0.186	0.005
	h4	Label/notice	H12	H6, H18	0.247	0.006
Transformer	h5	Selection	H2, H3, H10, H11, H13, H21	H8, H22	1.193	0.029
	h6	Mounting		H8	0.032	0.001
	h7	Location		H8	0.032	0.001
	h8	Access	H11, H12		0.326	0.008
	h9	Room design	H11, H12	H8	0.358	0.009
	h10	Noise reduction		H8	0.032	0.001
Cable and wiring	h11	Material	HI, H13, H16		0.829	0.020
	h12	Size	H1, H2, H5, H13, H16		1.299	0.031
	h13	Cable selection	H1, H2, H13, H16	H14	1.053	0.026
	h14	Insulation	H1, H2, H13, H16		1.020	0.025
	h15	Joints	H15		0.189	0.005
	h16	Thermal effect	H1, H2, H4, H13, H16, H27	H18	1.427	0.035
	h17	Ph. Protection		H6, H14	0.066	0.002
	h18	Laying method	H5	H14	0.313	0.008
	h19	Buswasy select	H1, H2, H5, H13, H16		1.299	0.031
	h20	Location	H13	H14	0.357	0.009
	h21	Layout	H1, H2, H4, H13, H16	H18	1.216	0.029

(*Continued*)

Table 9.11. (*Continued*)

Component	Maintainability Factors		Asso. Critical Defect	Asso. Noncritical Defect	Wt.	RW
Connector	h22	Jn./pull box		H6, H14, H17	0.101	0.002
	h23	Splice	H5, H15		0.469	0.011
	h24	Termination	H5, H15		0.469	0.011
	h25	Gen. spec.	H19	H18, H23	0.272	0.007
	h26	Housing	H3, H4, H19, H20	H18, H23	0.899	0.022
	h27	Switchboard		H18	0.029	0.001
	h28	Panelboard spec.	H19		0.210	0.005
	h29	Panelboard nos.	H3		0.181	0.004
	h30	E. rm./closet	H4	H18	0.197	0.005
	h31	Outlet box	H20		0.279	0.007
	h32	Switch		H23	0.033	0.001
	h33	Receptacle	H20	H22	0.305	0.007
	h34	Short-circuit	H1, H13, H16, H27	H7, H24, H31	1.136	0.028
	h35	Ground fault	H4, H16	H18	0.488	0.012
Lighting	h36	Aesthetics	H28		0.211	0.005
	h37	Flexibility	H28		0.211	0.005
	h38	Maintainability	H28	H30	0.245	0.006
	h39	Lamp selection	H28	H29	0.237	0.006
	h40	Ballast selection		H32	0.041	0.001

(*Continued*)

Table 9.11. (*Continued*)

Component	Maintainability Factors		Asso. Critical Defect	Asso. Noncritical Defect	Wt.	RW
Standby and emergency power	h41	Source selection	H33, H35, H36		0.460	0.011
	h42	Housing	H33, H36		0.348	0.008
	h43	Generator selection	H33, H35, H36		0.460	0.011
	h44	Control	H36		0.144	0.004
	h45	Battery selection	H36		0.144	0.004
	h46	Battery discharge	H36		0.144	0.004
Grounding	h47	Shape	H38		0.125	0.003
	h48	Conductor	H38	H37	0.153	0.004
	h49	Electrode	H38	H37	0.153	0.004
	h50	Location	H38	H39	0.254	0.006
	h51	Networking	H38		0.125	0.003
	h52	Access	H38	H39	0.254	0.006
LPS	h53	Shape	H38		0.125	0.003
	h54	Material	H38	H37	0.153	0.004
	h55	Joint	H38	H37	0.153	0.004
	h56	Fastener	H38	H37	0.153	0.004
Ancillary facility	h57	Coordination	H15, H28	H39	0.529	0.013
					Subtotal	0.527

(*Continued*)

Table 9.11. (*Continued*)

Component	Maintainability Factors		Asso. Critical Defect	Asso. Noncritical Defect	Wt.	RW
Construction phase						
Transformer	h58	Inspection	H11, H12	H8	0.358	0.009
	h59	Elec. test	H2, H3		0.371	0.009
Cable	h60	Prep.	H1, H13, H16	H14	0.719	0.017
	h61	Pulling	H15, H16	H14	0.513	0.012
	h62	Jointing	H1, H13, H15, H16	H14, H17	1.087	0.026
	h63	Protection	H5, H15	H14	0.502	0.012
	h64	Testing	H2		0.191	0.005
Busway	h65	Prep.	H1, H13, H16	H14	0.862	0.021
	h66	Install	H1, H13, H15, H16		1.018	0.025
	h67	Testing	H2		0.191	0.005
Dist. and prot. device	h68	Wiring	H2, H4, H25	H18	0.721	0.017
	h69	Connection	H4, H5, H25	H14, H17, H18	0.878	0.021
	h70	Testing	H2, H16	H14, H17	0.550	0.013
Lighting	h71	Fixing		H32	0.041	0.001
	h72	Testing		H29	0.034	0.001
Standby and emergency power	h73	Gen. install	H33, H36		0.348	0.008
	h74	Generator commissioning	H33, H36		0.348	0.008
	h75	Battery install	H36		0.144	0.004

(*Continued*)

Table 9.11. (*Continued*)

Component	Maintainability Factors		Asso. Critical Defect	Asso. Noncritical Defect	Wt.	RW
Grounding	h76	Prep.	H38	H37	0.153	0.004
	h77	Install	H38	H39	0.254	0.006
	h78	Test	H38		0.125	0.003
LPS	h79	Install	H38	H37	0.153	0.004
	h80	Test	H38		0.125	0.003
					Subtotal	0.235
Maintenance phase						
Transformer	h81	Clean	H8	H11, H12	0.358	0.009
	h82	Check	H8, H10	H11	0.288	0.007
	h83	Test		H11	0.140	0.003
Wiring	h84	Clean	H15, H16	H14	0.513	0.012
	h85	Check		H14, H17	0.069	0.002
Distr. equipment	h86	Clean		H18	0.029	0.001
	h87	Check		H14, H17	0.069	0.002
	h88	Test		H24	0.029	0.001
Protective equipment	h89	General	H3, H25		0.514	0.012
	h90	CB	H1, H3, H13, H16, H25		1.343	0.033
	h91	Fuse	H1, H3, H13, H16		1.010	0.024
	h92	GFCI	H13, H16, H25		0.948	0.023

(*Continued*)

Table 9.11. *(Continued)*

Component	Maintainability Factors		Asso. Critical Defect	Asso. Noncritical Defect	Wt.	RW
Lighting	h93	Clean	H28, H35		0.323	0.008
	h94	Check	H27, H28	H30, H31, H32	0.531	0.013
	h95	Replace	H27, H28	H31	0.456	0.011
Standby power	h96	Check	H36	H34	0.142	0.003
Generator	h97	Clean	H36	H34	0.142	0.003
	h98	Check	H33		0.203	0.005
	h99	Test	H35		0.113	0.003
Battery	h100	Clean	H36		0.144	0.004
	h101	Check	H36		0.144	0.004
	h102	Calibrate and test	H36		0.144	0.004
Grounding and LPS	h103	Check	H38	H37	0.153	0.004
	h104	Test	H38	H39	0.254	0.006
Ext. factors	h105	Building age	H4, H5, H12, H25, H38	H18, H30	1.155	0.028
	h106	Use		H22, H23	0.058	0.001
	h107	Vandalism	H12, H39	H14, H18, H22, H23, H39	0.560	0.014
					Subtotal	0.238
					Total	**1.000**

Table 9.12. Maintainability factors for fire protection system and their RWs.

Component	Maintainability Factors		Asso. Critical Defect	Asso. Noncritical Defect	Wt.	RW
Design phase						
Detector	j1	Performance	J1		0.251	0.015
	j2	Applicability	J1		0.251	0.015
	j3	Mounting	J1		0.251	0.015
Alarm	j4	Selection		J3	0.027	0.002
	j5	Location		J3	0.027	0.002
	j6	Connectivity		J4	0.046	0.003
Alarm panel	j7	Location		J4	0.046	0.003
	j8	Legibility		J3, J4	0.027	0.002
	j9	Indicator		J3	0.073	0.004
	j10	Safety		J4	0.046	0.003
	j11	Connectivity		J4	0.046	0.003
	j12	Power supply		J2, J3, J4	0.106	0.006
Hydrant	j13	Location		J4, J6	0.083	0.005
	j14	Security		J6		0.002
	j15	Material		J6, J8	J8	0.004
	j16	Supply		J8		0.002
Hosereel	j17	Cabinet location	J11		0.120	0.007
	j18	Cabinet spec.	J11	J12	0.161	0.009
	j19	Hose	J10		0.194	0.011

(Continued)

Table 9.12. (*Continued*)

Component	Maintainability Factors		Asso. Critical Defect	Asso. Noncritical Defect	Wt.	RW
Sprinkler	j20	Selection	J14		0.209	0.012
	j21	Location	J15		0.152	0.009
	j22	Material	J16, J17	J20, J21	0.403	0.024
	j23	Support		J18	0.032	0.002
	j24	Water quality	J16	J21, J25	0.264	0.016
	j25	Pump location	J19		0.135	0.008
Portable fire extinguisher	j26	Selection	J29		0.182	0.011
	j27	Location	J26		0.234	0.014
	j28	Quality	J26, J28	J30	0.464	0.027
Fire door	j29	Selection		J32	0.048	0.003
	j30	Operation	J31		0.221	0.013
	j31	Detailing	J31	J32	0.269	0.016
	j32	Marking		J32	0.048	0.003
Escape lighting	j33	Power supply	J34		0.175	0.010
	j34	System selection	J34		0.175	0.010
	j35	Lamp selection	J34		0.175	0.010
	j36	Battery discharge	J34		0.175	0.010
	j37	Battery location	J34		0.175	0.010
	j38	Charger	J34		0.175	0.010
Smoke ctrl.	j39	Safety and back-up	J36		0.116	0.007
					Sub-total	0.337

(*Continued*)

Table 9.12. (*Continued*)

Component	Maintainability Factors		Asso. Critical Defect	Asso. Noncritical Defect	Wt.	RW
Construction phase						
Detector and alarm	j40	Wiring		J2, J4	0.079	0.005
	j41	Mounting	J1		0.251	0.015
	j42	Testing	J1		0.251	0.015
Hydrant	j43	Storage		J6	0.037	0.002
	j44	Install		J5, J6	0.082	0.005
	j45	Testing	J7	J6, J8	0.266	0.016
Hosereel	j46	Base work	J11		0.120	0.007
	j47	Commissioning	J10, J11		0.314	0.018
Sprinkler	j48	Mounting	J15		0.152	0.009
	j49	Support	J15	J18	0.184	0.011
	j50	Supply network	J17, J19	J21, J24	0.345	0.020
Portable extinguisher	j51	Mounting		J27, J30	0.070	0.004
	j52	Protection	J26, J28		0.427	0.025
Fire door	j53	Storage and handling		J31	0.048	0.003
	j54	Fixing	J31		0.221	0.013
	j55	Checking	J31		0.221	0.013
Light	j56	Fixing	J34		0.175	0.010
	j57	Marking	J34		0.175	0.010
	j58	Testing	J34		0.175	0.010

(*Continued*)

Table 9.12. (*Continued*)

Component	Maintainability Factors		Asso. Critical Defect	Asso. Noncritical Defect	Wt.	RW
Smoke ctrl.	j59	Install	J36		0.116	0.007
					Sub-total	0.218
Maintenance phase						
Detector and alarm	j60	Clean	J1	J4	0.297	0.017
	j61	Test	J1	J4	0.297	0.017
	j62	Check and record		J2, J3, J4	0.106	0.006
Hydrant	j63	Clean		J6, J8	0.072	0.004
	j64	Check		J6, J9	0.076	0.004
	j65	Test and record		J6	0.037	0.002
Hosereel	j66	Clean	J11		0.120	0.007
	j67	Check	J10, J10		0.314	0.018
	j68	Test	J10		0.194	0.011
Sprinkler	j69	Clean	J14, J15		0.361	0.021
	j70	Check	J14, J15		0.361	0.021
Supply	j71	Clean	J16, J17		0.345	0.020
	j72	Check	J16, J19	J20, J23	0.396	0.023
	j73	Test	J19		0.135	0.008
Valves	j74	Clean		J21, J24, J25	0.106	0.006
	j75	Check		J21, J22, J23, J24, J25	0.149	0.009
	j76	Test		J21, J24	0.080	0.005

(*Continued*)

Table 9.12. (*Continued*)

Component		Maintainability Factors	Asso. Critical Defect	Asso. Noncritical Defect	Wt.	RW
Portable extinguisher	j77	Check	J26, J28, J29	J27, J30	0.679	0.040
	j78	Replace/recharge	J28, J29		0.374	0.022
	j79	Test and record	J28		0.193	0.011
Fire door	j80	Clean	J31, J33	J32	0.448	0.026
	j81	Check and record	J31	J32	0.269	0.016
	j82	Lubricate	J33		0.178	0.010
	j83	Repair and replace		J32	0.048	0.003
Lighting	j84	Clean	J34		0.175	0.010
	j85	Check and record	J34		0.175	0.010
	j86	Calibrate and test	J34		0.175	0.010
Smoke ctrl.	j87	Check and test	J36	J35	0.151	0.009
External factors	j88	Building age	J10, J33	J18, J21	0.439	0.026
	j89	Level of usage	J31	J32	0.269	0.016
	j90	Vandalism	J26, J28	J13, J22, J24	0.548	0.032
					Subtotal	0.445
					Total	**1.000**

Table 9.13. No. of maintainability factors.

			Design		Construction		Maintenance	
System	**Subsystem**	**Total**	**No.**	**%**	**No.**	**%**	**No.**	**%**
C&A	Basement	63	30	47.62	24	38.10	9	14.29
	Façade	79	42	53.16	26	32.91	11	13.92
	Wet area	59	32	54.24	18	30.51	9	15.25
	Roof	64	35	54.69	21	32.81	8	12.50
	Avg.	66.25	34.75	52.43	22.25	33.58	9.25	13.99
M&E	San-plumb.	93	49	52.69	25	26.88	19	20.43
	HVAC	92	54	58.70	12	13.04	26	28.26
	Elevator	84	44	52.38	10	11.90	30	35.71
	Electrical	107	57	53.27	23	21.50	27	25.23
	Fire prot.	90	39	43.33	20	22.22	30	33.33
	Avg.	93.20	48.60	52.07	18.00	19.11	26.40	28.59
Entire bldg.		731	382	52.26	179	24.49	169	23.12

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